FISH for the PEOPLE

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Harnessing technological innovations for sustainable fisheries and aquaculture in Southeast Asia

Southeast Asian Fisheries Development Center

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Editorial

This issue of the Fish for the People highlights the technological innovations in fisheries and aquaculture that are being promoted by SEAFDEC through its programs and projects which are the fulfillment of the strategies and actions included in the "Resolution on the Future of SEAFDEC" adopted during its 50th anniversary in 2017. Specifically, the relevant strategies and actions include "*Assessment of the status of inland fisheries, and compilation of baseline information on policies and regulations related to inland fisheries in the Member Countries*," "*Development and promotion of responsible fishing technologies, including energy optimization, carbon reduction and reduction of post-harvest losses onboard fishing vessels*," and "*Integration of habitat and fisheries management, and provision of support for the conservation of important fishery resources*" under Strategy 1. Securing the sustainability of fisheries to contribute to food security, poverty alleviation and livelihood of people in the region, as well as "*Development and promotion of technology to produce high quality, healthy and safe fish and fishery products to meet the international standards*" under Strategy 3. Ensuring the food safety and quality of fish and fishery products for the Southeast Asian region.

One of the initiatives of SEAFDEC in applying technological innovations in fisheries was the modification of one of its research vessels to enhance its compliance with relevant international requirements. Specific modifications include improving onboard working conditions for fishers and developing responsible fishing technologies. Auxiliary devices and tools were installed and techniques were applied including compliance with the ILO Work in Fishing Convention No. 188. In another project, in order to promote the use of energy-efficient technologies and alternative energy sources, SEAFDEC conducted a simulation study to evaluate the feasibility of different water pump systems in a fish landing site by comparing the economics and carbon emissions of four water pump systems *i.e.* diesel, electric, solar, and hybrid solar (70 % solar and 30 % electric). Taking into account the investment costs and environmental impacts, it was found that the hybrid solar water pump system is the most cost-efficient and ecologically friendly.

Southeast Asian countries are among the highest producers of seaweeds in the world. However, the continuous decline of seaweed production and deterioration of seaweed quality is not only due to climate change, pests and diseases, and biosecurity issues but also due to the repetitive use of vegetative cutting methods which is commonly practiced in many seaweed farms in the region. To address these pressing concerns in seaweed farming, SEAFDEC has been developing the technology to break from the conventional seaweed farming methods and optimize laboratory-based production to achieve a steady increase in micropropagule production, and a more sustainable source of propagules, better growth and survival in grow-out, and higher carrageenan quality.

The development of artificial reefs (ARs) in the Southeast Asian region since the 1970s was driven by the need to enhance fish stocks, protect natural coral reefs, and promote sustainable fishing practices. ARs are human-made structures placed in water bodies designed to mimic natural reefs and provide a substrate, shelter, habitat, or breeding areas for aquatic organisms while hampering destructive fishing activities. At present, SEAFDEC has been promoting the development program on ARs by utilizing the information obtained from the relevant studies.

For inland fisheries, unpiloted aerial vehicles (UAVs) such as drones are an effective tool for classifying and monitoring changes in inland bodies of water. Compared to other methods in identifying the types and extent of land cover in swamp areas, drones are the latest innovations that can access areas that are difficult to reach and can quickly and efficiently monitor, record, and gather data from routine observations. The high-quality images produced by drones are relatively accurate and efficient for implementing the measures for inland fisheries management such as in a Special Area for Conservation and Fish *Refugia* (SPEECTRA), a concept developed by SEAFDEC on artificial conservation area for fish or broodstock.

Another remote tool that could be used to support fisheries management is the Visible Infrared Imaging Radiometer Suite (VIIRS) of the NASA/NOAA which has a remarkable capability to detect electric lighting at Earth's surface. The cumulative VIIRS boat detection (VBD) data during 2012–2021 were reviewed for the SEAFDEC Member Countries and several types of sites have been found including anchorages, transit lanes, and aquaculture. For fishery agencies, the VBD could be reliable in implementing fishery regulations and management measures by understanding the features of VBD that provide up-to-date information on the activities of fishery vessels such as indications of illegal fishing activities in restricted areas.

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C O N T E N T S

Reducing the Impacts of Fishing Activities through the Application of Improved Fisheries Technology

Suthipong Thanasansakorn and *Thaweesak Thimkrap*

Fishing is an essential source of employment and protein for coastal communities. However, irresponsible fishing practices, such as the discard of unwanted catches, carbon emissions, destruction of seabed, and overfishing, may create negative impacts on fishery resources and the environment if not properly regulated. The impacts can be mitigated by promoting responsible fishing by using selective fishing gear. Moreover, the design of fishery vessels could be improved to enhance energy efficiency and safety at sea to alleviate living conditions and hygiene of the fishing crew onboard. In addition, the improvement of appropriate fishery machinery, tools, and refrigeration system is envisaged to optimize the required workforce of the fishery vessels, while maintaining the quality of the catch prior to landing.

In this regard, the project "Responsible Fishing Technology and Practices" supported by the Japanese Trust Fund is implemented by SEAFDEC Training Department (TD) from 2020 to 2024. The objectives of the Project are to: 1) promote responsible fishing technology and practices to mitigate fishing impacts on the marine ecosystem, 2) promote marine engineering technologies and their applicability in enhancing the capability of fuel consumption efficiency and safety in fishing operations, and 3) enhance human resource capacities on fish handling techniques onboard fishing vessels. It is envisaged that through the Project, the fishing and marine engineering technologies at the national and regional levels will be improved as well as human resource capacities in the Southeast Asian region are enhanced.

Furthermore, the activities undertaken by TD through this Project are also in line with the Resolution on Sustainable Fisheries for Food Security for the ASEAN Region Towards 2030 stipulating the need for the ASEAN Member States (AMSs) to undertake relevant actions, *i.e.*:

> *RES 7: Promote sound management of fishing capacity and use of responsible fishing technologies and practices, recognizing increasing emphasis on rights-based fisheries; and at the same time, secure the rights and well-being of inland and coastal fisheries communities as well as the ecological well-being;*

> *RES 9: Support the efforts to promote low carbon development technologies by minimizing the contribution of the fisheries sector to greenhouse gas emissions, with emphasis on promoting the use of energy-efficient equipment and alternative energy sources; and*

> *RES 21: Optimize the utilization of catch/harvest by reducing post-harvest losses and wastes to increase fish supply and improve economic returns through promotion of appropriate technologies, facilities and best practices along the supply chain.*

In 2020, the SEAFDEC Training Department (TD) acquired the 29.98 GT M.V. Plalung—a multipurpose wooden fishery vessel—with a size of 18.32 m length, 4.40 m breadth, and 1.71 m depth. In the following year, the vessel which is a typical Thai fishery vessel was modified to enhance its compliance with relevant international requirements particularly to improve onboard working conditions, safety at sea, and sanitation for fishers, while applying the low-impact and fuel efficiency (LIFE) concept. Since then, the vessel has been utilized to support the training and research activities of TD including the development of responsible fishing technologies that could be applied by fishers in the Southeast Asian region. Auxiliary devices and tools were installed and techniques were applied in M.V. Plalung to lessen fuel consumption, reduce workforce, and improve safety while operating at sea. These include reconditioning propulsion engines, selecting appropriate engine and generator sizes for the vessel, and monitoring fuel consumption by installing fuel flow meters. Using LED bulbs and proper fish handling practices were also promoted by TD as energy-efficient practices to minimize energy consumption on board, while renewable energy such as solar energy is being planned as an additional sustainable energy source.

Compliance with the Work in Fishing Convention No. 188

Appropriate fishery vessel design is crucial to ensure the well-being and safety of the onboard crew. Adequate and comfortable living conditions should be provided for the crew to increase job satisfaction, reduce the crew turnover rate, and ultimately improve the efficiency and profitability of the fishery vessel. In addition to the basic amenities such as food, drinking water, and sanitation facilities, it is also important to consider the crew's recreational needs by providing an entertainment corner and a comfortable space for rest to help reduce stress and fatigue during long fishing trips.

Therefore, M.V. Plalung was modified in 2021 to be a model vessel that complies with the Work in Fishing Convention No. 188 (C188) of the International Labour Organization with the objective of ensuring that fishers have decent conditions of work on board fishing vessels with regard to minimum requirements for work on board; conditions of service; accommodation and food; occupational safety and health protection; medical care and social security. The space allocated for crew members was made to be sufficient and well-designed where each crew member has a personal cabinet to store their belongings and the living space (main deck) has a height of at least 2.0 m to allow comfortable movement. The bedroom was renovated to accommodate all crew members and consists of comfortable beds that are at least 0.70 m × 1.90 m in size.

Hybrid refrigeration system

Hybrid power sources in the refrigeration system are being applied onboard M.V. Plalung with power either from the propulsion engine or generator (**Figure 1**) to deliver power and a relatively steady amount of torque and speeds that match the requirement for the refrigeration system. Besides, the split shaft power take-offs were applied to enable multiple sources of power to drive fishery machinery as the source of the prime mover of auxiliary devices *e.g.* nets drums, cranes. The compressor of the refrigeration system of M.V. Plalung is driven by an electric motor. The size of the motor depends on the cooling load capacity of the compressor times and storage temperature. This means that a lot of electricity is needed from the diesel generator. Hence, the demand for electricity is defined as fuel consumption. In the case of a fishery vessel moored at the fishing port, it is able to operate the refrigeration system via the electric motor. This is because fishing vessels must run the diesel generator ordinarily or utilize the shoreline power source by the main engine stop. But whenever the fishery vessel leaves the port, the main engine is in use. The refrigeration system can change the mode of operation to engine mode to drive the compressor. The merit of the refrigeration system is driven by the propulsion engine. Whenever the fishing vessel leaves the fishing port to the fishing ground or during the fishing period, it will take time to operate the engine until it reaches the fishing ground. Therefore, using the engine drive mode will result in energy utilization without the need for sources from a diesel generator.

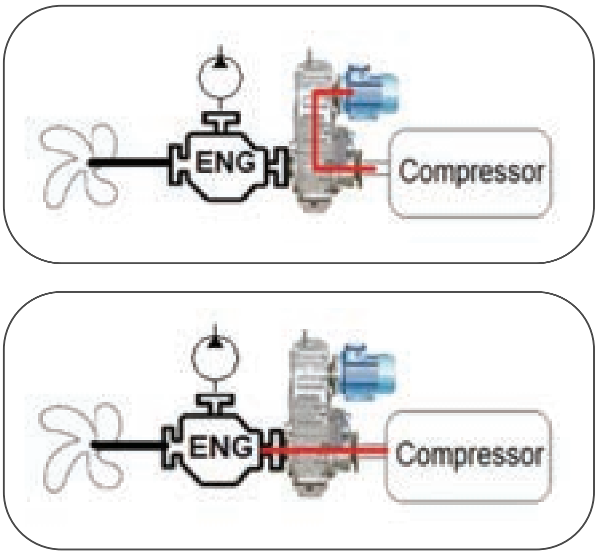

Figure 1. Hybrid refrigeration system: driven by an electric motor *(top)* and propulsion engine *(bottom)*

V-shaped otter board

Basically, the design of M.V. Plalung resembles typical Thai trawlers. However, bottom trawling is an indiscriminate fishing method and is considered one of the most destructive ways to catch fish causing significant harm to the seafloor. The bottom trawl (**Figure 2**) is an unselective fishing gear that often catches juvenile fish and results in overfishing due to a large number of dead fish discarded. With the goal of promoting responsible fishing practices to decrease the negative impacts of trawl fishing on the marine ecosystem, reduce carbon emissions, and mitigate climate change, TD applied the V-shaped otter board to the bottom trawl of M.V. Plalung. Sea trials were performed to examine the energy-saving efficiency and performance of the fishing gear design since 2018 in Tarutao Island, Satun Province, Thailand in the Andaman Sea.

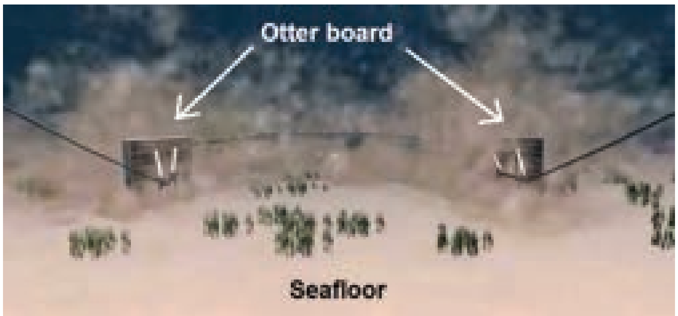

Figure 2. Otter boards of bottom trawl damage the seafloor

The otter board is a critical component of single trawlers as its hydrodynamic performance significantly affects catch and fishing efficiency. The main function of the otter board is to accelerate the settling of the trawl net by increasing the horizontal expansion of the trawl net. The negative impacts of bottom trawling can be reduced through responsible fishing practices. The V-shaped otter board (**Figure 3**) was applied for M.V. Plalung. The hydrodynamic force acting on the otter boards is decomposed into an expansion force, which is perpendicular to the flow velocity (**Figure 4**). This force increases the lifting force of the otter boards, reduces damage to bottom fauna, expands the sweeping area of the bottom trawl, and minimizes fuel consumption by allowing the trawl doors to avoid contact with the seabed.

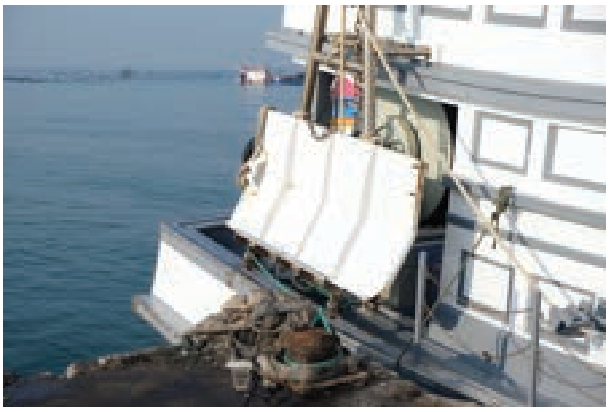

Figure 3. V-shaped otter board

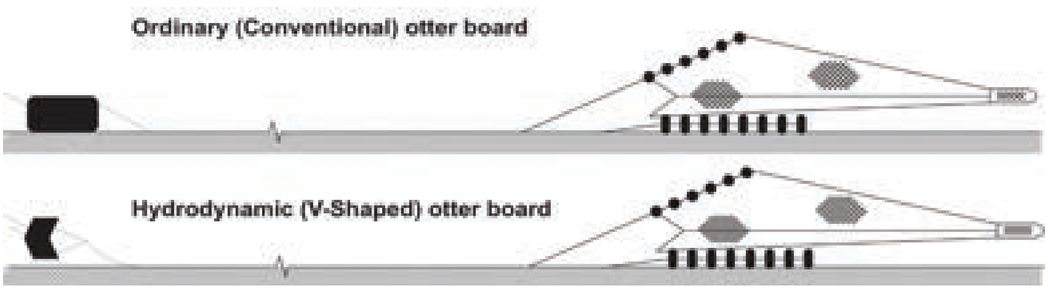

Figure 4. Hydrodynamic V-shaped otter board

The use of a V-shaped otter board resulted in a 5 % reduction in fuel consumption compared to the conventional otter boards, with engine speed reduced from 1,100 rpm to 1,050 rpm while maintaining the same trawl speed. This indicates that operating with V-shaped otter boards can save fuel by 5.4 % while maintaining the same trawl speed. Additionally, the V-shaped otter boards allow for longer trawling distances due to the vessel being able to trawl faster than before, all while using the same engine rotation speed as the conventional otter boards. Regarding vessel control, the V-shaped otter board made the maneuvering of the vessel easier, including turning, compared to the use of flat otter boards. Furthermore, there were a few marks on the painted footer plate (**Figure 5**) of the V-shaped otter board which indicated that the lifting force of the V-shaped otter board decreased the touch or drag of the bottom trawl resulting in reduced seabed destruction.

Figure 5. Fewer scratches on the painted footer plate of the V-shaped otter board of M.V. Plalung

Adjustable U-shaped gallows

The inverted U-shaped gallows are commonly used to hitch up heavy otter boards and for shooting and hauling towing warps in trawl fishing. TD designed a new type of gallows, the beam gallows, which can function as an outrigger or beam trawl and can adjust to the waterline angle, allowing for an extension on each side of the towline (**Figure 6**). The position of the gallows was crucial, as they must be located forward of the rudder axis to ensure the vessel has sufficient maneuverability.

Figure 6. Adjustable U-shaped gallows of M.V. Plalung designed by SEAFDEC/TD

Hydraulic net drum

Improving appropriate fishery machinery, tools, and fishing operation techniques includes using a power take-off for winch drives. The power take-off unit takes power from the main engine for the winch drive. It is recommended to use a belt drive from the power take-off point instead of a chain drive due to its greater flexibility. The hydraulic drive may be a cheaper option in the long run if expertise and spare parts are available locally. On small fishery vessels, the most commonly used power take-off is for a warp line winch or hydraulic oil pump for the net drum in the trawl fishery. TD used the hydraulic net drum and towline winches during the hauling and shooting process (**Figure 7**). These wide-powered spools helped to facilitate the hauling and releasing of the trawl nets and towline. A power takeoff from the propulsion

Figure 7. Operation of the hydraulic net drum of M.V. Plalung

engine was implemented to power these spools. The net drum, which consists of hydraulic components, was placed at the stern portion, while the towline was placed at the middle of both sides. This helped to improve the efficiency and safety of the vessel during trawling.

Way Forward

It is important to mitigate the impacts of fishing activities on fishery resources and minimize greenhouse gas emissions by monitoring energy consumption and implementing fishery vessel energy audit programs. Moreover, efforts should be made to reduce waste, discard, and oil pollution generated by fishery vessels.

In recognizing the need to reduce the use of fossil fuels, which is the biggest source of greenhouse gas emissions, TD would promote the use of renewable energy to mitigate the adverse effects of climate change. Specifically for trawl fishery, TD intends to promote responsible trawl fishing by extending its reach, facilitating collaborations, and working with experts and researchers from Member Countries to improve technology, techniques, and materials used in fishing to reduce its impact on fishery resources and marine environment.

On the other hand, many fishers reported a lack of funding to improve their vessels and they are concerned that the return on investment might not be justifiable, making it difficult for them to make improvements. To reduce costs and increase income from fishing operations, TD would focus on improving energy efficiency, storage methods, and maintenance of fish and fishery products to retain their original nutritional value. TD would also promote sustainable fisheries development both at the national and regional levels, with a focus on energy-saving fishing activities to reduce poverty among fishers.

Bibliography

FAO. (1974). Otter board design and performance. *FAO Fishing Manuals*. Rome. http://www.forceproject.eu/images/Training/Otterboard%20design%20and%20performance%20manual.pdf

FAO. (2001). *FAO/FIIT Gear Type Fact-Sheet: Bottom otter trawls*. https://www.fao.org/fishery/docs/CDrom/ARTFIMED/ArtFiWeb/descript/Gear/geartype/gt306.htm

Kozanoglu Kozmaksan Limited Company. (2018). What kind of split shaft PTO can you demand? https://www.kozmaksan.net/split-shaft-pto-category-10

Kunjipalu, K.K.; Boopendranath, M.R.; Kuttappan, A.C.; Krishna Iyer, H. (1984). On the comparative efficiency of "V" shaped and rectangular flat otter boards for trawling off Veraval, northwest coast of India. *Fishery Technology, 21*. http://hdl.handle.net/1834/33838

Mellibovsky, F., Prat, J., Notti, E., & Sala, A. (2018). Otterboard hydrodynamic performance testing in flume tank and wind tunnel facilities. *Ocean Engineering, 149*, 238–244. https://doi.org/10.1016/j.oceaneng.2017.12.034

Muncie Power Products. (2023). Split shaft PTOs. https://www.munciepower.com/products/power_take_off/split_shaft

SEAFDEC (2020). Resolution and Plan of Action on Sustainable Fisheries for Food Security for the ASEAN Region Towards 2030. Southeast Asian Fisheries Development Center, Bangkok, Thailand. https://repository.seafdec.org/handle/20.500.12066/6583

Wang, L., Zhang, X., Wang, L. M., Huang, H. L., Zhang, Y., Liu, Y. L., Feng, W. D., & Zhang, R. J. (2018). Effect of panel shape on hydrodynamic performances of vertical v-shaped double-slotted cambered otter-board. *E3S Web of Conferences, 38*, 03050. https://doi.org/10.1051/e3sconf/20183803050

Wang, L., Wang, L. M., Liu, Y. L., Yu, W. W., Qi, G. R., Wang, Y. J., Zhang, X., & Zhang, R. J. (2019). Study of board bending degree on hydrodynamic performances of a single-layer cambered otter-board. *E3S Web of Conferences, 131*, 01120. https://doi.org/10.1051/e3sconf/201913101120

About the Authors

Mr. Suthipong Thanasansakorn is the Training and Research Supporting Division Head of the SEAFDEC Training Department in Samut Prakan, Thailand (Email: suthipong@seafdec.org)

Mr. Thaweesak Thimkrap is the Marine Engineering Section Head of the SEAFDEC Training Department in Samut Prakan, Thailand (Email: thaweesakt@seafdec.org)

Promoting Green Energy in Fisheries Activities:
a simulation study on water pump systems in fish landing site

Khunthawat Manomayithikan, Suthipong Thansarnsakorn, and *Thaweesak Thimkrub*

The fishery supply chain is facing challenges due to rising fuel costs and sharp declines in marine resources. Thus, it is imperative to establish a low-cost, hygienic, and greener fishery supply chain with the goals of lowering poverty, securing food, promoting gender equality, and mitigating the effects of climate change to achieve sustainability by 2030. In response to the profound implications of climate change, the United Nations has prioritized achieving net-zero carbon emissions in the near future. Thailand, as part of this global effort, has developed a comprehensive plan to reduce greenhouse gas emissions at 20–25 percent by 2030 based on current conditions. In this regard, the Training Department (TD) of SEAFDEC also supports the use of low-carbon emissions, energy-efficient technologies, and alternative energy sources to minimize greenhouse gas emissions from the fisheries sector to fulfill the Resolution on Sustainable Fisheries for Food Security for the ASEAN Region Towards 2030, specifically *Resolution No. 9. Support the efforts to promote low carbon development technologies by minimizing the contribution of the fisheries sector to greenhouse gas emissions, with emphasis on promoting the use of energy-efficient equipment and alternative energy sources.*

The fisheries industry in many countries generates significant revenue from the export of fish and fishery products. However, recently, importers have begun to demand stricter sanitary standards throughout the fisheries value chain. Fish landing sites, which are crucial components of the fisheries value chain, require substantial amounts of water for cleaning tools, workspaces, and equipment, leading to increased operational costs for water and electrical systems. Additionally, growing concerns about greenhouse gas emissions, particularly carbon dioxide, are raising public awareness of the consequences of global warming.

It is widely acknowledged that sunlight represents an inexhaustible energy resource with versatile applications, including the generation of heat and light. The technology converting sunlight into electricity is commonly referred to as a photovoltaic cell or solar cell. These cells are typically integrated into panels, wherein multiple individual cells are combined to enhance the overall power output (Raza *et al.*, 2015). When sunlight impinges on the photovoltaic cells, the solar panel generates electrical energy. The amount of electricity produced varies throughout the day, contingent upon the availability of light. Typically, solar electricity

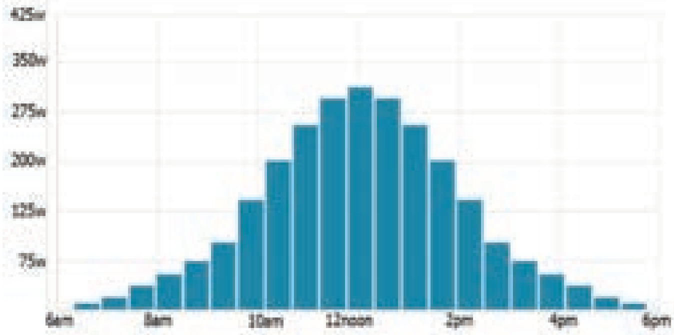

Figure 1. Electrical power generation of a 350-watt solar panel (Mclnerney, 2023)

generation exhibits a pattern characterized by increasing output in the morning, reaching its peak around midday due to the maximum intensity of sunlight, and subsequently declining. **Figure 1** illustrates the power generation profile of a specific 350-watt solar panel over a day, assuming ideal conditions of clear skies and no interference on the surface of the solar panels (Mclnerney, 2023). The incorporation of this power generation profile within a controlled setting enables an estimation of the overall electricity production achievable by solar panels.

Since solar energy is a clean and unlimited energy source, systems for producing electricity from solar cells are used in many sectors, including agriculture and fisheries. Previous research have shown that solar-powered water pump systems are attractive technology and are widely used for irrigation in the agricultural, industrial, and domestic sectors. In the capture fisheries sub-sector, some solar energy system applications include charging batteries onboard small-scale fishing vessels, cool rooms, and water pumps. Typically, fish landing sites utilize two types of water pump systems, namely: a) electric water pumps in areas with electric service and b) diesel water pumps in areas without electric service. Nevertheless, studies have shown that solar water pumps have several benefits over diesel or electric water pumps, in terms of cost-effectiveness, environmental friendliness through the absence of greenhouse gas emissions, low maintenance costs, and suitability for use in hybrid on/off-grid or remote areas (Korpal *et al.*, 2016; Ibrahim, 2017; Zhou & Abdullah, 2017; Imjai *et al.*, 2020; Nelson, 2021; Raza *et al.*, 2015; Schnetzer & Pluschke, 2017).

In 2022, the Training Department (TD) of SEAFDEC applied a 20-kW hybrid solar energy system with a budget of USD 20,000. Solar panels were installed on the rooftop of one of the office buildings of TD (**Figure 2**). Between 8:00 and 16:00, approximately 70 % of the electricity was generated from the solar panel while around 30% was generated from the electric power line (**Figure 3**) (SEAFDEC, 2022). After 1.5 years of installation, the hybrid solar energy system had the capacity to generate an average of 13 kW of electricity per day (**Figure 4**). This consistent performance was achieved through uninterrupted daily operation, devoid of errors and minimal maintenance. The maintenance routine primarily involved monthly cleaning of the solar panels with minimal costs. Taking into consideration the monthly savings in electricity costs, which ranged from USD 267 to USD 450 depending on the recent electric utility rate, the payback period of the hybrid solar energy system is estimated to be 5–6 years.

Figure 2. Solar panels installed on the rooftop of one of the SEAFDEC/TD office buildings in 2022

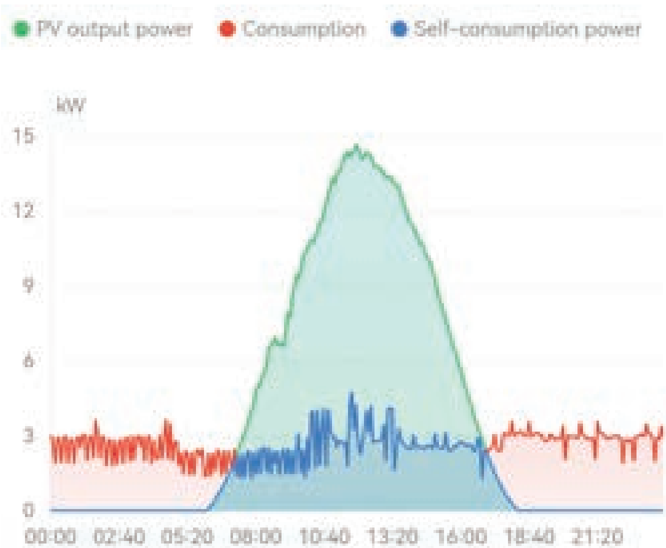

Figure 3. Electricity generated by a 20-kW hybrid solar energy system (70 % solar and 30 % electricity) installed at SEAFDEC/TD in 2022

Figure 4. Power generation of the 20-kW hybrid solar energy system applied by SEAFDEC/TD in 2022-2023

Comparing the four water pump systems

The successful operation of the hybrid solar energy system applied by SEAFDEC/TD demonstrated stability and suitability for practical utilization of such system in fish landing sites that necessitate electricity cost reduction. Therefore, TD conducted a simulation study to compare the cost-benefit analysis and carbon emissions of four water pump systems powered by diesel fuel, electricity, solar energy, and hybrid solar energy (70 % solar and 30 % electric). The simulated scenario for the four water pump systems was at a 100 m2 fish landing site with the postulation that they operate under optimal maintenance conditions and are free from any breakdowns or efficiency reductions based on an 8-hr operation per day, representing the typical working hours in a fish landing site.

The diesel (**Figure 5a**) and electric (**Figure 5b**) water pump systems required only a single set of installations, and the key factors to consider were size and flow rate. In this context, a motor power or engine capacity of 4 kW can deliver water at a maximum flow rate of 600 L/min. On the other hand, the solar (**Figure 5c**) and hybrid solar (**Figure 5d**) water pump systems required the installation of three parallel panels of solar cells with a peak voltage of 45 Vp. Since the peak solar radiation occurs at noon, when the maximum power output reaches 9,900 watts, utilizing a 4,000-watt water pump in such circumstances would result in excessive production of electricity. Therefore, the installation of three parallel panels was crucial to accommodate the highest range of power generation. Moreover, the operations of the solar and hybrid solar water pump systems were under unobstructed sunlight and clear sky, thereby mitigating any potential external influences that could adversely affect their optimal performance.

Economic analysis

The associated costs of the four water pump systems were assumed to remain constant throughout the 5th year and 15th year duration (**Table 1**). The operational requirements of the diesel water pump system and electric water pump system necessitate a consistent provision of diesel fuel and electricity, respectively; resulting in continuous expenditures. As the duration of their usage increases, these expenses also tend to escalate with both the diesel and electric motor pumps necessitating replacement every five years. The diesel and electric water pump systems are specifically designed for nocturnal operations, utilizing off-peak electricity between 00:00 and 08:00. Consequently, the attributed variable costs demonstrate a negative trend for the diesel engine water pump system at about USD -4,161.00 per year, while the electric water pump system at USD -836.30 per year (**Table 2**).

For the solar water pump system and hybrid solar water pump system, the water pump and inverter require replacement every five years, solar panels every fifteen years, and water tanks every fifteen years for the solar water pump system (**Table 1**). Nonetheless, the solar water pump system and hybrid solar water pump system provide an opportunity for income generation or reduction in electricity expenses with estimated values of USD 2,027.00 per year and USD 1,419.00 per year, respectively (**Table 2**). Typically, the investment cycle of the solar water pump system and hybrid solar water pump

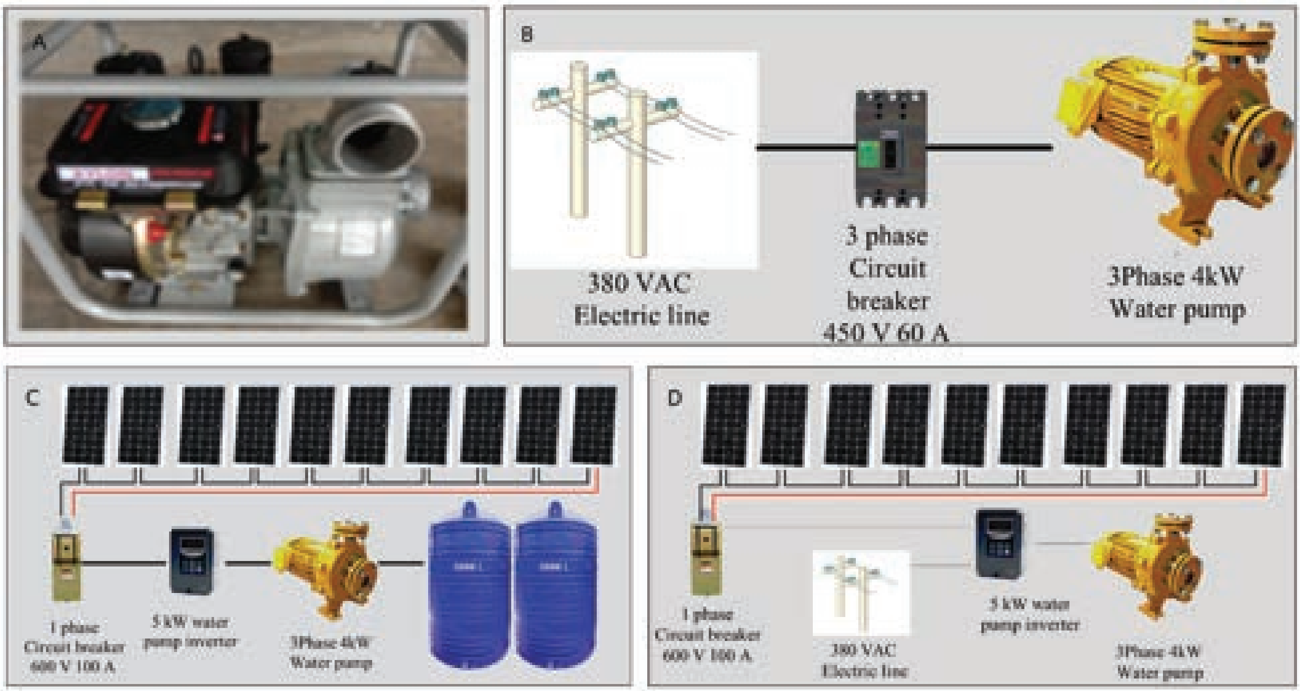

Figure 5. Components of each water pump system *(A: diesel, B: electric, C: solar, and D: hybrid solar)* for the simulation study conducted by SEAFDEC/TD

Table 1. Investment costs for diesel, electric, solar, and hybrid solar water pump systems

Components	Power rate (kW; Hp)	Lifespan (years)	Quantity	Cost/unit (USD)	Initial investment (USD)	5th year investment (USD)	15th year investment (USD)
Diesel water pump system							
Diesel engine model:178FE	4.0; 5.5	5	1	333.33	333.33	333.33	
Water pump brand: XYLON (Model XY-30DE)							
Installation cost					166.67		
Total investment					**500.00**		
Electric water pump system							
Water pump	4.0; 5.5	5	1	400.00	400.00	400.00	
Installation					1,333.33		
Total investment					**1,733.33**		
Solar water pump system							
Solar cell (W)	0.35	25	30	100.00	3,000.00		3,000.00
Water pump power	4.0; 5.5	5	3	400.00	1,200.00	1,200.00	
Inverter	5.0; 6.75	5	3	400.00	1,200.00	1,200.00	
5 m^3 water tank cost		15	2	500.00	1,000.00		1,000.00
Installation					4,000.00		
Total investment					**10,400.00**		
Hybrid solar water pump system							
Solar cell (W)	0.35	25	30	100.00	3,000.00		3,000.00
Water pump power	4.0; 5.5	5	3	400.00	1,200.00	1,200.00	
Inverter	5.0; 6.75	5	3	400.00	1,200.00	1,200.00	
Installation					3,333.00		
Total investment					**8,733.00**		

Table 2. Variable costs for diesel, electric, solar, and hybrid solar water pump systems

Diesel water pump system	
Fuel consumption (g/kWh)	285.60
Fuel consumption (L/h)	1.63
Operation period (hr/day)	8
Operation period (days/year)	365
Fuel consumption (L/day)	13.06
Diesel oil price (USD/L)	0.86
Lubricating oil (USD/year)	80.00
Total fuel cost (USD/year)	-4,161.00
Electric water pump system	
Electric utility rate (USD/kWh)	
On-peak period (09:00-22:00)	0.15
Off-peak period (22:00-09:00)	0.07
Operation period (hr/day)	8
Operation period (days/year)	365
Total electricity consumption (unit/year)	11,680.00
Annual electricity savings during 00:00-08:00 (USD)	-836.30
Solar water pump system	
Annual electricity savings during 8:00-16:00 (USD)	2,027.00
Hybrid solar water pump system	
Annual electricity savings during 8:00-16:00 (USD)	1,419.00

system is based on the 15-year warranty of the solar panels, and multiple rounds of investment could result in higher cumulative profits from lower electrical costs. Considering the duration of the solar panel warranty, the payback period for the solar water pump system is seven years while the hybrid solar water pump system is eight years.

CO_2 emission analysis

In Thailand, the existing electric generating process of the Electric Generating Authority of Thailand (EGAT) is reliant on multifuel sources. Based on the consumption and CO_2 emissions of each type of fuel, the weighted average specific CO_2 emission from all types of fuel is roughly 0.18 kg CO_2 per kWh (**Table 3**). Comparing the specific CO_2 emissions of different fuels, the carbon footprint of each water pump system is illustrated in **Figure 6**. The diesel water pump system and electric water pump system emit a significant quantity of CO_2 into the environment when in use. But since solar energy is a green technology, the solar water pump system does not release into the environment, the hybrid solar water pump system releases some CO_2 from its electric source.

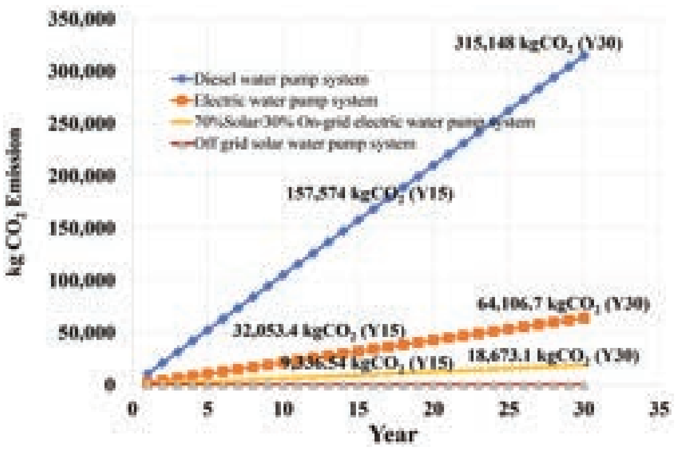

Figure 6. Simulated CO_2 emissions (kg) of diesel, electric, solar, and hybrid solar water pump systems

Conclusion and Way Forward

Taking into account the long-term operating costs and environmental impacts of the four water pump systems, it seemed that the solar water pump system provides the most advantages in terms of economic aspects and environmental impacts. However, the solar water pump system exhibits constraints with regard to energy source stability and storage space requirements, making it less optimal compared to the hybrid solar water pump system.

The use of solar energy is limited only during the day since solar cells require sunlight to generate electricity; thus, the solar water pump system and hybrid solar water pump system are exclusively operational during daylight hours and the water flow rate varies depending on light intensity. During low light intensity, the flow rate is low, but during four hours of midday when the light intensity is high, the flow rate is high. To ensure a consistent and adequate water flow rate during low light intensity, large-capacity water tanks are needed as water accumulators to store potential energy and water supply in a fish landing site. These storage tanks play a crucial role in maintaining the flow rate and increasing the potential pressure of water in the pipeline without depending on sunlight intensity. In contrast to the solar water pump system, the hybrid solar water pump system does not require water storage tanks, which are considered a significant cost in the initial investment and will require a lot of space which could be an issue for a fish landing site that has limited space. Although the hybrid solar water pump system needs a higher initial investment than the solar water pump system, its long-term investment is lower than those of diesel and electric water pump systems over time.

Table 3. Electric-grid generation by fuel type of Thailand (EGAT, 2021) and specific CO_2 emission of each type of fuel (Engineering ToolBox, 2009)

Fuel type	Thailand electric-grid generation (January-August 2021)		Specific CO_2 emission		
	Unit (MWh)	%	$kgCO_2$/kgfuel	$kgCO_2$/kWh	Weighted average
Compressed natural gas	75,552.61	57.55	2.75	0.185	10.65
Diesel	185.42	0.14	3.15	0.25	0.04
Coal (lignite)	30,499.15	23.23	1.10	0.31	7.20
Heavy oil	341.32	0.26	3.11	0.27	0.07
Wood	NA	NA	1.83	0.41	NA
Renewable energy (biogas, solar, wind, hydro, geothermal)	23,185.60	17.66	0	0	0.00
Others (Lao PDR, Malaysia, etc.)	1,517.02	1.16	NA	NA	0.00
Total	131,281.12	100.00			0.18

Considering the various benefits such as cheaper investment costs and lesser environmental impacts, the hybrid solar water pump system is ideal and could be a successful application in fish landing sites for reducing power costs and requiring less equipment. The results of this simulation study should not be confined to a 4-kW water pump system that can be scaled up or down to achieve similar outcomes. This innovation could be adopted by key stakeholders, thereby contributing to the promotion of sustainable and responsible fishing practices.

References

Korpal, V.S., Kokate, D.H., and Deshmukh, S.P. (2016). Performance assessment of solar agricultural water pumping system. *Energy Procedia, 90*, 518–524. https://doi.org/10.1016/j.egypro.2016. 11.219

Alkhubaizi, I. (2017). Solar water pump. *Journal of Engineering Research and Application*, 1–5. http://www.ijera.com/papers /Vol7_issue5/Pa rt-3/A0705030105.pdf

Zhou, D., Abdullah, (2017). The acceptance of solar water pump technology among rural farmers of northern Pakistan: A structural equation model. Cogent Food & Agriculture. https://doi.org/10. 1080/23311932.2017.1280882

Imjai, T., Thinsurat, K., Ditthakit, P., Wipulanusat, W., Setkit, M., & Garcia, R.. (2020). Performance study of an integrated solar-water supply system for isolated agricultural areas in Thailand: a case-study of the royal initiative project. doi:10.3390/w12092438. https://www.mdpi. com/2073-4441/12/9/2438

Andres, N. (2021). Development of Solar-powered water pump with 3D printed impeller. 249-253 http://doi.org/10.1515/ eng -2.21-0015

Raza, A., Qiang, Z. Y., Zaigham Nasir Khan, N. A., & Muhammad Basit Ali. (2015). Solar powered water pump lifting agriculture. *Applied Mechanics and Materials 789-790*, 193–199. DOI:10.4028/ www.scientific.net/AMM. 789 -790-193

Schnetzer, J., & Pluschke, L., (2017). Solar-Powered Irrigation Systems: A clean-energy, low-emission option for irrigation development and modernization, PRACTICE BRIEF Climate-smart agriculture, 1-9, https:// www.fao.org/3/b t437e/bt437e.pdf

Ben Mclnerney, Go Solar Quotes pty Ltd. (2023). *What time of day are solar panels most efficient?* https://gosolarquotes. com.au/ what-time-of-day-are-solar-panels-most-efficient/

Harrison, G., Edward (Ned). J. McLean, Karamanlis, S., & Ochoa, L. (2010). Life cycle assessment of the transmission network in Great Britain, Edinburgh. *Research Explorer, 36223621*. https://www. pure.ed.ac.uk/ ws/portalfiles/ portal/21980985/Grid_Carbon_Footprint_Paper.pdf

Royal Thai Embassy, Washington D.C., (n.d.), https://thaiembdc. org/2021/04 /15/thailand-drafting-zero-carbon-emissions-master-plan/

Engineering ToolBox. (2009). *Combustion of fuels for carbon dioxide emission*. https://www.en gineeringtoolbox.com/ co2-emission-fuels-d_10 85.html

Electric Generating Authority of Thailand (EGAT). (2021) Types of fuel consumption in electricity production of Electric Generating Authority of Thailand. https://www.egat.co.th/ home/ statistics -fuel-usage/

Southeast Asian Fisheries Development Center/Training Department. (2022). *Report on-grid solar roof system*. https://repository.seafdec.or.th/handle/20.500.12067/1758

About the Authors

Mr. Khunthawat Manomayidthikarn is a Mechanical Engineer at the Marine Engineering of the Training and Research Supporting Division of the SEAFDEC Training Department in Samut Prakan, Thailand (Email: khunthawat@seafdec.org)

Mr. Suthipong Thanasansakorn is the Training and Research Supporting Division Head of the SEAFDEC Training Department in Samut Prakan, Thailand (Email: suthipong@seafdec.org)

Mr. Thaweesak Thimkrap is the Marine Engineering Section Head of the SEAFDEC Training Department in Samut Prakan, Thailand (Email: thaweesakt@seafdec.org)

Achieving High Production of Micropropagated Seaweed through Optimization of the Culture Protocol

Hananiah Sollesta-Pitogo, Joseph Faisan, Jr., and Joesyl Marie de la Cruz-Aranas

Sea-based seaweed farming in Bubog, Guimaras, Philippines

Kappaphycus and *Eucheuma* are the two carrageenan-producing red algae extensively cultured and farmed in tropical and subtropical waters. Seaweed production accounted for 5.4 percent of the world's aquaculture production in 2019, which was over USD 15 billion in value. With this value share, the production of seaweed farming was higher than other aquatic commodities, such as tilapia, carp, shrimps, and others (Cai *et al.*, 2021). The red algae production of the Philippines started in the 1960s (Ronquillo & Gabral-Llana, 1989), and by the early 2000s, the country had become the world's top supplier of seaweed, particularly *Kappaphycus* sp., until 2007, when Indonesia outperformed it.

Problems and challenges in seaweed farming, including climate change, pests and diseases, and biosecurity issues, caused the continuous decline of the seaweed production yield (Faisan, Sollesta-Pitogo, & de la Peña, 2022). Furthermore, the deterioration of seaweed quality caused by the repetitive use of vegetative cutting methods has also become one of the most pressing concerns in seaweed farming. Unfortunately, this procedure of growing plantlets for farming is one of the most common methods many seaweed farms used in the Philippines and other countries.

Research in SEAFDEC Aquaculture Department (AQD) looks into breaking from the conventional method of farming seaweed plantlets and optimizing laboratory-based production. With this, it hopes to create a more sustainable source of propagules, better growth and survival in grow-out, and a higher carrageenan quality in cultured *Kappaphycus alvarezii*.

Break from the 'conventional method'

Traditionally, seedlings for seaweed farming are collected through a method called "vegetative cutting." This method entails taking small pieces of the healthy thallus of seaweed for planting in a separate environment that is sustainable enough to support growth (Faisan, Sollesta-Pitogo, & de la Peña, 2022). Upon reaching marketable size, it is harvested by removing the entire plant or leaving small pieces to grow into a new batch (McHugh, 2003). Conventional production of seaweed seedlings has successfully propagated in-demand eucheumatoid red seaweeds such as *Kappaphycus* sp., a species with high carrageenan content that is widely produced in the Philippines. However, this heavy reliance on the conventional and unoptimized cultivation of seedlings will eventually have some disadvantages (Jiksing *et al.*, 2022).

Seaweed is the top aquaculture commodity in the Philippines and the country is the fourth top seaweed-producers in the world. Most of the production that supplies this demand is cultured by marginal seaweed farmers (Luhan & Sollesta, 2010; Tahiluddin & Terzi, 2021). For years, local farmers have had growing concerns about the deteriorating production and quality of carrageenan in cultured seaweeds as well as the shortage of seedlings. This makes the seaweed they produced unattractive to the international and export market. Seaweed health problems, including disease and pest outbreaks in seaweed farms, caused annual production losses. However, one of the main factors affecting production is the most common practice of producing seedlings—using cuttings from existing crops as plantlets for subsequent harvests. Continuous repetition of this method could erode the genetic traits of seaweeds, reducing their vigor and making growth and survival slower and weaker. In addition, seaweeds now become more susceptible to diseases and pests as this method eventually wears out the good genetic traits. This calls for a new and optimized method of producing seaweed seedlings (Hayashi *et al*., 2010; Luhan & Sollesta, 2010).

To improve the quality of plantlets, micropropagation or in vitro clonal propagation was developed. The first attempt to cultivate seaweed explants under axenic conditions was conducted by Aharon Gibor from the University of California in the 1950s (Polne-Fuller, 1988). Since then, many studies have been conducted to better laboratory-based propagule production. Dawes and Koch (1991) demonstrated the first successful branch tissue culture of *Eucheuma denticulatum*, a red seaweed that thrived in sandy to rocky coastal areas, which were usually exposed to strong water currents. Hurtado and Biter (2007) used a small section of the seaweed for tissue culture and then grow-out farming. These include studies conducted within the facilities of the SEAFDEC Aquaculture Department (AQD), where spores were used to produce young seaweeds. Seaweeds from reproductive cells were grown in a laboratory setting and were subsequently cultured in grow-out farms (Luhan & Sollesta, 2010). Modern seaweed seedling production, such as micropropagation, is a more sustainable and scalable alternative to the conventional method, which can help yield larger production and bolster the livelihood of local producers. However, these methods are far from ideal. Further studies to improve the existing systems have been one of the ongoing researches in AQD.

The benefit of 'acclimation'

Currently, the method for micropropagation of seaweeds, particularly *Kappaphycus alvarezii*, lasts for 90 days in the laboratory and is followed by direct stocking in the field nurseries without acclimation. However, survival in the sea-based nursery using the aforementioned method is only about 30–50 %. Direct planting of micropropagules in the open sea has caused stress and shock to the seaweeds because of the sudden change in environmental conditions.

A study was conducted in AQD in 2020, to improve the existing micropropagation systems by modifying the protocols. The 90-day laboratory culture of micropropagules was shortened and replaced with tank culture to produce seedstock for sea-based nursery and out-planting purposes for commercial cultivation of carrageenophytes. This tank culture period served as the acclimation phase for the micropropagules. A study by Yong *et al*., (2015) stated that the growth of acclimatized micropropagules was significantly higher compared to the non-acclimatized ones and the presence of epiphytes was not noted when these were cultured in the field. Acclimation of tissue-cultured seedlings was also recommended to achieve higher survival growth (Jiksing *et al*., 2022).

Figure 2. Collection sites of seaweed explants in Western Visayas, Philippines

The main objective of the study was to produce tank-acclimated seaweed propagules and see if the acclimation does favor better growth and survival when the seaweed plantlets are later transferred to the open sea. The seaweed explants (**Figure 1**) were collected from San Dionisio in Iloilo, Pandan in Antique, and Bubog in Guimaras (**Figure 2**). They were brought to AQD Tigbauan Main Station and stocked in rectangular concrete tanks in the seaweed hatchery (**Figure 3**). Conditioning of seaweed explants in tanks lasted for at least

Figure 1. Seaweed explants from a seaweed farm in Pandan, Antique, Philippines

Figure 3. Acclimation of seaweeds in tanks in SEAFDEC/AQD

seven days, and each tank was provided with flow-through seawater (0.5 L/min flow rate) and moderate aeration.

Once healthy explants were produced from the vegetative seaweeds, they were collected and cleaned before stocking them in culture bottles with UV-treated seawater and, later, in carboy containers for two months. After two months in the laboratory, propagules were transferred to a plastic net-covered tray and stocked in the concrete tanks. Tank-acclimation of propagules lasted for 30 days. The culture in the land-based tanks served as the acclimation area of propagules; hence, parameters such as salinity, temperature, and light intensity were closer to the natural condition.

Steady increase in micropropagule production

Improving and modifying the protocols for culturing micropropagated seaweeds led to a steady increase in production in AQD. The highest recorded yield was a total of 69,870 pieces of *K. alvarezii* propagules in 2022. This exceeded the production in the previous years, with 61,644 in 2020 and 62,751 in 2021. These are huge leaps compared to the production of 25,617 pieces in 2019 (**Figure 4**).

Moreover, the modification in stocking density and inclusion of an acclimation stage improved not only the yield but also the average survival rate, as it reached an 87 % average survival rate from 2020 to 2022. Over 100,000 micropropagated plantlets (**Figure 5**) can be produced from 5,000 explants collected from the wild for this optimized method. Moreover, the carrageenan quality of seaweeds from laboratory-produced plantlets after 45–60 days of culture in the field showed no significant difference when compared to the farmed ones in terms of gel strength, yield, and viscosity.

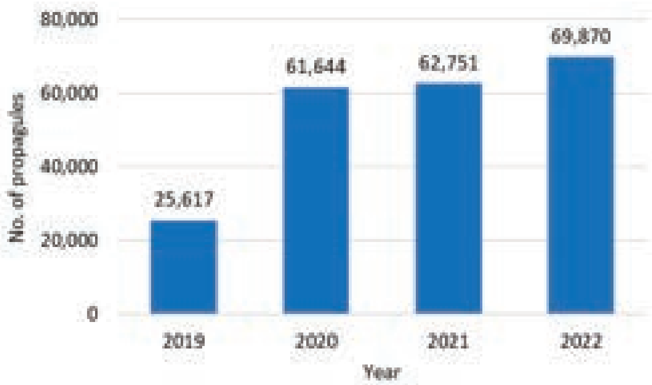

Figure 4. Increasing production of seaweed plantlets in AQD from 2019 to 2022 through modified culture protocols

Way Forward

Currently, the seaweed propagule production of AQD can only steadily supply the needs of the sea-based seaweed nursery. To increase the production of propagules in the land-based nursery, AQD is looking for an expansion of its land-based seaweed nursery operation. and aims to make healthy and high-quality seaweed plantlets available to growers in the Philippines. In addition, refining this optimized protocol in order to make it adaptable and transfer-ready to stakeholders through training courses and the production of manuals is also being targeted.

Figure 5. Seaweed micropropagules produced in AQD

References

Cai, J., Lovatelli, A., Aguilar-Manjarrez, J., Cornish, L., Dabbadie, L., Desrochers, A., Diffey, S., Garrido Gamarro, E., Geehan, J., Hurtado, A., Lucente, D., Mair, G., Miao, W., Potin, P., Przybyla, C., Reantaso, M., Roubach, R., Tauati, M. & Yuan, X. (2021). Seaweeds and microalgae: an overview for unlocking their potential in global aquaculture development. FAO Fisheries and Aquaculture Circular No. 1229. Rome, FAO. https://doi.org/10.4060/cb5670en

Dawes C., & Koch, E. (1991). Branch, micropropagule and tissue culture of the red algae *Eucheuma denticulatum* and *Kappaphycus alvarezii* farmed in the Philippines. *J. Appl. Phycol., 3*(3), 247–257.

Faisan, Jr., J. P., Sollesta-Pitogo, H., & de la Peña, L.D. (2022). Issues and challenges in sustainable development of fisheries and aquaculture of Southeast Asian Region: Marine fishery resources: Seaweeds. In *The Southeast Asian State of Fisheries and Aquaculture 2022* (pp. 59–64). Secretariat, Southeast Asian Fisheries Development Center. http://hdl.handle.net/20.500.12066/6997

Hayashi, L., Hurtado, A. Q., Msuya, F. E., Bleicher-Lhonneur, G., Critchley, A. T. (2010). A review of *Kappaphycus* farming: prospects and constraints. In J. Seckbach, R. Einav, & A. Israel. (Eds.), *Seaweeds and their role in globally changing environments* (pp. 225–283). Cellular Origin, Life in Extreme Habitats and Astrobiology, Vol. 15. Springer, Dordrecht. https://doi.org/10.1007/978-90-481-8569-6_15

Hurtado A., & Biter A. (2007) Plantlet regeneration of *Kappaphycus alvarezii* var. *adik-adik* by tissue culture. *J. Appl. Phycol., 19*(6), 783–786.

Jiksing, C., McMarshall, M. O., Thien, V. Y., Rodrigues, K. F., & Wilson, T. L. Y. (2022). Recent advances in seaweed seedling production: a review of eucheumatoids and other valuable seaweeds. *Algae 2022, 37*(2), 105–121. https://doi.org/10.4490/algae.2022.37.5.11

Luhan, M. R. J., & Sollesta, H. (2010). Growing the reproductive cells (carpospores) of the seaweed, *Kappaphycus striatum*, in the laboratory until outplanting in the field and maturation to tetrasporophyte. *J. Appl. Phycol.,* 22, 579–585. https://doi.org/10.1007/s10811-009-9497-7

McHugh, D. J. (2003). A guide to the seaweed industry (Fisheries Technical Paper No. 441). Food and Agriculture Organization of the United Nations.

Polne-Fuller, M. (1988). The past, present, and future, of tissue culture and biotechnology of seaweeds. In T. Stadler, J. Mollion , M-C. Verdus, Y. Karamanos, & M. H. Christiaen (Eds.), *Algal Biotechnology* (pp. 17–31). Elsevier.

Ronquillo, I. A., & M. E. Gabral-Llana. (1989). The Philippine Eucheuma seaweed industry. *Fishery Resources Journal, Philippines, 14*(1), 23–29.

Tahiluddin, A. B., & Terzi, E. (2021). An overview of fisheries and aquaculture in the Philippines. *J. Anatolian Env. and Anim. Sciences, 6*(4), 475-486. https://doi.org/10.35229/jaes.944292

Yong, Y. S., Yong, W. T. L., Thien, V. Y., Ng, S. E., Anton, A., & Yassir, S. (2015). Acclimatization of micropropagated *Kappaphycus alvarezii* (Doty) Doty ex Silva (Rhodophyta, Solieriaceae) in outdoor nursery system. *J Appl Phycol 27,* 413–419 (2015). https://doi.org/10.1007/s10811-014-0289-3

About the Authors

Ms. Hananiah Sollesta-Pitogo is an Associate Researcher from SEAFDEC Aquaculture Department in Tigbauan, Iloilo, Philippines (Email: htsollesta@seafdec.org.ph)

Mr. Joseph Faisan, Jr. is an Associate Researcher and the current seaweed commodity team leader from SEAFDEC Aquaculture Department in Tigbauan, Iloilo, Philippines (Email: jfaisan@seafdec.org.ph)

Ms. Joesyl Marie de la Cruz-Aranas is an Information Specialist and designated Special Department Coordinator from SEAFDEC Aquaculture Department in Tigbauan, Iloilo, Philippines (Email: JMdelaCruz@seafdec.org.ph)

Development of Artificial Reefs in Southeast Asia: Malaysia in focus

Muhammad Amirullah Al Amin Ayob, Mazalina Ali, Hamizah Nadia Alias@Yusof, and *Abd Haris Hilmi Ahmad Arshad*

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

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).

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

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**).

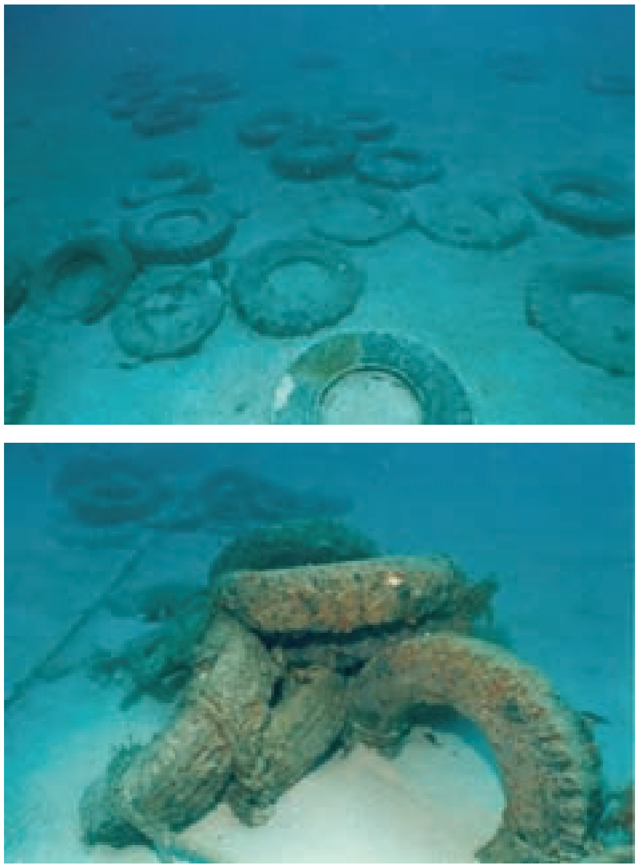

Figure 3. Tire reefs deployed in the open sea of Terengganu in 1990 destroyed by strong water currents (survey in 2007-2008)

- **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

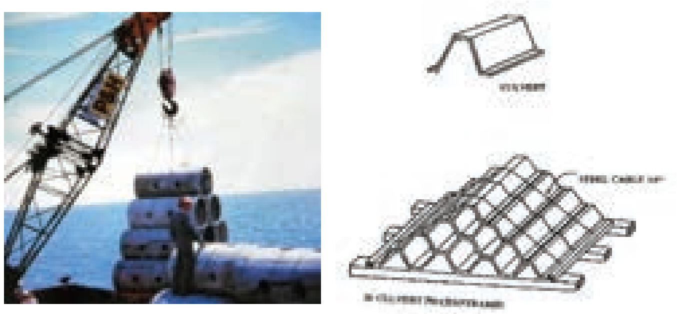

Figure 5. Concrete culvert ARs: cylinder *(left)* and V-shaped *(right)*

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).

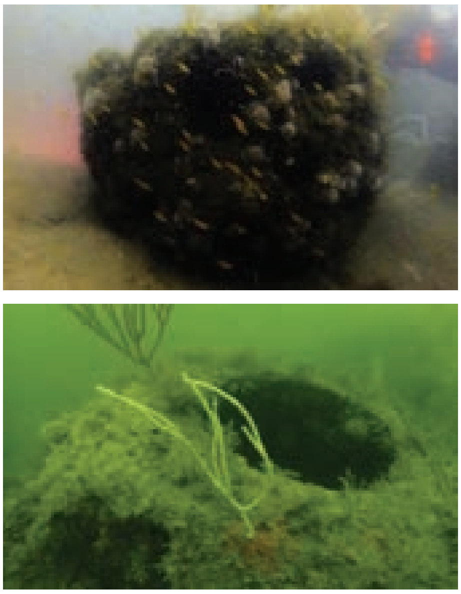

Figure 10. Reef balls deployed in Sarawak waters in 1998 for coral reef enhancement monitored in April 2021

- **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 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).

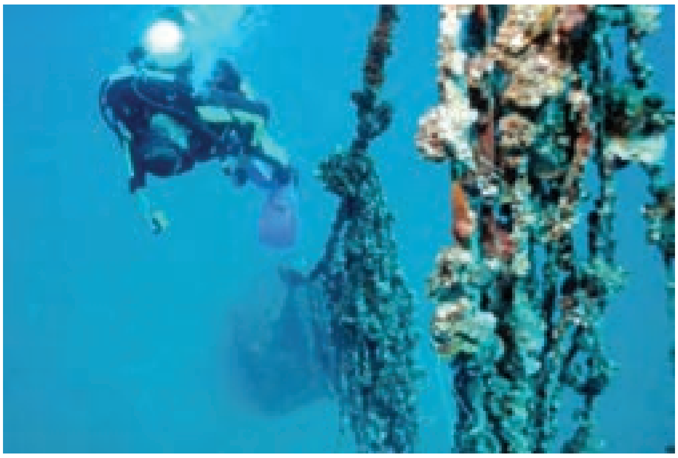

Figure 11. Plastic straps of ARFADs colonized by biofouling and marine organisms

- **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

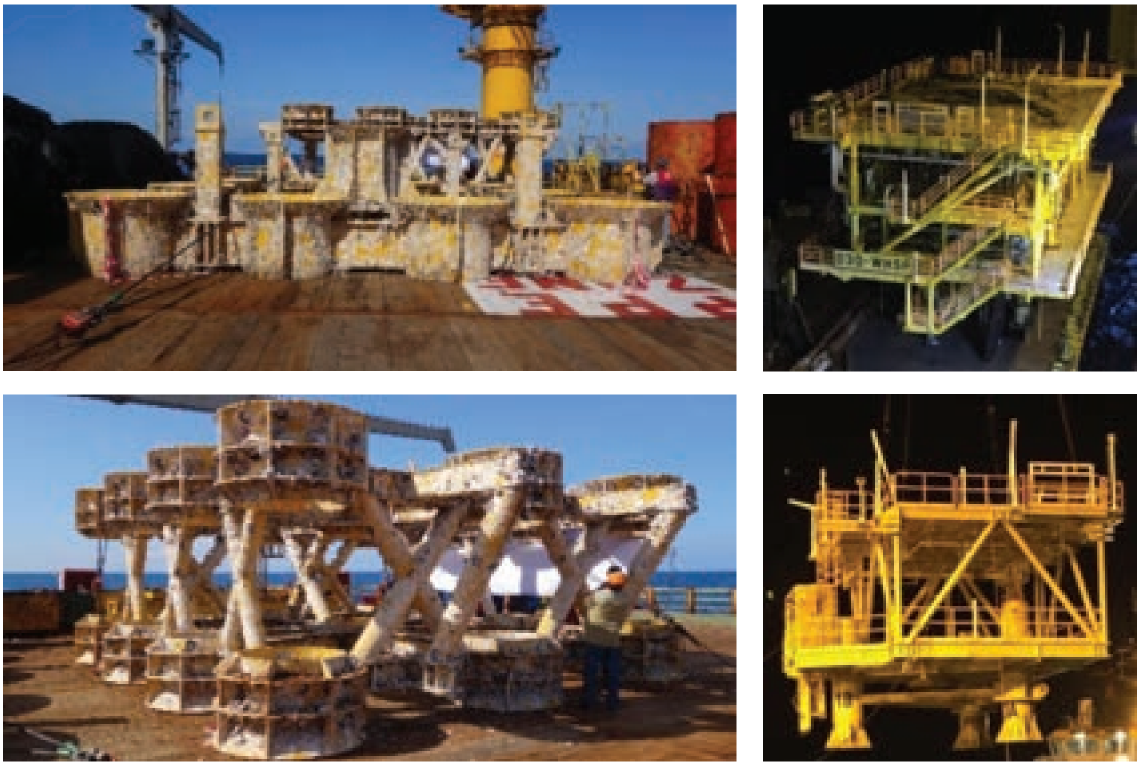

Figure 12. Oil platforms converted to ARs (*top and bottom left*: KAPAL oil rigs deployed in Pulau Kapas, Terengganu; *top right*: DANA platform; and *bottom right*: D30 platform deployed in Miri, Sarawak)

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.

References

Abdul Razak, L., & Ismail, I. (1994). An analysis of the efficacy of three artificial reef designs, at Pulau Lembu, Kedah. In: Proceedings fisheries research conference, 4-6 October 1993, Kuala Terengganu, Malaysia. Department of Fisheries Malaysia. pp 410-419.

Ahmad, A., Mahyam, Mohd. I., Zaidnuddin, I., Mohamed Pauzi, A., Ku Kassim, K.Y., & Nor Azman, Z. (2008). Status of artificial reefs in Terengganu waters based on images analysis using side-scan sonar (In Malay). SEAFDEC/MFRDMD, Kuala Terengganu, Malaysia. 57pp.

Ahmad, A., Mohamed Pauzi, A., Rafezi, A., Abdul Halim, M., & Raja Bidin, R, H. (2013). Protecting coastal habitats and enhancing fisheries resources using big size artificial reefs in the East Coast of Peninsular Malaysia. Malaysian Journal of Science 32 (SCS Sp Issue): 19-36

Ahmad, A., Rafezi, H., Nur Iskandar, T., Nor Azman, Z., Muhammad Amirullah Al Amin, A., & Mohd Saki, N. (2018). Penyelidikan dan Pembangunan Reka Bentuk dan Pembinaan Tukun Tiruan Di Malaysia (1975-2017) (In Malay). SEAFDEC/SP/37. 63pp.

Balgos, M., C. (1995). Evaluation of artificial reef development in the Philippines, p. 6-22. In J.L. Munro and M., C. Balgos (eds.) Artificial reefs in the Philippines. ICLARM Conf. Proc. 49, 56 p.

Beverly, S., Griffiths D. & Lee, R. (2012). Anchored fish aggregating devices for artisanal fisheries in South and Southeast Asia: benefits and risks. FAO Regional Office for Asia and the Pacific, Bangkok, Thailand, RAP Publication 2012/20, 65p.

Chaiyawat, C., Klinthong, W., & Paphavasit, N. (2019). Artificial reefs: An effective tool for fisheries management in Thailand. Ocean & Coastal Management, 177, 121-128.

Che Omar, M. H., & Sukarno, W. (1994). Early observation of artificial reefs for squid in Terengganu waters (In Malay). In: Proceedings fisheries research conference, 4-6 October 1993, Kuala Terengganu, Malaysia Department of Fisheries Malaysia. pp 404-409.

Chou L.M. (2005). Artificial Reef Programmes in Singapore. In: Proceedings of the 2nd Regional Workshop on Enhancing Coastal Resources: Artificial Reefs in Southeast Asia 9 - 12 November, 2004. TD/SP/33. pp 87-94.

Dahuri, R., Rais, J., Ginting, S. P., & Sitepu, M. J. (2006). The benefits of artificial reefs in Indonesia. Ocean & Coastal Management, 49(9), 643-651.

Daud, A., & Mohd. Zakaria, M. (2007). First rig to reef in Malaysia. In: Proceedings of 4th National Fisheries Symposium 2006, Kuching, Sarawak, Malaysia. Department of Fisheries Malaysia. pp 138-143.

Department of Fisheries Malaysia (DOFM). (2008). Regional guidelines for responsible fisheries in Southeast Asia; Responsible Fisheries Management. Department of Fisheries Malaysia. 152pp.

Garcia, L. M. B., & Aliño, P. M. (2012). The Status of Coral Reefs in Southeast Asia. In Coral Reefs of the World. pp 223-233.

Hung N.Q. (2005). Country Report of Viet Nam. In: Proceedings of the 2nd Regional Workshop on Enhancing Coastal Resources: Artificial Reefs in Southeast Asia 9 - 12 November, 2004. TD/SP/33. pp 113-120.

Idris A.H. (2005). Artificial Reefs Current Situation in Brunei Darussalam. In: Proceedings of the 2nd Regional Workshop on Enhancing Coastal Resources: Artificial Reefs in Southeast Asia 9 - 12 November, 2004. TD/SP/33. pp 31-38.

Jothy, A. A. (1986). Artificial reef development in Malaysia. In: Meng, W.T., Eong, O.J. and Ong, K. S. (eds). Proceedings of the Ninth Annual Seminar Towards Greater Productivity of Our Coastal Waters 12th April 1986. Malaysia Society of Marine Science. pp 5-16.

Meier, H. M., Martin, J. R., Feigenbaum, L.D., & Bell, M. (1986). Artificial reefs in Virginia old beginnings and new directions. In: F.M. D'Tri, (ed). Artificial reefs: Marine and freshwater applications. Lewis Publisher, Inc. Chelsea, Michigan. pp 337-347.

Mohammed Pauzi, A., Abdul Razak, L., & Hussin, M.A. (1995). The role of coral reef and artificial reefs research in conservation and enhancement of fishery resources. Paper presented at Senior Fisheries Officer Seminar, 22-24 September 1995, Johor Bahru, Johor, Malaysia.

Muhammad Amirullah Al Amin, A., Annie Nunis, B., Abd Haris Hilmi, A, A., & Hamizah Nadia, A. (2022). Research & Development of Artificial Reefs in the East Coast Peninsular Malaysia. FRI Newsletter, Volume 25: 4-5

Richard, R., & Daud, A. (2007). Research activities on reef balls in Sarawak. In: Proceedings of 4th National Fisheries Symposium 2006, Kuching. Sarawak Malaysia. Department of Fisheries Malaysia. pp 138-143.

Saharudin, A.H., Ahmad, A., Lokman, M.H., & Wan Salihin, W.A. (2012). Historical Development and Management of Malaysian Artificial Reefs (ARs). Proceedings of MTS-IEEE Oceans, 2012-Yeosu, Korea. 28pp.

SEAFDEC/TD. (2005). Proceedings of the 2nd Regional Workshop on Enhancing Coastal Resources: Artificial Reefs in Southeast Asia 9–12 November, 2004. TD/SP/33. 255 p.

Sitha P. (2005). Status and Evolution of Coral Reefs in Cambodia. In: Proceedings of the 2nd Regional Workshop on Enhancing Coastal Resources: Artificial Reefs in Southeast Asia 9–12 November, 2004. TD/SP/33. pp 39-46.

Stone, R. B. (1972). Artificial reefs of waste material for habitat improvement. Marine Pollution Bulletin, 3 (2): 27–28.

Sukarno, W., Raja Mohammad Noordin, R. O., Che Omar, M. H. & Rosdi, M. N. (1994). Artificial Reefs in Malaysia (In Malay). Department of Fisheries Malaysia. 132 pp.

Supongpan, S. (2006). Artificial reefs in Thailand. Southeast Asian Fisheries Development Center, Training Department. TD/TRB/74; 23 p.

Wong, F.H. (1991). Artificial reefs development and management in Malaysia. In: Proceedings Symposium on artificial reefs and fish aggregating devices as tools for the management and enhancement of marine fishery resources, Colombo, Sri Lanka, 14-17 May 1990. RAPA Report 1991/11. pp 392-422.

About the Authors

Mr. Muhammad Amirullah Al Amin Ayob is the Head of the Resource Enhancement Unit of SEAFDEC/MFRDMD in Terengganu, Malaysia (Email: amin_ayob@seafdec.org.my)

Ms. Mazalina Ali is the Special Departmental Coordinator of SEAFDEC/MFRDMD in Terengganu, Malaysia (Email: mazalina@seafdec.org.my)

Ms. Hamizah Nadia Alias@Yusof is the Head of the Fishery Oceanography Unit of SEAFDEC/MFRDMD in Terengganu, Malaysia (Email: hamizah@seafdec.org.my)

Mr. Abd Haris Hilmi Ahmad Arshad is the Chief of SEAFDEC/MFRDMD in Terengganu, Malaysia (Email: haris_arshad@seafdec.org.my)

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Utilizing Drone Imagery to Classify Swamp Cover in Patra Tani Village, South Sumatra Province, Indonesia

Freddy Supriyadi, Zulkarnaen Fahmi, Dina Muthmainnah, Ellis Nurjuliasti Ningsih, Aroef Hukmanan Rais, Rezki Antoni Suhaimi, Sevi Sawestri, and *Tomohito Shimizu*

The initial step of successful land use is the selection of the appropriate location in line with the type or concentration of land exploration which requires land mapping. However, mapping activities undertaken in a territory with a comprehensively changing land cover, such as swamp ecosystems, requires considerable time and cost, which could make the work ineffective. Nevertheless, through technological developments, the land with changing ecosystem can be mapped easily using remote sensing systems and aerial photography by drones. The advantages of this technology are its effectiveness and efficiency in terms of time and cost.

Under the project "Management Scheme of Inland Fisheries in the Southeast Asian Region," implemented in 2020-2024 and supported by the Japanese Trust Fund VI Phase 2, SEAFDEC Inland Fishery Resources Development and Management Department (IFRDMD) conducted the study to monitor the land cover of the Special Area for Conservation and Fish *Refugia* (SPEECTRA) in a swamp area by using a drone. Drones could produce high-resolution aerial images that can be quickly processed by analysis software such as geographic information systems and image classification algorithms. Using drone imagery to manage inland waters has great potential, both for monitoring the aquatic environmental health index and mitigating ecological damage.

A swamp is a wetland area characterized by being saturated with water, either permanently or seasonally, and is often characterized by the type of vegetation such as cypress or hardwood. The freshwater swamp is found in inland waters, while saltwater swamps can be found along coastlines (Rudledge *et al*., 2022). In inland waters, a swamp is a dynamic ecosystem that becomes a terrestrial habitat during the dry season and an aquatic habitat during the rainy season (Muthmainnah *et al*., 2019) where the water depends on discharges from inflowing streams and groundwater. The low rainfall influences the flooding of swamps and changes the habitats to become wet or dry (Roshier *et al*., 2001). The change in vegetation affects the migration of aquatic organisms, mainly in the availability of feeding, nursing, and spawning grounds (Boyd & Madsen, 1997).

In Indonesia, the Inland Fishery Resources Development and Management Department (IFRDMD) of SEAFDEC in collaboration with the Sub-Institute for Swamp Fisheries of the Research Institute for Inland Fisheries and Extension (RIIFE), Ministry of Marine Affairs and Fisheries of Indonesia developed the Special Area for Conservation and Fish *Refugia* (SPEECTRA) concept since 2019. SPEECTRA is an artificial conservation area that can accommodate fish from the river or introduce brood stock. The system should be connected to the river or other natural water bodies through canals. The main objectives of SPEECTRA development are to 1) function as artificial conservation or protected area for native species; 2) provide freshwater fish genetic bank, especially for the black fish group; 3) prevent land fires that usually occur in marginal lands; and 4) serve as a study area for developing conservation zones in inland waters.

From January to October 2022, IFRDMD monitored the land cover of the SPEECTRA established in a swamp area in Patra Tani Village, South Sumatra Province, Indonesia. The 4.8 ha SPEECTRA operated since 2019 as artificial ponds to preserve fisheries, support food security, and prevent forest fires. At the beginning of 2022, the SPEECTRA was developed for educational and tourism areas focusing on swamp fishery

Figure 1. SPEECTRA ponds in Patra Tani Village, South Sumatra Province, Indonesia observed from January to October 2022

Table 1. Characteristics of the SPEECTRA ponds in Patra Tani Village, South Sumatra Province, Indonesia observed from January to October 2022

SPEECTRA Ponds	Area (ha)	Depth (m)	Water level (cm)
Pond 1 • Connected to the main canal and river • Built with barrier soil to control the migration of fish populations • Built with a trap door between the center of the pond and canal to prevent fish from returning to the river	1.0	4	170-290
Pond 2 • Conservation model for fish and crop cultivation • Plants were planted around the pond to provide shelter for fish	1.0	4	140-200
Pond 3 • Consisted of four interconnected plots (400 m^2 each) as fish protection areas, especially for juvenile	2.0	4	150-215
Pond 4 • Away from the river and used as a nursery • Connected to Pond 3 and Pond 5 where fish can easily migrate for their life cycle	1.5	4	140-155
Pond 5 • Built based on the agroforestry concept where nutrients produced by the trees would enter the water body for phytoplankton growth	2.5	4	160-170
Pond 6 • Has a large canal connected to the outside of the SPEECTRA area • Trees and swamp grass were planted at the center of the pond to shelter fish	0.8	5	100-120

activities. The SPEECTRA is composed of six ponds as shown in **Figure 1** and the characteristics of each pond are described in **Table 1**.

Mapping the land cover of SPEECTRA

It is important to assess the extent of land cover in swamp areas in order to manage natural resources which can be done through drone imagery. Using drones which are unpiloted aerial vehicles (UAVs) in computer vision applications offers advantages over traditional surveillance cameras. The ultrahigh-resolution images acquired by small UAVs are valuable in identifying and characterizing swamp areas using a low-cost drone (Ventura *et al*., 2016). Drone imagery is a relatively accurate and efficient data source for land cover identification, which has greater efficiency and flexibility and has been quickly adopted for various purposes including agriculture, aerial photography, and surveillance (Du *et al*. 2018; Zu *et al*., 2020). It can capture high-resolution images and access areas that are difficult to reach, compared to other methods in helping to identify the types and extent of land cover in swamp areas. A drone can be used to quickly and efficiently monitor, record, and gather data from routine observations. By providing aerial capabilities for capturing and recording images and data, it can be used to study ecological phenomena at higher resolutions and on impossible scales with satellites or crewed aircraft. The drone can also gather spatial information for wildlife surveys, aquatic habitats, water resource analysis, and valuable data in scientific remote sensing to evaluate resource management.

The DJI Phantom 4 Pro drone was utilized for capturing high-resolution images of the land cover of each pond of the SPEECTRA. The drone was equipped with a 20 MP camera and a 3-axis gimbal that stabilizes the images. The aerial photographs were taken at a height of around 100 m with a spatial resolution of 2.40–2.97 cm (Hernina *et al*., 2019). Besides, the rugged and water-resistant Garmin 79s handheld GPS device was used to map the study area at a scale of 1:2,000.

Data validation by ground check is a commonly used method to ensure the accuracy and reliability of drone-generated data. Thus, the ground check was done by comparing data generated by drones with data obtained from direct measurements in the field (ground truth). After the drone flight was completed, direct measurements were taken in the field at predetermined measurement points. These measurements were made using measuring instruments such as GPS, total station, or other devices.

Agisoft software was used to create flight plans for drones as well as image processing and analysis. The software was explicitly designed for photogrammetry and 3D modeling applications and included various tools for image enhancement, georeferencing, and land cover classification. Aerial photographs were analyzed by interpreting elements such as spatial, spectral, texture, color, shape, pattern, and size. Based on object-based image analysis, the land cover of each pond was classified into different types (*i.e.* shrubs, trees, aquatic plants, water, and riparian) and was assigned corresponding colors (**Table 2**).

The spatial and temporal land cover captured by the drone from January to October 2022 is illustrated in **Figure 2**. **Pond 1** was dominated by riparian in January and February

Table 2. Classification of the land cover of SPEECTRA ponds in Patra Tani Village, South Sumatra Province, Indonesia

Land cover	Description	Assigned color
Shrubs	area covered by grass, herbaceous plants, and seedlings	Light yellow
Water	area with the deepest pool and covered by water the whole year	Light blue
Riparian	area covered by water during the rainy season or with a little water or dry during the dry season	Maroon
Trees	area covered by woody plants	Green
Aquatic plants	area covered by plants that have adapted to living in aquatic environments	Brown

which decreased slightly from March to October. In contrast, the abundance of trees increased significantly from April to October. The growth of trees was influenced by the addition of nutrients from the river flowing into the SPEECTRA system. This condition indicated that trees grew faster and changed the dominance of riparian in Pond 1.

The dominance of trees was observed for ten months in **Pond 2**. Approximately 45–78 % of Pond 2 was covered by trees while aquatic plants fluctuated depending on the water level. The riparian was not observed which could be because Pond 2 was covered by vegetation and other types of plants. The presence of trees and other vegetation in the riparian zone can stabilize the banks of the pond, filter pollutants, and provide habitat for a variety of plant and animal species. Overall, the ecology of Pond 2 was complex and dynamic, and a variety of factors including vegetation cover and water level fluctuations made impacts on the plant and animal species that inhabit the pond and its surrounding area.

Aquatic plants were dominant in **Pond 3** with around 33–55 % cover. The abundance of aquatic plants and shrubs fluctuated equally indicating that there may be a dynamic interplay between these two types of vegetation. The small percentage of aquatic plants in the pond had bloomed which could have been due to favorable environmental conditions such as increased sunlight, nutrient availability, and water temperature. The dominance of aquatic plants in Pond 3 can have important ecological implications. Aquatic plants play an important role in the pond ecosystem by providing a habitat for fish and other aquatic animals, stabilizing sediments, and helping to maintain water quality by filtering pollutants.

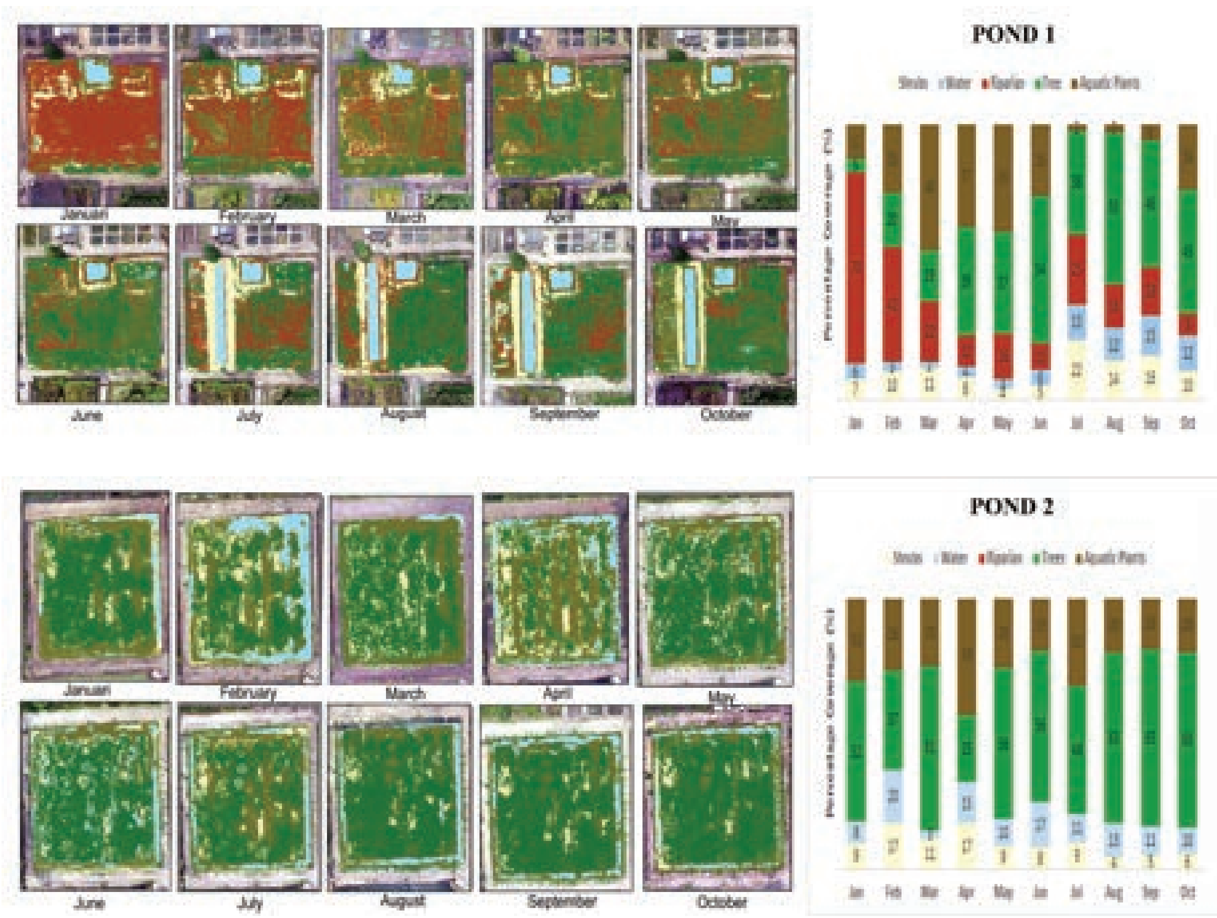

Figure 2. Land cover classification in SPEECTRA ponds in Patra Tani Village, South Sumatra Province, Indonesia observed from January to October 2022

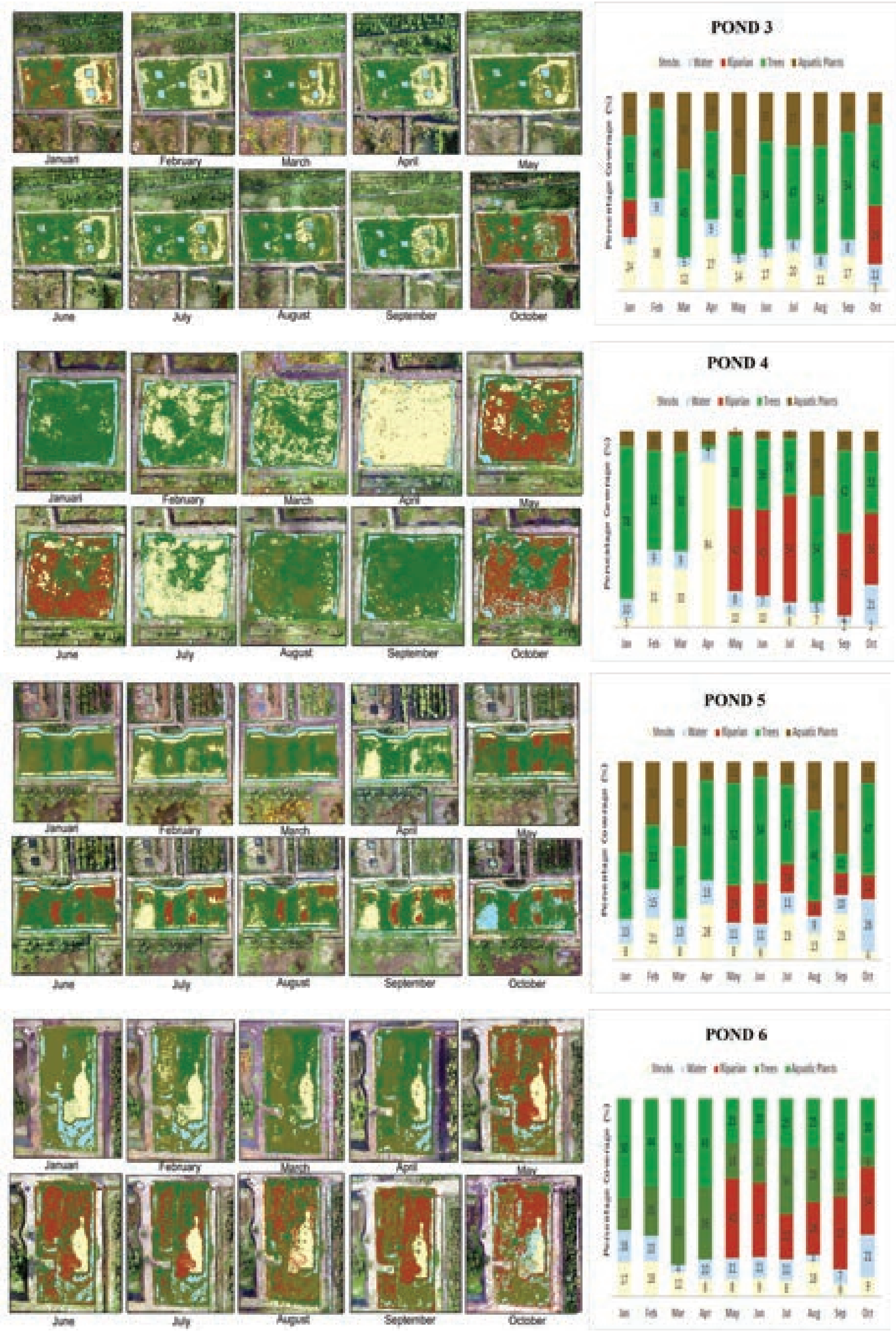

Figure 2. Land cover classification in SPEECTRA ponds in Patra Tani Village, South Sumatra Province, Indonesia observed from January to October 2022 *(Cont'd)*

However, if the growth of aquatic plants becomes too dense, it can lead to problems such as reduced oxygen level, increased sedimentation, and decreased light penetration, which can negatively impact other species in the pond.

A predominance of trees has been observed in **Pond 4** but there was a significant decrease in April. Shrubs increased dramatically from February to April but dropped significantly thereafter. In contrast, the abundance of shrubs increased dramatically from February to April but dropped significantly afterward. Riparian abundance increased from May to October suggesting that there may have been an increase in the number of plants and other vegetation in the area surrounding the pond during this time period. Riparian vegetation can be important for stabilizing the banks of the pond, filtering pollutants, and providing important habitats for a variety of plant and animal species. Overall, Pond 4 had a dynamic ecosystem where the abundance of trees, shrubs, and riparian vegetation fluctuated over time. It is possible that there are complex interactions between these different types of vegetation, and that changes in one type of plant made important implications for the others.

The agroforestry system was implemented in **Pond 5** where abundant trees and aquatic plants are a positive step towards sustainable land management. Agroforestry combines agricultural practices with cultivating trees and other vegetation to create a productive and ecologically balanced system. The abundance of trees and aquatic plants in Pond 5 indicates a diverse ecosystem, which can provide many benefits—trees provide shade, stabilize soil and contribute to nutrient cycling, while aquatic plants improve water quality, provide habitat for marine organisms, and reduce erosion. Combining these elements in an agroforestry system created a more resilient and productive environment. The recorded abundance of riparian from May to October indicated a thriving riparian zone during the wet season. The presence of abundant riparian vegetation indicated a healthy riparian ecosystem, which contributed to the overall ecological integrity of Pond 5.

In **Pond 6**, both riparian and aquatic plants had a significant presence. The riparian grew well during the rainy season from May to October as well as other vegetation surrounding the pond. Riparian can be important for stabilizing the banks of the pond, filtering pollutants, and providing important habitats for a variety of plant and animal species. Moreover, aquatic plants also had a significant cover in Pond 6, which provided a habitat for fish and other aquatic animals, helped to stabilize sediments, and maintained water quality by filtering pollutants.

Conclusion and Way Forward

Drones could be an effective tool for monitoring changes in land cover classifications in the SPEECTRA. The development of camera technology has made it possible to produce high-quality images to produce more robust algorithms for inland fisheries management. Accurate land cover maps provide adequate assistance for building the recommendations for managing aquatic resources in swamp areas. However, it is important to note that monitoring land cover change using drones should be conducted periodically in order to produce accurate and reliable data. Besides, the use of drones should also consider local regulations so as not to interfere with human activities.

Each of the SPEECTRA ponds has a unique ecological composition and dynamics that were influenced by various environmental factors such as water level, nutrient availability, and rainfall. In general, riparian and aquatic plants played important roles in stabilizing the banks of the pond, filtering pollutants, providing habitat for a variety of plant and animal species, and maintaining water quality. However, the excessive growth of aquatic plants made negative impacts on other species in the ponds. The presence of trees and other vegetation in the riparian zone also made important impacts on the ecology of the ponds and surrounding areas.

IFRDMD would continue the monitoring of land cover using drones in Patra Tani and other locations to produce high-resolution images and obtain higher-quality data. The data and information obtained would be used to support the proper management of inland fisheries in the countries in Southeast Asia.

References

Boyd, H. & Madsen, J. (1997). Impacts of Global Change on Arctic-Breeding Bird Populations and Migration. *Global Change and Arctic Terrestrial Ecosystems*. pp 201–217.

Du, D., Qi Y., Yu H., Yang Y., Duan K., Li G., Zhang W., Huang Q., Tian Qi. (2018). The Unmanned aerial vehicle benchmark: object detection and tracking. *European Conference on Computer Vision (11214)*. Springer, Cham. https://doi.org/10.1007/978-3-030-01249-6_23

Hernina R., Putera R., Rosyidy M. K., Ramadhan M. I., Putra T. A. (2019). Analisis tinggi terbang drone dan resolusi untuk pemetaan penggunaan lahan menggunakan DJI Phantom 4 Pro (studi Kasus kampus UI). *Seminar Nasional Penginderaan Jauh Ke*-6. 99–105.

Muthmainnah, D., Makmur, S., Rais, A.H., Sawestri, S., Supriyadi, F., & Fatah, K. (2019). The Features of Inland Fisheries in Southeast Asia, Wiadnyana, N.N, Adrianto, L., Sulit, V.T., Wibowo, A. (Eds), IPB Press.

Roshier, D., Whetton, P., Allan, R., Robertson, A.I., (2001). Distribution and persistence of temporary wetland habitats in arid Australia in relation to climate. *Austral Ecology 26*:371–384.

Rudledge, K., McDaniel M., Teng S., Hall H., Ramroop T., Sprout E., Hunt J., Boudreau D., Costa H. (2022). *Swamp*. National Geographic Society. Accessed 4 January 2023.

Ventura, D., Bruno, M., Lasinio, G.J., Belluscio, A. & Ardizzone, G. (2016). A low-cost drone-based application for identifying and mapping of coastal fish nursery grounds. *Estuarine Coastal and Shelf Science (171)*85–98.

Zu, P., Wen, L., Du, D., Bian, X., Hu, Q., & Ling, H. (2020). Vision Meets Drones: Past, Present and Future. *ArXiv, abs/2001.06303*.

About the Authors

Mr. Freddy Supriyadi is an officer at SEAFDEC/IFRDMD and Instructor at the Ministry of Marine Affairs and Fisheries, Indonesia (Email: freddy.supriyadi@seafdec.id)

Mr. Zulkarnaen Fahmi is the Chief of SEAFDEC/IFRDMD and Senior Fisheries Extension at the Ministry of Marine Affairs and Fisheries, Indonesia (Email: fahmi.p4ksi@kkp.go.id).

Dr. Dina Muthmainnah is the Special Departmental Coordinator of SEAFDEC/IFRDMD and Senior Policy Analyst at the Ministry of Marine Affairs and Fisheries, Indonesia (Email: dina.muthmainnah@seafdec.id).

Ms. Ellis Nurjuliasti Ningsih is a lecturer at the Marine Sciences Department of Math and Science Faculty, Sriwijaya University, Indonesia (Email: ellis_nurjuliasti@unsri.ac.id).

Mr. Aroef Hukmanan Rais is an officer at SEAFDEC/IFRDMD and Instructor at the Ministry of Marine Affairs and Fisheries, Indonesia (Email: aroef.hukmanan@seafdec.id).

Mr. Rezki Antoni Suhaimi is an officer at SEAFDEC/IFRDMD and Acting Head of the Research Institute for Inland Fisheries and Extension, Ministry of Marine Affairs and Fisheries, Indonesia (Email: rezki.antoni@kkp.go.id).

Ms. Sevi Sawestri is an officer at SEAFDEC/IFRDMD and Instructor at the Ministry of Marine Affairs and Fisheries, Indonesia (Email: sevi.sawestri@seafdec.id).

Mr. Tomohito Shimizu is the Deputy Chief of SEAFDEC/IFRDMD (Email: deputy_chief@seafdec.id).

Lights on the Water? Accumulating VIIRS boat detection grids in Southeast Asia spanning 2012–2021

Christopher D. Elvidge, Tilottama Ghosh, Namrata Chatterjee, and *Mikhail Zhizhin*

It has been known since the 1970s that heavily lit fishing boats can be detected with nighttime visible low-light imaging data collected by polar-orbiting meteorological sensors (Croft, 1979). The two-sensor series having low-light imaging capabilities include the U.S. Air Force Defense Meteorological Satellite Program (DMSP) Operational Linescan System (OLS) and the NASA/NOAA Visible Infrared Imaging Radiometer Suite (VIIRS). These sensors use light intensification to enable the detection of moonlit clouds at night—to satisfy a requirement from meteorologists for day and night visible and thermal imagery of clouds. The OLS digital archive extends from 1992 to the present and collects relatively coarse resolution (2.7 km ground sample distance) global data. The VIIRS sensor provides key improvements (Elvidge *et al.*, 2013) in low-light imaging from 2012 to the present and the pixel resolution (742 m × 742 m) is finer and has in-flight calibration to radiance units. In 2015, the Earth Observation Group (EOG) developed the VIIRS boat detection (VBD) algorithm (Elvidge *et al.*, 2015a; Elvidge *et al.*, 2018; Hsu *et al.*, 2019) with support from NOAA's Joint Polar Satellite System (JPSS) proving ground program and United States Agency for International Development (USAID). The VBD data were produced in near real-time and the nightly record extends back to April 2012 in Asia. In addition to the nightly product, the EOG also made monthly and annual summary grids. These temporal compilations reveal spatial patterns that are not evident in data from single nights. In this article, the cumulative VBD images during 2012-2021 for the SEAFDEC Member Countries are reviewed.

Fishery agencies could rely on VIIRS boat detection (VBD) data in implementing regulations and management measures. VBD data could provide up-to-date information on the activities of fishery vessels such as indications of illegal fishing activity in restricted areas and incursions across exclusive economic zones (EEZ). Also, VBD could enable the authorities to identify "dark vessels" that lack a vessel monitoring system (VMS) or automatic identification system (AIS) operating in fishery closures, restricted waters, or EEZ boundary zones. Another potential VBD data application is the identification of offshore transshipment events. While the data are unable to discern the ownership of a fishery vessel, several ways the data can be used to enhance fishery management and combat illegal, unregulated and unreported (IUU) fishing are summarized in **Box** (Elvidge *et al.*, 2015a; Hsu *et al.*, 2019).

Box. Applications of VIIRS boat detection data

- Cross-reference with location data from a vessel monitoring system (VMS) or automatic identification system (AIS) to identify fishery vessels that are not operating a location beacon
- Overlay with outlines of marine protected areas or seasonally restricted fishing grounds to identify illegal fishing
- Identify possible incursions of foreign fishery vessels across EEZ borders
- Identify fishery vessels that are exceeding wattage limits placed on lighting
- Track spatial and temporal shifts in fishing grounds and identify stationary boats that may be storage boats collecting catch from a cadre of fishing boats by using monthly summary data
- Target enforcement efforts and inspections in areas with concentrated fishery vessel activities

In Southeast Asia and several other regions, VIIRS is a widely used practice. In Indonesia, 32 months of VMS data was segmented into fishing and transit activity types and then cross-matched with the VBD record. The cross-matching indicated that 96 % of the matches occur while the vessel is fishing. There was an indication that VMS vessels using submersible lights could be identified based on consistently low average radiances and match rates under 45 %. Overall, VIIRS detected large numbers of fishing boats under the 30 GT level set for the VMS requirement and the cross-matching could be used to identify "dark" vessels that lack AIS or VMS (Hsu *et al.*, 2019).

Moreover, a VIIRS closure index (VCI) was developed to rate the effectiveness of three types of closures: *ad hoc* fishery closure associated with toxic industrial discharge in Viet Nam, seasonal fishery closure in Palawan, Philippines, and permanent closure in restricted coastal waters in Negros Occidental, Philippines (Elvidge *et al.*, 2018). The VCI results indicated that it was possible to rank the effectiveness of different closures, year-to-year differences in compliance levels, and identify closure encroachments that may warrant additional enforcement effort. For the closure in Viet Nam, the VCI registered a modest level of compliance with a range of 13–44 % which indicated that a substantial amount of fishing occurred during the closure months. In the Philippines, VIIRS boat detection alerts were running for more than 900 fishery closures with email and short message service (SMS) transmission modes which are being actively used to plan enforcement actions and there was a growing list of apprehensions that occurred based on tip-offs from VIIRS.

Understanding the Features of VBD

In defining the types of features that can be seen in the ten-year VBD accumulation grid, **Figure 1** shows a **diffuse cloud** of VBD detections south of Aru Island, Indonesia. There are spots embedded in the cloud with many more detections than the surroundings which are called **recurring detection sites**. Near major ports and heavily trafficked straits, there can be dense clusters of detections associated with anchorages that serve as vessel parking lots with the example presented in **Figure 2** is a set of anchorages east of Singapore. While vessel freighters, tankers, and passenger vessels are only occasionally detected by VBD, there are some places exhibiting faint linear traces of detections from vessels in **transit lanes** (**Figure 3**)

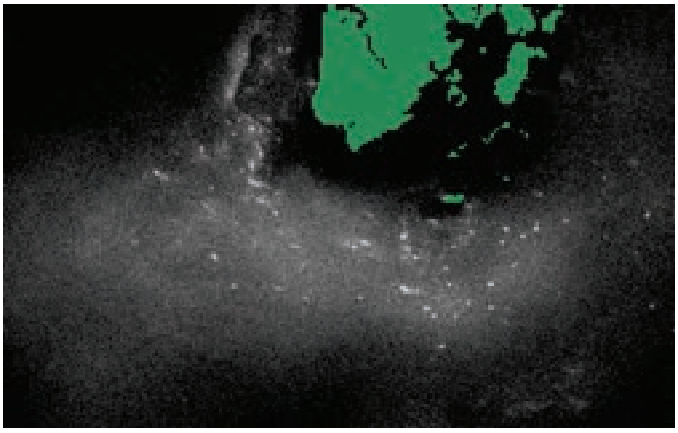

Figure 1. Diffuse cloud of VBD detections defining the outline of the fishing ground. Embedded in the clouds are spots having many more detections called **recurring detection sites**

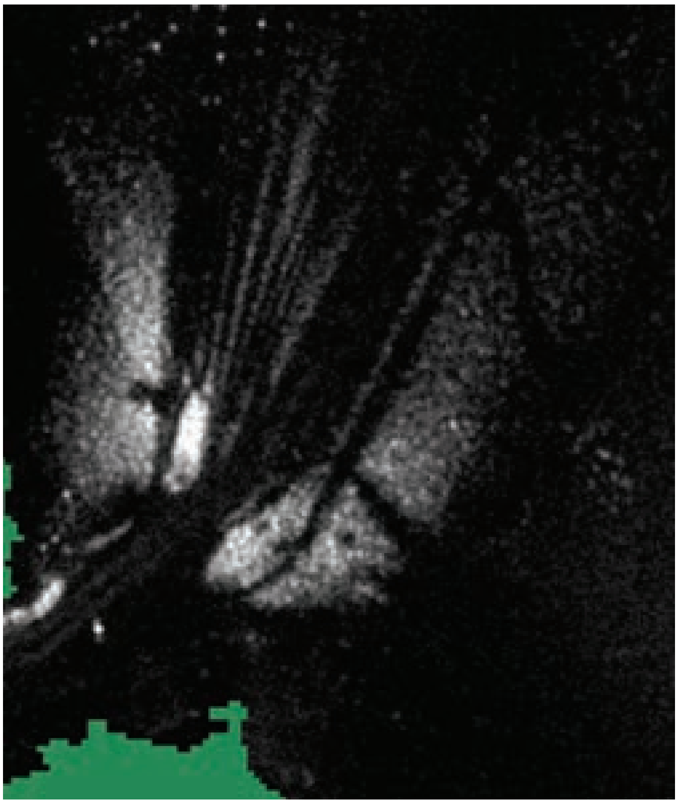

Figure 2. Anchorages east of Singapore

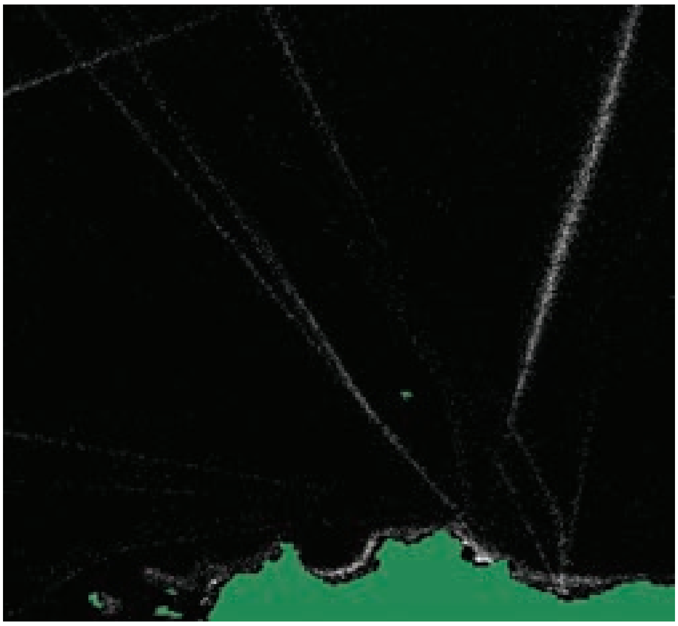

Figure 3. Transit lanes north of Sicily, Italy which are the result of lit passenger ferries transiting in largely straight lines between ports in the Mediterranean Sea

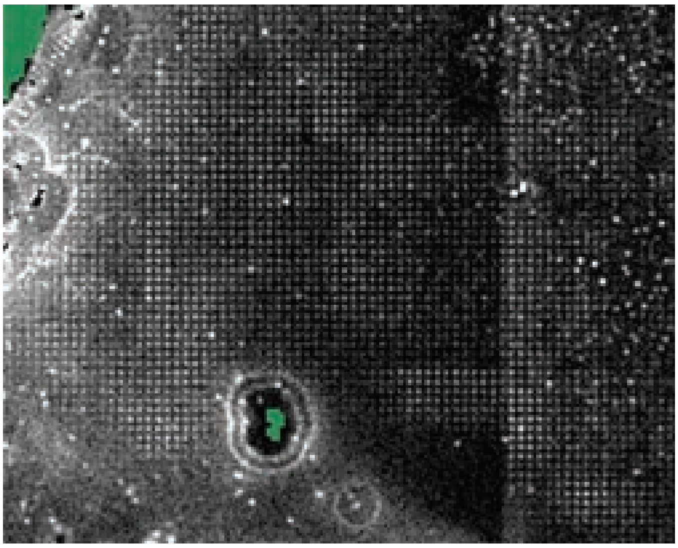

Figure 4. The Gulf of Thailand features excellent examples of regular **grid patterns** in the placement of recurring VBD detection spots. Ko Tao Island in Thailand is surrounded by two rings indicating that fishing boats are adhering to an **exclusion buffer** surrounding the shoreline. The double ring indicates a change occurred in the buffer distance

when VBD are accumulated for ten years. In some areas, the recurring detections form regular **grids and linear features** and good examples of this can be found in the Gulf of Thailand (**Figure 4**). **Figure 4** also shows the result of the effective exclusion of fishing boats near high-value islands, in this case, Koh Tao has two **exclusion rings** indicating at least two distance buffers for fishing boats have been active from 2012 to 2021. Finally, there are also aquaculture areas where sufficient lighting is deployed to produce VBD detections. The example here is the **ribbon** of offshore detections in Uchiura Bay, Hokkaido, Japan (**Figure 5**).

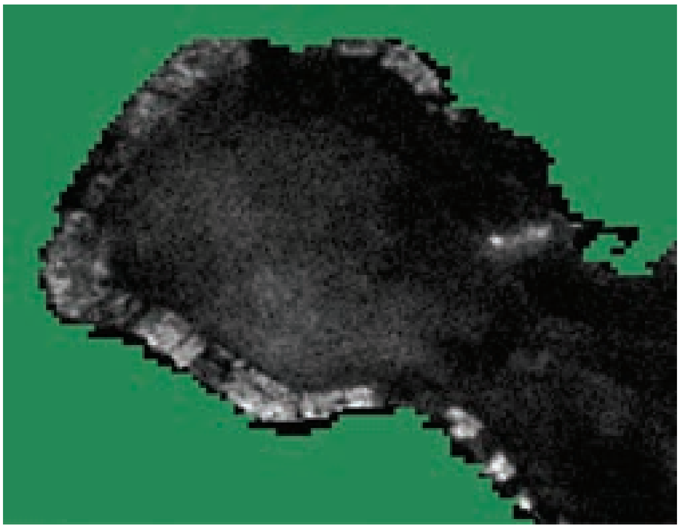

Figure 5. There is a **ribbon** of lit aquaculture parallel to the shore in Uchiura Bay, Hokkaido, Japan

Cumulative VBD images in SEAFDEC Member Countries

Brunei Darussalam

There are multiple recurring detections and several anchorages near the port in Brunei Darussalam (**Figure 6**).

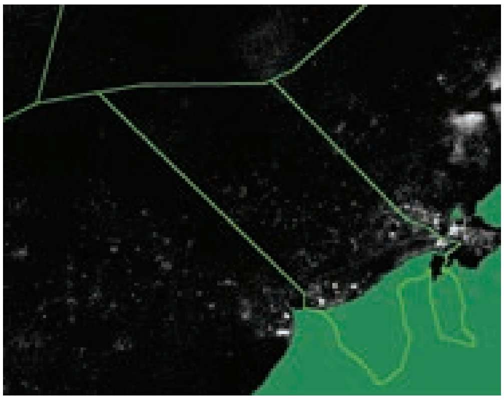

Figure 6. Cumulative VIIRS boat detections for Brunei Darussalam in 2012-2021

Indonesia

As shown in **Figure 7**, there are clusters of fishing grounds with embedded recurring detection in the Arafura Sea. In Sulawesi, near-shore fishing ground clusters with embedded recurring detections are primarily found in the south. Meanwhile, diffuse and dense fishing ground clusters with embedded recurring detections could be found in the Java Sea. There are several diffuse and dense fishing ground clusters with clouds of evenly spaced recurring detections in the Natuna Sea. The Straits of Malacca displayed diffuse and dense fishing ground clusters plus large numbers of evenly spaced recurring detections. In West Sumatra, diffuse fishing ground clusters with multiple recurring detection sites were found.

Japan

Multiple diffused to dense fishing grounds and close-to-shore ribbons of aquaculture were detected in Uchiura Bay, Hokkaido anchorages near major ports (**Figure 8**).

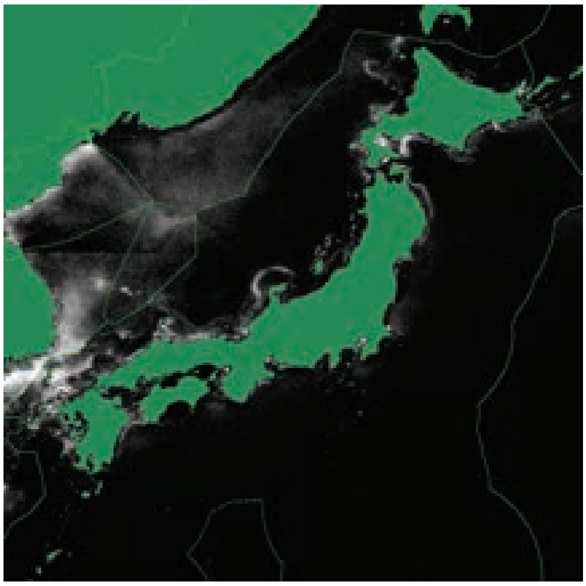

Figure 8. Cumulative VIIRS boat detections for Japan in 2012-2021

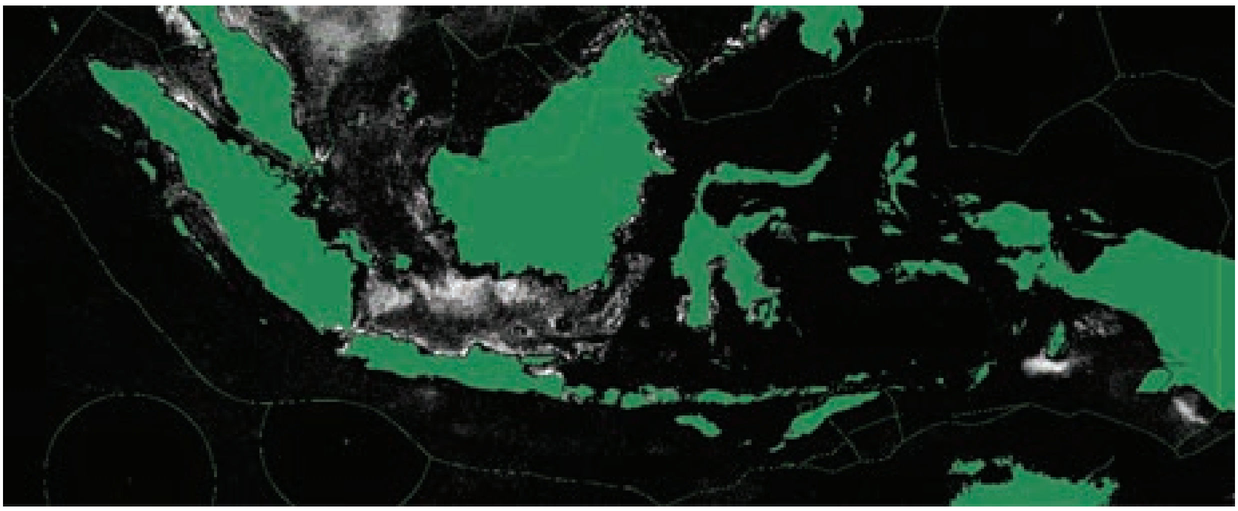

Figure 7. Cumulative VIIRS boat detections for Indonesia in 2012-2021

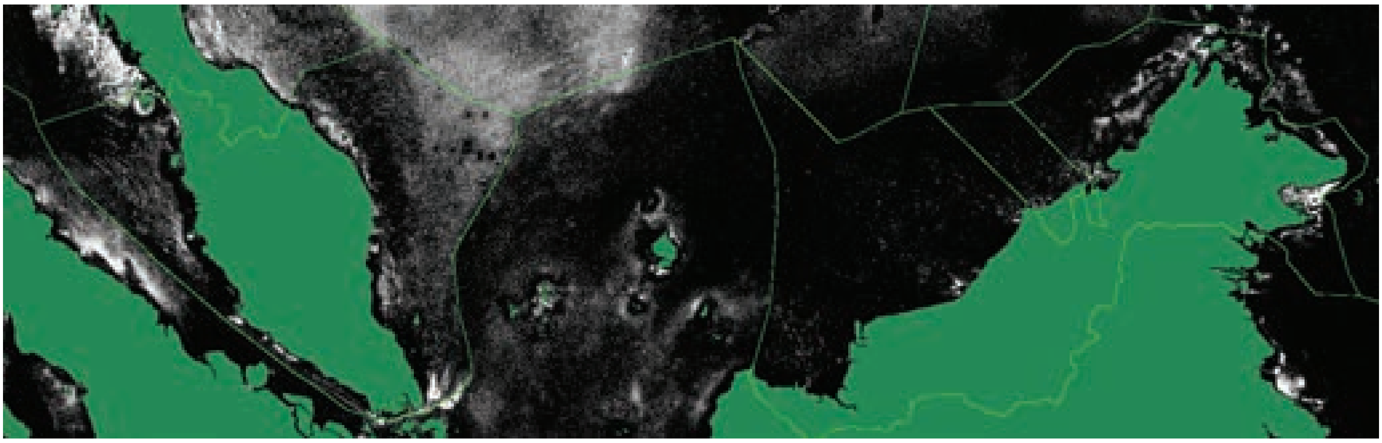

Figure 9. Cumulative VIIRS boat detections for Malaysia in 2012-2021

Malaysia

Figure 9 shows that in Malacca Strait there were curved and diagonal strings of regularly spaced recurring VBD detection, an anchorage near Kuala Lumpur, multiple anchorages near the shore northwest of Singapore, and faint tracks of detections in transit lands approaching Singapore. Moreover, in the East of Peninsular Malaysia, east-west linear and curved strings of recurring VBD detections; diffuse detection clouds centered on the exclusive economic zone (EEZ) junctions of Malaysia, Thailand, and Viet Nam; several nearshore fishing grounds; and large anchorages near Singapore were perceived. In Sarawak, there were numerous randomly spaced recurring detections across the EEZ and several dense anchorages near Bintulu. In Sabah, multiple irregularly shaped fishing ground clusters were sensed.

Myanmar

There is a 100 km wide ribbon of fishing boat detections in southern Myanmar along the Andaman Sea. In northern Myanmar, there are several dense fishing boat clusters indicating fishing grounds (**Figure 10**).

Philippines

Figure 11 shows that the northern part of Luzon Island is largely devoid of VBD. Nevertheless, there are several anchorages associated with Manila. From Manila to the south, there are multiple dense VBD clusters in the southern part of Luzon extending through the Visayas. Furthermore, dense clusters of fishing boats were also found in Palawan and Zamboanga Islands.

Figure 10. Cumulative VIIRS boat detections in Myanmar in 2012-2021

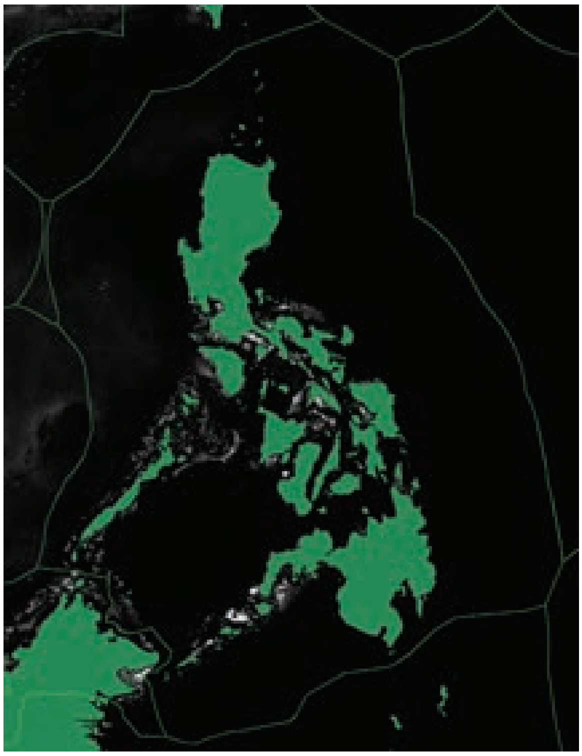

Figure 11. Cumulative VIIRS boat detections in the Philippines in 2012-2021

Singapore

Near Singapore, there were multiple large anchorages and evidence of transit lanes. Further south, there were several dense fishing ground clusters in Indonesia (**Figure 12**).

Figure 12. Cumulative VIIRS boat detections in Singapore in 2012-2021

Thailand and Cambodia

The Thailand portion of the Gulf of Thailand has numerous adjoining grids of recurring VBD detecting points (**Figure 13**). In the southern part of the gulf, the grid patterns begin breaking up into linear strings of recurring detections. There was a wide ribbon with a diffuse cloud of VBD detections which is overprinted by grids of recurring detections. This ribbon extends 100 km into the Andaman Sea. on the other hand, Cambodian waters feature a diffused cloud of VBD detections and extensions of the grid pattern of recurring detection spots along the boundary with Thailand waters.

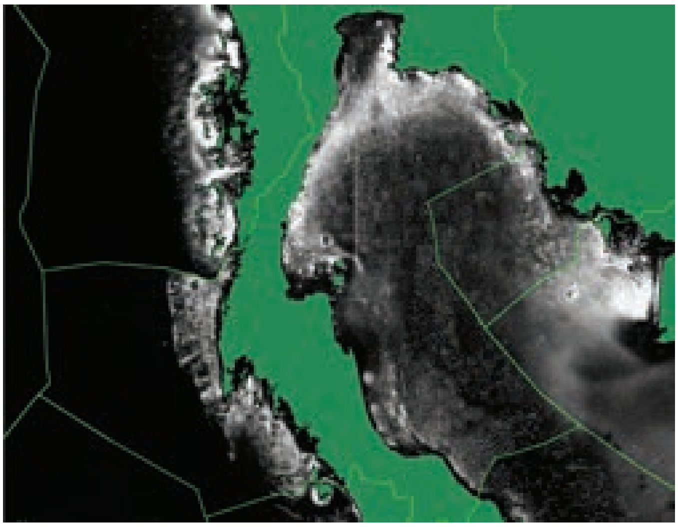

Figure 13. Cumulative VIIRS boat detections for Thailand and Cambodia in 2012-2021

Viet Nam

Figure 14 shows that Viet Nam had an extended dense to diffuse cloud of VBD detections in the north with embedded recurring detection points. This northern cloud straddled the EEZ boundary with China. In central Viet Nam, the VBD detection cloud was denser nearshore and more diffuse further out, with several linear density changes. In the south, there was a large diffuse to a dense cloud of VBD detections with large numbers of recurring detection sites, but lacking the grids and linear alignments typical in Malaysian and Thai waters.

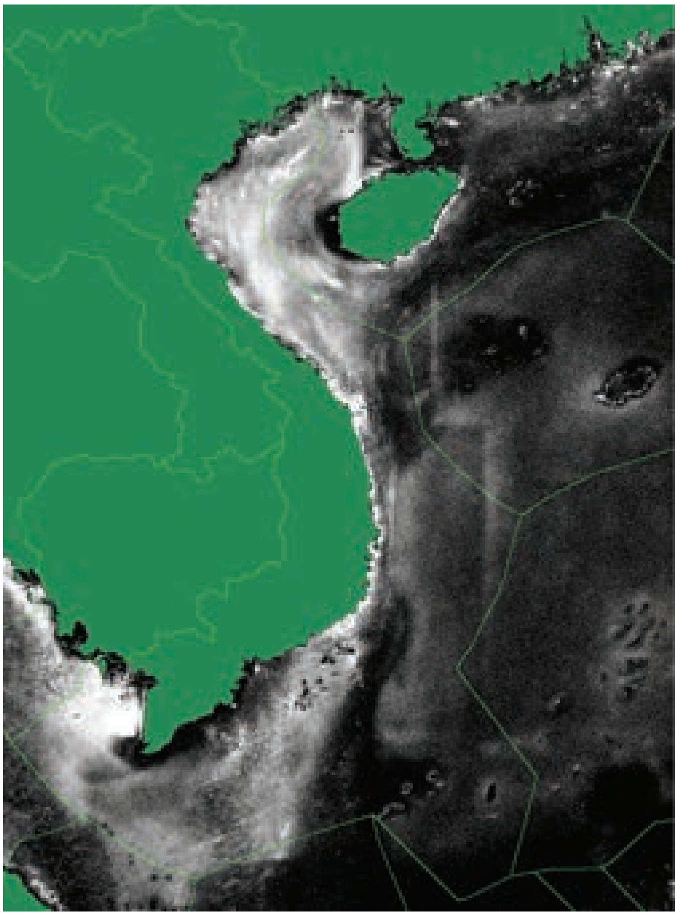

Figure 13. Cumulative VIIRS boat detections in Viet Nam in 2012-2021

Conclusion

The VIIRS day/night band has a remarkable capability to detect electric lighting present at the Earth's surface. Onshore, the lighting is primarily from human settlements, industrial sites, and transportation corridors. Offshore, the majority of lighting comes from fishery vessels using lights to attract fish. However, several other types of sites have been found in a ten-year accumulation of VBD data. This includes anchorages, transit lanes, and aquaculture. One of the features found in the ten-year compilation remains a mystery which is the recurring detection points. These may be solitary, in regular grids, or equally spaced lines and curves. It was checked that the recurring detection sites with the mapping of offshore gas flares and a small number of the sites aligned with known flares (Elvidge *et al*., 2015b). But the function filled by the vast majority of the recurring sites has yet to be determined. Though it was suspected that they were a combination of fishing platforms and anchored fish aggregating devices.

Way Forward

For fishery agencies and other relevant stakeholders that are interested to learn more about VBD data and potentially use it for offshore monitoring, please contact the lead author by email. In the past, his team has given 1–2-day training courses to several fishery agencies and their local collaborators in several countries.

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References

Croft, T.A. (1979). The brightness of lights on Earth at night, digitally recorded by DMSP satellite. *SRI International*. https://doi.org/10.3133/ofr80167

Elvidge, C. D., Baugh, K. E., Zhizhin, M., & Hsu, F.-C. (2013). Why VIIRS data are superior to DMSP for mapping nighttime lights. *Proceedings of the Asia-Pacific Advanced Network, 35*(0), 62. https://doi.org/10.7125/apan.35.7

Elvidge, C., Zhizhin, M., Baugh, K., & Hsu, F.-C. (2015a). Automatic Boat Identification System for VIIRS Low Light Imaging Data. *Remote Sensing, 7*(3), 3020–3036. https://doi.org/10.3390/rs70303020

Elvidge, C., Zhizhin, M., Baugh, K., Hsu, F.-C., & Ghosh, T. (2015b). Methods for Global Survey of Natural Gas Flaring from Visible Infrared Imaging Radiometer Suite Data. *Energies, 9*(1), 14. https://doi.org/10.3390/en9010014

Elvidge, C. D., Ghosh, T., Baugh, K., Zhizhin, M., Hsu, F.-C., Katada, N. S., Penalosa, W., & Hung, B. Q. (2018). Rating the Effectiveness of Fishery Closures with Visible Infrared Imaging Radiometer Suite Boat Detection Data. *Frontiers in Marine Science, 5*. https://doi.org/10.3389/fmars.2018.00132

Hsu, F.-C., Elvidge, C. D., Baugh, K., Zhizhin, M., Ghosh, T., Kroodsma, D., Susanto, A., Budy, W., Riyanto, M., Nurzeha, R., & Sudarja, Y. (2019). Cross-Matching VIIRS Boat Detections with Vessel Monitoring System Tracks in Indonesia. *Remote Sensing, 11*(9), 995. https://doi.org/10.3390/rs11090995

About the Authors

Dr. Christopher D. Elvidge is the Director of the Earth Observation Group, Payne Institute for Public Policy, Colorado School of Mines in Golden, Colorado, USA (https://payneinstitute.mines.edu/eog/). He can be reached at celvidge@mines.edu.

Dr. Tilottama Ghosh is a researcher at the Earth Observation Group, Payne Institute for Public Policy, Colorado School of Mines in Golden, Colorado, USA (Email: tghosh@mines.edu).

Ms. Namrata Chatterjee is a Ph.D. student at the Department of Geography, University of Denver, Denver, Colorado, USA (Email: Namrata.Chatterjee@du.edu).

Dr. Mikhail Zhizhin is a researcher at the Earth Observation Group, Payne Institute for Public Policy, Colorado School of Mines in Golden, Colorado, USA (Email: mzhizhin@mines.edu).

Guide to Contributing Articles

Fish for the People is a policy-oriented Special Publication produced by the Southeast Asian Fisheries Development Center (SEAFDEC). The first issue of the Special Publication was launched in early 2003 to commemorate the first anniversary of the ASEAN-SEAFDEC Conference on Sustainable Fisheries for Food Security in the New Millennium: "Fish for the People" organized in 2001 from which the Special Publication got its banner title *Fish for the People*. Through the years, *Fish for the People* has been recognized by various stakeholders as a significant source of information to support their works on the sustainable development and management of fisheries and aquaculture in the region. The SEAFDEC Secretariat publishes three issues of the Special Publication each year with support from the Japanese Trust Fund. The publication of articles in *Fish for the People* is free of charge.

Prospective Contributors

- SEAFDEC Secretariat and Departments (researchers, technical staff, project managers)
- SEAFDEC Member Countries (national focal persons of SEAFDEC projects, researchers, fishery officers, professors, students)
- SEAFDEC partner organizations (researchers, technical staff, project managers)
- Non-member countries and other organizations (researchers, managers of projects in the SEAFDEC Member Countries, researchers, fishery officers, professors, students, and those who wish to share experiences that could be applicable to Southeast Asia)

Types of Articles

- **Research article** - report of new and original research findings including the methodology, data, and analysis in popularized format (2,000–4,000 words)
- **Short communications** - brief analysis and commentary on fisheries development and management that may not be suitable for a full-length research article (1,000–2,000 words)
- **Report on activities under projects** - results and implications including strategy or approach, conclusions, and recommendations for the future direction of work (2,000–4,000 words)
- **Conference analysis** - a comprehensive overview of a meeting or session and discuss how the presentations and discussions may affect fisheries development and management (1,000–1,500 words)
- **Feature article** - a brief overview of scientific findings for a general audience; interviews and newsworthy topic based on the author's personal experience
- **Review article** - critical and constructive analysis of existing published literature in fisheries and aquaculture, through summary, analysis, and comparison, often identifying specific gaps or problems and providing recommendations (1,000–2,000 words)
- **Book review** - analysis of recent publications relevant to fisheries development and management (500–1,500 words)
- **Emerging studies** - discuss and analyze new fields of research and methodologies relevant to ecological, economic, cultural, and social aspects of fisheries development and management (1,000–2,000 words)

Format and Structure

- Articles should be written in Times New Roman font 11, single space, one-column layout
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- Articles should contain standard style and formats based on SEAFDEC Style (access at http://www.seafdec.org/documents/2021/12/seafdec-style.pdf)
- Articles should be written in gender-sensitive and inclusive language
- The title should be concise and informative for easy retrieval in information systems
- Authorship should be limited to those who have made a significant contribution to the conception, design, execution, or interpretation of the article, and therefore share collective responsibility and accountability for the information provided
- Abstract/summary should be concise and accurate and should be able to stand alone and briefly state the issues/problems, objectives, methods, key results, discussions, and major conclusions (200–300 words)
- A maximum of five keywords should be provided for indexing purposes and easy retrieval of the article in search engines
- Introduction should provide sufficient background (*e.g.* relevance to the RES&POA-2030 and/or other international, regional, or national instruments) and specify the goal and objectives of the work
- Describe the details of materials and method applied, as appropriate for the specific type of article
- Discuss the significance of the key results of the work
- Tables should be created as editable text and not as images
- Figures should be in line with text and not wrapped with text; figure caption should be written below the figure and not in a text box
- Math equations should be given in editable text and not as images
- National currencies should be converted to or provided with equivalent US Dollars (USD)
- Present the main conclusions based on the objectives of the work and applicability of the work to other sites, countries, or regions
- Indicate the future activities of the work, if any
- For non-SEAFDEC articles, indicate the relevance of the work to Southeast Asia
- Briefly describe the role of the donor(s) in the conduct of the work and/or preparation of the article
- Recognize the individuals who provided help during the research and participated in certain substantive aspects of the article (*e.g.* data collection, translations, language editing)
- Ensure that all in-text citations are included in the reference list, and vice versa, please see SEAFDEC Style for the detailed guide to the proper format; consider using a reference management software (*e.g.* Zotero, Mendeley, others) for automatic formatting and make sure to unlink citations and remove all field codes before submitting the article
- Provide the complete names and affiliations of each author including the office/organization's full name and address, email, and other contact details
- Articles should be free of plagiarism and false information; SEAFDEC will not be responsible for any copyright violations

Publication Process

- Please submit the editable file of the article to the Editor of *Fish for the People* through the SEAFDEC Secretariat at fish@seafdec.org
- Articles will be evaluated and reviewed through SEAFDEC review mechanism
- Approved articles will be published in electronic and printed formats
- Published articles in electronic format are immediately and permanently made accessible for free read and download from the SEAFDEC Institutional Repository; a unique link is assigned to each published article which can be shared through any communication channels including email and social media
- Printed copies of *Fish for the People* are distributed for free to authors, SEAFDEC Departments, Member Countries, partner organizations, libraries, and other networks around the world

For more details, please scan the QR code or visit https://repository.seafdec.org/handle/20.500.12066/6968.

CALENDAR OF EVENTS

Date	Venue/mode	Event	Organizer
2023			
23-25 January	Bangkok, Thailand	FAO Regional Workshop for a Network of Practitioners on Fishery Stock Assessment	FAO
14-17 March	Cebu, Philippines	Regional Meeting Focused on Implementing the Convention on International Trade in Endangered Species (CITES) for seahorses (*Hippocampus* spp.) in Asia	CITES
21-23 February	Rome, Italy	4th Session of the Intergovernmental Technical Working Group on Aquatic Resources for Food and Aquaculture	FAO
6 March	Malaysia	Meeting of Stock and Risk Assessment New Methodologies for Pelagic Fish	SEAFDEC/MFRDMD
16-17 March	Bali, Indonesia	RPOA-IUU MCS Sub-Regional Workshop 2023	RPOA-IUU
20-24 March	BFS, Philippines	Training Course on Giant Freshwater Prawn Hatchery and Grow-out Operations (Session 1)	SEAFDEC/AQD
17 April-2 May	TMS, Philippines	Training Course on Sandfish (*Holothuria scabra*) Seed Production, Nursery and Management	SEAFDEC/AQD
24-28 April	BFS, Philippines	Training Course on Tilapia Hatchery and Grow-out Operations (Session 1)	SEAFDEC/AQD
8-12 May	Bali, Indonesia	4th Meeting of the Parties to the FAO Agreement on Port State Measures	FAO
9 and 11 May	Online	55th Meeting of the SEAFDEC Council	SEAFDEC/SEC & Myanmar
15-25 May	TMS, Philippines	Training Course on Abalone (*Haliotis asinina*) Hatchery and Grow-out	SEAFDEC/AQD
22-26 May	BFS, Philippines	Training Course on Giant Freshwater Prawn Hatchery and Grow-out Operations (Session 2)	SEAFDEC/AQD
24-25 May	Siem Reap, Cambodia	Regional Workshop on Development of Management and Conservation Action Plan for the Mekong Freshwater Dolphins and Biodiversity	FiA, Cambodia
30-31 May	Online	18th ASEAN Working Group on CITES and WE Meeting (AWG-CITES and WE)	ASEAN & Singapore
13-15 June	Qingdao, China	37th Session of the Asia-Pacific Fishery Commission (APFIC)	FAO/RAP
19 June	Samut Prakan, Thailand	Seminar on Updated Menu-driven Software for Fish Stock Assessments and Managements	SEAFDEC/TD
19-23 June	BFS, Philippines	Training Course on Tilapia Hatchery and Grow-out Operations (Session 2)	SEAFDEC/AQD
19 June-24 July	TMS, Philippines	Training Course on Marine Fish Hatchery Operations	SEAFDEC/AQD
19-23 June	Geneva, Switzerland	32nd Meeting of the Animals Committee of CITES	CITES
26-30 June	London, UK	13th FIRMS Steering Committee meeting (FSC13) and the CWP intersessional meetings of Aquaculture and Fisheries subject groups	FAO
10-13 July	Terengganu, Malaysia	Regional Training Course on Artificial Reefs Development Program	SEAFDEC/MFRDMD & TD
13-14 July	Bangkok, Thailand	Data Analysis Workshop on Socio-economic of Small-scale Fisheries	SEAFDEC/TD
18-19 July	Nha Trang, Viet Nam	Workshop on Developing the Field Guide for Glass Eel Species Identification	SEAFDEC/IFRDMD
24 July	Online	13th Meeting of the ASEAN Shrimp Alliance (ASA)	ASEAN
25 July	Online	15th Meeting of the ASEAN Fisheries Consultative Forum (AFCF)	ASEAN
26-27 July	Online	31st Meeting of the ASEAN Sectoral Working Group on Fisheries (ASWGFi)	ASEAN
30 July-4 August	Halifax, Canada	7th Global Fisheries Enforcement Training Workshop "Moving from Words to Action: Innovative Collaborative Partnerships to Combat Illegal, Unreported, and Unregulated (IUU) Fishing"	IMCS Network
3-5 August	Samut Prakan, Thailand	Regional Training Course on Data Collection and Bio-Statistic for Fishery	SEAFDEC/TD
6-10 August	Samut Prakan, Thailand	Data-limited Fish Stock Assessments Using R-Statistical Program	SEAFDEC/TD
8 August	Online	Webinar on Aquatic Genetic Resources	SEAFDEC/SEC
14-18 August	BFS, Philippines	Training Course on Carp Hatchery and Grow-out Operations	SEAFDEC/AQD
14 Aug-4 Sep	TMS, Philippines	Training Course on Mangrove Crab Hatchery Operations	SEAFDEC/AQD
22-24 August	Chiang Mai, Thailand	3rd Regional Technical Consultation on Fishery Statistics and Information in Southeast Asia	SEAFDEC/SEC
29-31 August	Thailand	Regional Workshop: Towards a new era of support for small-scale fisheries in Southeast Asia	SEAFDEC/TD

Southeast Asian Fisheries Development Center (SEAFDEC)

What is SEAFDEC?

SEAFDEC is an autonomous intergovernmental body established as a regional treaty organization in 1967 to promote sustainable fisheries development in Southeast Asia. SEAFDEC currently comprises 11 Member Countries: Brunei Darussalam, Cambodia, Indonesia, Japan, Lao PDR, Malaysia, Myanmar, Philippines, Singapore, Thailand, and Viet Nam.

Vision

Sustainable management and development of fisheries and aquaculture to contribute to food security, poverty alleviation and livelihood of people in the Southeast Asian region

Mission

To promote and facilitate concerted actions among the Member Countries to ensure the sustainability of fisheries and aquaculture in Southeast Asia through:

i. Research and development in fisheries, aquaculture, post-harvest, processing, and marketing of fish and fisheries products, socio-economy and ecosystem to provide reliable scientific data and information.
ii. Formulation and provision of policy guidelines based on the available scientific data and information, local knowledge, regional consultations and prevailing international measures.
iii. Technology transfer and capacity building to enhance the capacity of Member Countries in the application of technologies, and implementation of fisheries policies and management tools for the sustainable utilization of fishery resources and aquaculture.
iv. Monitoring and evaluation of the implementation of the regional fisheries policies and management frameworks adopted under the ASEAN-SEAFDEC collaborative mechanism, and the emerging international fisheries-related issues including their impacts on fisheries, food security and socio-economics of the region.


Secretariat


TD

MFRD


AQD


MFRDMD


IFRDMD

SEAFDEC Addresses

Secretariat

P.O. Box 1046
Kasetsart Post Office
Bangkok 10903
Thailand
Tel: (66-2) 940-6327
Fax: (66-2) 940-6336
E-mail: *secretariat@seafdec.org*
http://www.seafdec.org

Training Department (TD)

P.O. Box 97
Phrasamutchedi
Samut Prakan 10290
Thailand
Tel: (66-2) 425-6100
Fax: (66-2) 425-6110 to 11
E-mail: *td@seafdec.org*
http://www.seafdec.or.th

Marine Fisheries Research Department (MFRD)

52, Jurong Gateway Road,
#14-01, Singapore 608550
Tel: (65) 9046-4787
Fax: (65) 6334-1831
E-mail: *Ong_Yihang@sfa.gov.sg*
http://www.seafdec.org

Aquaculture Department (AQD)

Main Office:
5021 Tigbauan, Iloilo, Philippines
Tel: +63 33 330 7000
Fax: +63 33 330 7002
Manila Office:
Room 100-E, Ground Floor
Philippine Social Science Center (PSSC)
Commonwealth Avenue, Diliman
1101 Quezon City, Philippines
Tel & Fax: +63 2 8927 7825
E-mail: *aqdchief@seafdec.org.ph*
http://www.seafdec.org.ph

Marine Fishery Resources Development and Management Department (MFRDMD)

Taman Perikanan Chendering,
21080 Kuala Terengganu, Malaysia
Tel: (609) 617-5940
Fax: (609) 617-5136
E-mail: *mfrdmd@seafdec.org.my*
http://www.seafdec.org.my

Inland Fishery Resources Development and Management Department (IFRDMD)

Jl. Gub. HA. Bastari No.08
RT.29 RW.27 Kel. Silaberanti
Kec. Seberang Ulu I, Jakabaring, Palembang 30252
Sumatera Selatan, Indonesia
Tel: +627115649600; Fax: +627115649601
E-mail: *ifrdmd@seafdec.id*
http://www.seafdec.id

The fourth prize winner, *Hamizah binti Sani*, from the national drawing contest in Brunei Darussalam

National Drawing Contests were organized in all ASEAN-SEAFDEC Member Countries as part of the preparatory process for the ASEAN-SEAFDEC Conference on Sustainable Fisheries for Food Security Towards 2020 "Fish for the People 2020: Adaptation to a Changing Environment" held by ASEAN and SEAFDEC in June 2011 in Bangkok, Thailand, in order to create awareness on the importance of fisheries for food security and well-being of people in the region.