Sustainable management of blood cockles (*Tegillarca granosa*) industry in Malaysia from the life cycle assessment perspective: A review

[1]Siti Dina R. Pahri, [2]Raja Yana, [2]Muhammad A. Danial

[1] Centre for Research in Development, Social and Environment, Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, Bangi, Selangor, Malaysia; [2] Department of Fisheries Malaysia, Ministry of Agriculture and Food Security, Putrajaya, Malaysia. Corresponding author: S. D. R. Pahri, sitidina@ukm.edu.my

Abstract. Malaysia is well known as one of the blood cockles (*Tegillarca granosa*) producers in the Asian region. Blood cockles dominate 91% of Malaysia's shellfish production, higher than abalone, mussel and other clams. However, adult cockle production declined drastically by almost 78% from 2010 to 2021, indicating that the industry is struggling with various natural and anthropogenic threats such as natural disasters, climate change (CC), juveniles biological material smuggling and pollution from point and non-point sources. This undesirable condition has resulted in higher price of cockles paid by the consumers, with fishermen facing the risk of losses due to the unforeseen causes of cockle mortality. The problems plaguing the cockles industry need to be explicitly determined and analyzed in each of the phases of its production chain, from reproduction, rearing or natural breeding, harvesting, grading, packaging, and marketing, as well as waste management, which has a potential for commercialization. This review will discuss current challenges in the blood cockles industry and revisit the potential of the Life Cycle Assessment (LCA) approach in the shellfish industry for cockles management in Malaysia. LCA is one of the best methods to assess the environmental impact inherent in cockle culturing activities. This review also proposes a management framework for sustainable management of the cockles industry from the LCA perspective.
Key Words: food safety, impact assessment, molluscs, production chain, strategies.

Introduction. *Tegillarca granosa*, formerly known as *Anadara granosa*, is a highly salient species of shellfish in Southeast Asia. It is prominent for its practicality as a cheap protein source for human consumption (Chan et al 2002; Saffian et al 2020). Malaysia is well-known as one of the blood cockles producers in Asia, with its primary market in Thailand, Singapore and, recently, Taiwan (Pawiro 2010). Blood cockles have dominated 91% of Malaysia's shellfish production, more than mussels, oysters, abalone, and other clams (DOFM 2020).

Blood cockles have been cultured in Malaysia since the 1960s, with annual production in 1957 recorded at 6666 metric tons, and the highest peak was recorded in 1980 with 121000 metric tonnes (Pullin & Smith 1984). The major producers then were Perak, Selangor and Pulau Pinang States (Pullin & Smith 1984). Nowadays, Perak remains the primary producer, followed by Pulau Pinang, Selangor, Johor and Kedah (DOFM 2020). As a result, cockles culture area production was 8889 ha with 382 culturists in 2020, compared to 6749.72 ha with 346 culturists in 2001 (DOFM 2001; DOFM 2020). Figure 1 shows the production trend for cockles in Malaysia from 2000 to 2022.

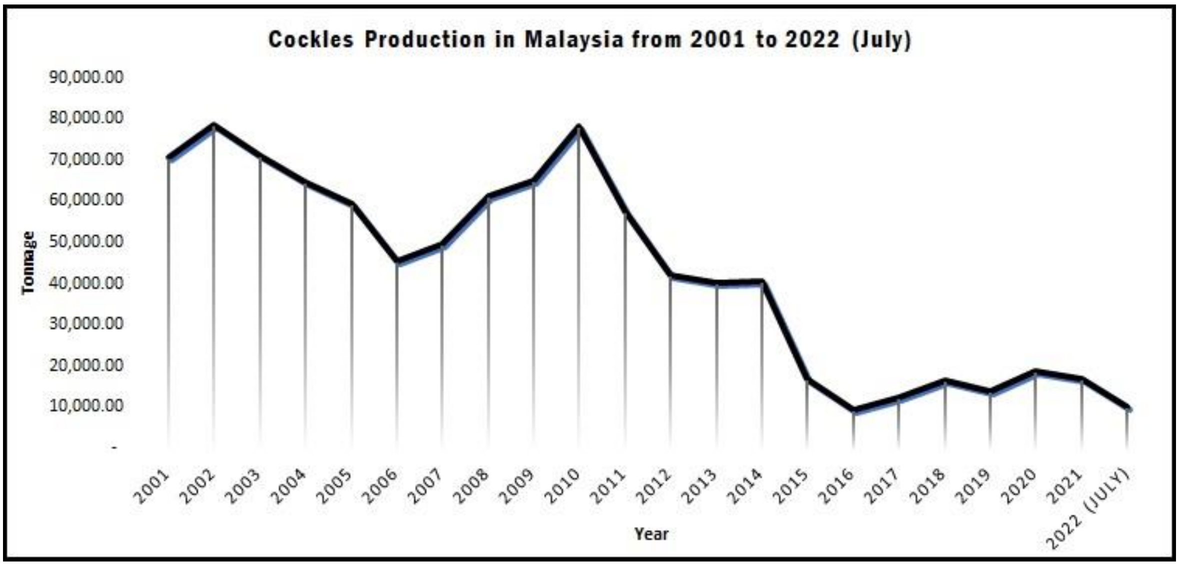

Figure 1. Cockles production from 2000 to 2022 in Malaysia (source: DOFM 2001, 2022).

Cockles production declined drastically by almost 78% from 2010 to 2021. This decline indicates that the industry is struggling with various natural and anthropogenic threats, such as natural disasters, climate change (CC), and spats and juvenile smuggling. Furthermore, the nature of its production system, which requires an open ecosystem, makes it vulnerable to pollution from point and non-point sources (Buck et al 2004; Yurimoto et al 2014; Saffian et al 2020). This undesirable condition has resulted in the higher price of cockles paid by the consumers (Malik 2017; CEMACS 2022). Fishermen face the risk of losses due to the unforeseen causes of cockle mortality. Therefore, the problems plaguing the cockles industry need to be explicitly determined and analyzed in each phase of its production chain. This includes seeding, rearing or natural breeding, harvesting, grading, packaging, marketing, and waste management, which may have a potential for commercialization. By enhancing the potential of the cockles industry along its production chain, it is possible to boost the industry's production level and encourage all stakeholders to pay attention and make changes in management strategies.

Life Cycle Assessment (LCA) generally assesses the environmental burdens connected with a product or service, back from the raw material to the end of life or waste removal (Klöpffer 1997). LCA is now an essential environmental tool in assessing the environmental sustainability of a system, product, supply or consumption chain and potentially promote the environmental footprint and ecolabelling, including those from agriculture (Teillard et al 2016). In addition, LCA can be applied in aquaculture at various levels. The micro-level focuses on specific processes (such as feed production), the meso-level focuses on larger processes (such as assessing an entire farm), and the macro-level can focus on a country’s aquaculture assessment (Bohnes et al 2019).

Many LCA studies have been conducted across a diversity of farming systems and species of marine fish, freshwater fish, shellfish and prawn farming (Aubin et al 2009; Bosma et al 2011; Iribarren et al 2011; Jerbi et al 2012; Haslawati et al 2022). Nevertheless, there is still a limited number of LCA studies for shellfish because they may impose a lower environmental impact than fish species. However, studies for mussels and cockles revealed the potential environmental impact due to capital goods, which suggested the enhancement of the type of materials used in shellfish farming (Iribarren et al 2011; Siti Dina et al 2016).

The cockle subsector still needs improvement in developing its integrated management system that addresses issues at every level of the cockle production chain to formulate the most appropriate strategies. This paper will discuss current challenges in the blood cockles industry and revisit the potential of the LCA approach in the shellfish industry. Furthermore, LCA can be seen as one of the best methods to assess the environmental impact inherent in cockle culturing activities and can potentially be the primary foundation for implementing sustainable cockle management. Thus, this study conducts a review of the current management of the blood cockles industry based on the LCA perspectives in Malaysia. Current cockles management information was gathered from official reports from the related government agencies and journal articles.

Issues, Challenges and Current Management of the Blood Cockles Industry in Malaysia. Like other valued species in the aquaculture sector, the blood cockle industry must be prepared to face the wave of the fourth industrial revolution, which involves innovation and technological development along the aquaculture production chain (from farm to table). Meanwhile, the industry needs to ensure sufficient and sustainable resources to meet the demand for food security as part of the efforts to achieve the Sustainable Development Goals (SDG) 2030. Hence, in efforts to overcome the challenges, appropriate strategies must be in place to address specific problems using precise and suitable solutions. Therefore, issues and challenges were identified and summarized based on the phases of production in the cockle production chain (Table 1).

Table 1

Issues and challenges along the production chain in the blood cockles industry

No	*Production chain*	*Issues and challenges*
1	Cockle seeding	Trespassing and spats and juveniles theft; maintaining the performance of spats and juveniles production in existing natural areas; pollution due to anthropogenic sources; influence of natural resources (current, tide, predators).
2	Cockle farming	Details on issues faced by cockle breeders according to the farming process (from a to f).
a	Placement of spat and juveniles at breeding areas	Trespassing Maintaining the quality of soil substrate and water quality following pollution caused by anthropogenic sources; influence of natural resources (current, tide, predators).
b	Scattering process	Labor force issues (lack of involvement of youths, mostly family members); equipment assistance (very minimal; major assistance in the form of boat usage and fuel); maintaining the quality of soil substrate and water quality due to pollution caused by anthropogenic sources; influence of natural resources (current, tide, predators); harmful algae bloom.
c	Harvesting process	Maintaining production; dilapidated jetty; settlements near the jetty (cause of *E. coli* and *F. coliform* pollution); overharvesting.
d	Depuration process	Still lacking, although it has been listed in the DOFM Strategic Plan 2011-2020.
e	Cleaning and grading process	The level of safety of cockle consumption is still not guaranteed, especially regarding the level of *E. coli* and *F. coliform* pollution.
f	Packaging process	No certification or eco-labelling program; basic packaging for the local market.
3	Processing	Lack of the exploration of downstream activities for the cockle industry; in certain areas, activities of selling shelled cockles are carried out by fishermen family members.
4	Marketing	Limited to local markets; possibility to be explored for export purposes, including certification.
5	Waste management	Lacking exploration on the potential use of cockle waste (for example, as pharmaceutical and decorative goods).

Note: sources: Norhana et al (2016); Srisunont et al (2020); Saffian et al (2020); Tatsuya (2020).

The appropriate agency has implemented many initiatives for the holistic management of the cockle industry to solve the highlighted concerns and challenges. In 2007, the Department of Fisheries Malaysia (DOFM) gazetted cockle breeding areas along the Selangor coastline, following a drop in cockle productivity for a few years. Despite this, the area has been plagued by natural and anthropogenic concerns, which resulted in a large mortality catastrophe in 2014 (Yurimoto et al 2014). Activities related to cockle farming are also under several risks from natural and anthropogenic sources. While spat and juveniles smuggling is another issue that has long plagued the sector (The Star 2009; Utusan Malaysia 2022), it is being combated as the DOFM conducts its enforcement under the Fisheries Act (1985) (Table 2).

Table 2

Current management practices of cockles by the Department of Fisheries Malaysia (DOFM)

Aspect	*Details*
Management	1. Internal committee toward the holistic management 2. Gazetting of cockles breeding area along the Selangor coastline in 2007 3. Scheduled monitoring in terms of biosecurity for raw cockles and water quality in the farming area under the National Shellfish Sanitation Program (NSSP) 4. Provision of assistance in terms of equipment and advisory services 5. Research, development, commercialization and innovation
Legislation and enforcement (Fisheries Act 1985)	1. Fisheries (Marine Culture Systems) Regulations 1990: - application for permit to install marine culture system - application for license to handle marine culture system - obligation to inform upon having ceased handling marine culture system - obligation to dispose of marine culture systems 2. Fisheries (Cockles Conservation and Culture) Regulations 2002 - prohibition against taking cockle spat - prohibition against taking cockle seeds or adult cockles without a license - the period allowed to take cockle seeds and adult cockles from a natural cockle bed - application to obtain a license to take cockle seed or adult cockles - sale and purchase of cockle seeds with license 3. Fisheries (Fish Disease Control, Compliance for Exports and Imports) Regulations 2012, 26 March 2012 - section 2(a), (b) provides that any person who exports fish shall comply with the measures for fish disease control prescribed by the competent authority; - section 2(b) - source the fish from culture system approved by the authority; - section 3(a) provides that any person who imports fish and fishery products into Malaysia must comply with the fish disease control measures prescribed by the Department of Fisheries. - section 6(1) - the Director General shall prepare and keep under continual review fisheries plans based on the best scientific information available and designed to ensure optimum utilization of fishery resources, consistent with sound conservation and management principles and with the avoidance of overfishing, and in accordance with the overall national policies, development plans and programmes. - section 40(2) - the Director General may impose such conditions as he thinks fit in the permit, including conditions concerning the state of cleanliness of the fish to be exported, imported, or transported and measures to avoid the spread of communicable fish diseases, or to avoid or control the release into the natural environment of non-indigenous species of fish. - section 40(1) (a), (2) and (3) provides that any person intending to import into or to export live fish out of Malaysia must secure an import permit from the Malaysian Quarantine and Inspection Services (MAQIS).

Note: 'Fish' as defined under the Fisheries Act 1985 includes all species of Mollusca, and 'fishery' under the act includes aquaculture; source: Fisheries Act 1985 (GOM 1985); definition of "cockle seed" under Malaysia Fisheries Regulation (Conservation and Cockle Culture) 2002, means a cockle which is more than four millimeters but less than twenty-five millimeters measured in a straight line across the widest part of the shell.

Food safety measures in the primary production of the cockle industry are a vital part of the overall management that should be highlighted. Shellfish is a filter-feeding organism that tends to accumulate contaminants, such as viruses, bacterial pathogens, toxic phytoplankton and other pollutants in the water (Norhana et al 2016). As a result, harvesting shellfish from areas exposed to faecal pollution or areas with toxic phytoplankton may pose a health hazard (Norhana et al 2016). In addition, food-borne diseases have been well associated with consuming raw or partially cooked shellfish.

Acknowledging these issues as part of national and international (importing countries) safety requirements, Malaysia has its official control measures to ensure the safety of shellfish production for consumers under the National Sanitation Shellfish Program (NSSP) (DOFM 2021). NSSP started in 2013. However, from 1999 to 2012, Malaysia monitored shellfish safety level under the Sanitary and Phytosanitary (SPS) Marine Program. Such official control measures are regulated under the Fisheries Act 1985 under Section 40 (Control of Live Fish), Fisheries (Fish Disease Control Compliance to Import and Export) Regulation 2012 (AGC 2012), Fisheries Regulation (Conservation and Cockle Culture) 2002 (AGC 2002) and Fisheries Regulation (Marine Culture System) 1990 (AGC 1990). The shellfish monitoring program under NSSP is conducted at the selected sampling area (wild and registered marine/shellfish culture systems), prioritizing the major shellfish production area. The sampling parameters include: a) microbiology – including faecal indicator groups of bacteria, pathogens such as *Salmonella* and *Vibrio* spp. (*Vibrio cholerae* and *Vibrio parahaemolyticus*); b) viruses; c) biotoxins; d) plankton ID; e) water sampling; f) heavy metals; g) polychlorinated biphenyls (DOFM 2021).

Currently, depuration is not enforced as a mandatory control measure for exported shellfish products. However, it is well known that *Vibrio* spp. naturally live in coastal and brackish water areas, and the Ministry of Health (MOH) Malaysia and DOFM closely monitor any reports of seafood poisoning cases caused by *Vibrio* spp. in Malaysia. There are no such cases reported, and immediate investigation and re-sampling will be conducted if there is any event of contravening cases under the NSSP Program (DOFM 2021). If a contravene case is detected after re-sampling, corrective actions will be taken under the stated legislation (above), and the Food Act (1983) under MOH. Emergency notifications and measures will be organized accordingly (including removing potentially contaminated shellfish from the supply chains through seafood product tracking) with the cooperation of related agencies such as MOH (at federal levels) and State Health Departments at state levels.

Revisiting Previous LCA Studies in the Shellfish Subsector. Asia is the largest global producer of molluscs, with 15 million tonnes recorded in 2018 (Bartley 2022). In 2020, global aquaculture production has produced more molluscs than finfish and crustaceans (FAO 2022a), which should be a positive indicator in meeting the consumer demand for more protein resources. Nevertheless, the global shellfish production rise has also raised environmental concerns (Vélez-Henao et al 2021), driven by consumers' increasing demand for safe and high-quality seafood. Not many LCA studies have been applied for shellfish production, although LCA has been extensively applied in other aquaculture systems (Vélez-Henao et al 2021).

LCA is primarily used in decision support and intends to be a holistic assessment identifying the transfer of environmental loads among supply chain levels or the environmental impact types (Teillard et al 2016). Generally, for the shellfish subsector, reviews conducted by Vélez-Henao et al (2021) found limited information for countries outside Europe and species different from mussels. Nine papers on the LCA study for shellfish production have been selected and summarized in Table 3.

Mussels, oysters and clams dominated most of the LCA studies for shellfish. Most LCA studies are from the European Union (EU) countries (Iribarren et al 2011; Spångberg et al 2013; Aubin et al 2018; Tamburini et al 2019; Tamburini et al 2020; Turolla et al 2020), and only limited LCA studies are from Asia, for example Siti Dina et al (2016), studying cockles in Malaysia. This situation indicates that countries were focusing on LCA study for their major commodity, in order to boost the environmental performance.

Some mid-point approach LCA studies in shellfish focused particularly on global warming potential (GWP), climate change (CC), abiotic depletion (ABD), ozone layer depletion (OLD), human toxicity (HT), freshwater ecotoxicity (FWT), marine ecotoxicity (MET), terrestrial ecotoxicity (TET), photochemical oxidation (PO), acidification (ACD), and eutrophication (EUT) (Iribarren et al 2011; Siti Dina et al 2016; Tamburini et al 2020; Turolla et al 2020). In addition, a study by Tamburini et al (2019) considered other two impacts, which were fossil depletion (FD), and water depletion (WD). Meanwhile, a study by Ziegler et al (2013) focused solely on the impact of CC.

Table 3

Selected life cycle assessment studies for shellfish production

Study	*Country*	*Shellfish/ Species*	*Impact categories*	*Methodology/ software*
Iribarren et al (2011)	Spain, Galicia	Mussel, *Mytilus galloprovincialis*	CC, EUT, ACD, POF, OD, MET, HT, AD, FET, TET	CML 2001/ SimaPro 7.0
Ziegler et al (2013)	Norway	Mussel, *Mytilus edulis*	CC	IPCC 2007/ SimaPro 7.3.2
Spångberg et al (2013)	Sweden	Mussel, *Mytilus edulis*	CC, EUT, ACD, EU	CML 2001/ SimaPro 7.3.0
Siti Dina et al (2016)	Malaysia	Cockles, *Anadara granosa*	ABD, GWP, OLD, HT, FWT, MET, TET, PO, ACD, EUT	CML-IA Baseline V3.01 method/midpoint/ SEMIPRO 8
Lourguioui et al (2017)	Algeria	Mussel, *Mytilus galloprovincialis*	CC, EUT, ACD, EU	CML 2000;CED V 1.03/SimaPro 7.3.0
Aubin et al (2018)	France	Mussel, *Mytilus edulis*	CC, A, EUT, EU, WD	CML 2000; CED V 1.03; Aubin et al (2009)/SimaPro 7.3.0
Tamburini et al (2019)	Italy	Oyster, *Crassostrea gigas*	HH, EQ, RD	Eco-indicator® 99-H and ReCiPe® midpoint (H) v.1.12/ OpenLCA 1.8.0
Tamburini et al (2020)	Italy	Mussel, *Mytilus galloprovincialis*	CC, EUT, A, HT, ABD, OLD, POF, MET	CML 2000/OpenLCA 1.8.0
Turolla et al (2020)	Italy	Clam, *Ruditapes philippinarum*	CC, EUT ACD, PO, OLD, MET, HT, FD, WD	ReCiPe midpoint (H) v.1.12/ OpenLCA 1.8.0

Note: ABD - abiotic depletion; GWP - global warming potential; OLD - ozone layer depletion; HT - human toxicity; FWT - freshwater ecotoxicity; MET - marine ecotoxicity; TET - terrestrial ecotoxicity; PO - photochemical oxidation; ACD - acidification; EUT - eutrophication; CC - climate change; FD - fossil depletion; WD - water depletion; HH - human health; EQ - ecosystem quality; RD - resource damage; sources: Siti Dina et al (2016); Vélez-Henao et al (2021).

Most LCA studies focused on finding the critical cause of capital and operational goods, such as non-recyclable plastic materials and the energy use for transportation activities, including vessel use. In comparison, the LCA study for oysters by Tamburini et al (2019) considered the endpoint approach, which finalizes with the impact on human health (HH), ecosystem quality (EQ), and resource damage (RD) categories. The study has revealed that the environmental impacts due to the equipment and facilities, particularly barges, have the most impact on HH, followed by the wooden cassettes for commercial packaging and the basket for fattening. In addition, an assumption has been made that there is an important impact of all non-recyclable materials, such as high-density polyethene (HDPE) and wood, compared to steel and other materials for barge construction.

All LCA studies have considered capital and operational goods, leading to concerns in physical waste management (Iribarren et al 2011; Siti Dina et al 2016; Tamburini et al 2019; Tamburini et al 2020; Turolla et al 2020). However, most studies cover capital goods, possibly because the data obtained are complex. For example, Iribarren et al (2011) compared two situations of fresh mussels at the dispatch center and canned mussels, revealing the environmental impact potentially from the generation of cardboard and cans as waste (including shopping bags) of canned mussels. Meanwhile, Tamburini et al (2020) found that the growing and harvesting phases are the most critical life cycle stages due to the production and use of boats and the great quantity of non-recyclable HDPE socks used during the yearly production cycle. Moreover, most farm equipment is based on plastics, and nowadays, global environmental management is seriously trying to combat microplastic issues. Apart from this, research has been conducted to assess the microplastic levels caused by the aquaculture sector (Wu et al 2020). This concern can be translated into the cradle-to-cradle concept, in which waste could be regenerated as a raw material for a new product.

Aubin et al (2018) and Lourguioui et al (2017) have emphasized the impact related to the inclusion of nutrients such as carbon (C), nitrogen (N) and phosphorus (P) to explain the role of shellfish as an alternative to C sequestration. However, according to the review provided by Vélez-Henao et al (2021), 38% of the total samples are associated with N and P values leading to the impact of EUT. In comparison, less focus is placed on C. This may be because the potential of shellfish as a C sequester is still debatable (Ray et al 2018).

Discussion. Shellfish aquaculture has always been portrayed as a green industry as its farming practices usually involve no or minimal use of chemicals farmed in a gazetted area. Moreover, their product's environmental impact is usually lower than that of other fish species per unit of protein (Tamburini et al 2020). However, Turolla et al (2020) stated that environmental impact analysis in shellfish farming could have local socioeconomic implications. Identifying environmental impacts along the production chain can recommend mitigation, enhancement, or the creation of new technology to address the particular impact. Furthermore, technological advancement can increase the system's production, reducing conflicts of land use by optimizing production technology, cutting down the use of labor and lessening environmental impact. Hence, natural fishery resources, including cockle-rich areas, will continue to be preserved. On the other hand, systematic and accessible documentation and enhanced traceability will open up more extensive market opportunities for shellfish products.

Cockles, together with clams, ark shells, and oysters, have been classified among the 10 top species group production in the world fisheries statistics 2020 (FAO 2022b). However, in LCA analyses for shellfish, the EU countries clearly dominate mussel and oyster production, as these two species are the most important mollusc output for the EU (Iribarren et al 2011; Tamburini et al 2019; Tamburini et al 2020; Turolla et al 2020). More research into LCA is therefore required because it has the potential to provide useful data to the socioeconomic players, consumers, and final consumers of the shellfish industry at the regional and national levels as well as to other emerging markets (Iribarren et al 2011).

As Malaysia is still in its infancy of LCA study for aquaculture, the insights of the LCA approach can be formulated based on previous LCA studies for other shellfish species production. However, an effort towards identifying the actual environmental impacts must be in place, as we need strategies that may not only be developed to mitigate the environmental impacts, but to uplift the performance of this industry. Figure 2 depicts how an LCA study for cockle production can help identify gaps and create opportunities for improving the current cockles resources management using the three (3) main approaches, which are the One Health, Circular Economy, and Blue Economy, to secure the future of the country's food security and form a sustainable, competitive, and strong industry for the well-being of the people (World Bank & UNDESA 2017; FAO et al 2021; OHHLEP et al 2022; EP 2022; WHO 2022). The blue economy concept seeks to promote economic growth, social inclusion, and preservation or improvement of livelihoods, while ensuring environmental sustainability (World Bank & UNDESA 2017). The Circular Economy approach implies that the whole production/supplies chains will reduce loss and waste and increase efficiency, extending the life cycle of the products (EP 2022). The One

Health approach aims to sustainably balance and optimize the health of humans, animals, ecosystems, and the wider environment (FAO et al 2021; OHHLEP et al 2022; WHO 2022).

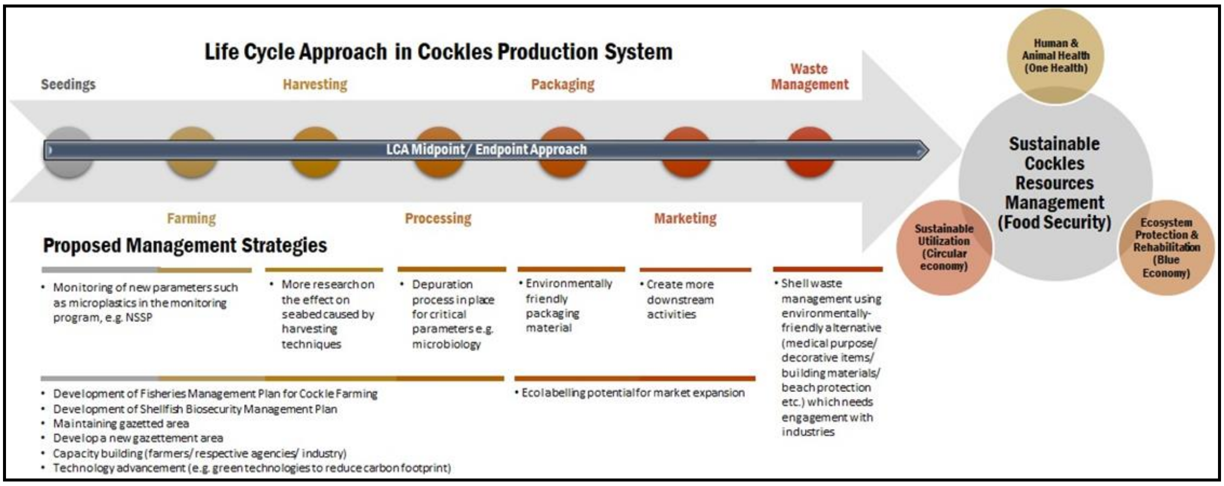

Figure 2. Proposed framework for strategies towards sustainable blood cockles industry in Malaysia based on the life cycle assessment perspective.

All these approaches will facilitate addressing the main challenges, which are to understand and better manage the many aspects of fisheries resources sustainability, ranging from sustainable fisheries to ecosystem health and pollution, as well as fostering well-being and addressing health threats (including food safety) and ecosystems (World Bank & UNDESA 2017; FAO et al 2021). Addressing these challenges will require collaboration across nation-states and the public-private sectors, on a scale that has not been previously achieved (World Bank & UNDESA 2017; FAO et al 2021).

Malaysia needs to promote itself as a significant producer of cockles in Asia. It is undeniable that market empowerment can change the image of the cockle industry from traditional characteristics to one that is advanced, competitive and modern. By considering the LCA perspective in managing resources, LCA provides an opportunity to identify new insights from environmental, technical and economic solutions to which improvement actions might be focused (Van der Giesen et al 2020). Moreover, emphasis is given to research and development (R&D), technology and modernization along the value chain (from lab to table) in the blood cockles industry. LCA also potentially assists in evaluating the suitable depuration process, which is crucial in shellfish production to monitor critical parameters such as microbiology, but it is not fully applied in Malaysia. The other approach is to improve the performance and expand the market for cockles in the Asian region by carrying out LCA within economic and social development contexts.

Conclusions. Strategies and action plans for managing essential resources, such as blood cockles, call for the government's intentions to spur demand for the nation's abundant, high-quality, and secure blood cockle production. In addition, LCA can provide fresh insights into resource management that can be spread to the larger cockle production chain, such as the marketing process, which will favorably impact the entire cockle production chain and lead to better waste management.

Acknowledgements. We are grateful for the close collaboration between Universiti Kebangsaan Malaysia and the Department of Fisheries Malaysia in completing this review study.

Conflict of Interest. The authors declare that there is no conflict of interest.

References

Aubin J., Fontaine C., Callier M., Roque d'orbcastel E., 2018 Blue mussel (*Mytilus edulis*) bouchot culture in Mont-St Michel Bay: potential mitigation effects on climate change and eutrophication. The International Journal of Life Cycle Assessment 23:1030-1041.

Aubin J., Papatryphon E., van der Werf H. M. G., Chatzifotis S., 2009 Assessment of the environmental impact of carnivorous finfish production systems using life cycle assessment. Journal of Clean Production 17(3):354-61.

Bartley D. M., 2022 World aquaculture 2020 – A brief overview. FAO Fisheries and Aquaculture Circular No. 1233, Rome, 9 p.

Bohnes F. A., Hauschild M. Z., Schlundt J., Laurent A., 2019 Life cycle assessments of aquaculture systems: a critical review of reported findings with recommendations for policy and system development. Reviews in Aquaculture 11(4):1061-1079.

Bosma R., Anh P. T., Potting J., 2011 Life cycle assessment of intensive striped catfish farming in the Mekong Delta for screening hotspots as input to environmental policy and research agenda. The International Journal of Life Cycle Assessment 16(9):903.

Buck B. H., Krause G., Rosenthal H., 2004 Extensive open ocean aquaculture development within wind farms in Germany: the prospect of offshore co-management and legal constraints. Ocean & Coastal Management 47(3-4):95-122.

Chan M. K., Othman R., Zubir D., Salmijah S., 2002 Induction of a putative metallothionein gene in the blood cockle, *Anadara granosa*, exposed to cadmium. Comparative Biochemistry and Physiology Part C Toxicology & Pharmacology 131(2):123-132.

Haslawati B., Saadiah I., Siti-Dina R. P., Othman M. Latif M. T., 2022 Environmental assessment of giant freshwater prawn, *Macrobrachium rosenbergii* farming through life cycle assessment. Sustainability 14(22):14776.

Iribarren D., Moreira M. T., Feijoo G., 2011 LCA of mussel culture. In: Mussel: anatomy, habitat, and environmental impact. McGevin L. E. (ed), Nova Science, pp. 357-378.

Jerbi M. A., Aubin J., Garnaoui K., Achour L., Kacem A., 2012 Life cycle assessment (LCA) of two rearing techniques of sea bass (*Dicentrarchus labrax*). Aquacultural Engineering 46:1-9.

Klöpffer W., 1997 Life cycle assessment: From the beginning to the current state. Environmental Science and Pollution Research International 4(4):223-228.

Lourguioui H., Brigolin D., Boulahdid M., Pastres R., 2017 A perspective for reducing environmental impacts of mussel culture in Algeria. The International Journal of Life Cycle Assessment 22:1266-1277.

Norhana W. M. N., Yurimoto T., Nurlemsha B. I., Roziawati M. R., Saadon K., 2016 Food safety aspects in blood cockles (*Tegillarca granosa*) cultured off Selangor, peninsular Malaysia. Malaysian Journal of Science 35:226-240.

One Health High-Level Expert Panel (OHHLEP), Adisasmito W. B., Almuhairi S., Behravesh C. B., Bilivogui P., Bukachi S. A., Casas N., Becerra N. C., Charron D. F., Chaudhary A., Zanella J. R. C., Cunningham A. A., Dar O., Debnath N., Dungu B., Farag E., Gao G. F., Hayman D. T. S., Khaitsa M., Koopmans M. P. G., Machalaba C., Mackenzie J. S., Markotter W., Mettenleiter T. C., Morand S., Smolenskiy V., Zhou L., 2022 One Health: A new definition for a sustainable and healthy future. PLoS Pathogens 18(6):e1010537.

Pawiro S., 2010 Bivalves: global production and trade trends. In: Safe management of shellfish and harvest waters. Rees G., Pond K., Kay D., Bartram J., Santo D. J. (eds), IWA Publishing, pp. 11-19.

Pullin R. S. V., Smith I. R., 1984 Development and management of cockle (*Anadara granosa*) culture in Malaysia. Project description and Work Plan prepared for the Bay of Bengal Programme (BOBP) and the Malaysian Department of Fisheries. ICLARM, 49 p.

Ray N. E., O'Meara T., Williamson T., Izursa J. L., Kangas P. C., 2018 Consideration of carbon dioxide release during shell production in LCA of bivalves. The International Journal of Life Cycle Assessment 23:1042-1048.

Saffian N. S., Peng C., Ilias N., Hwai A. T. S., 2020 Overview and challenges of blood cockle culture in Malaysia. IOP Conference Series: Earth and Environmental Science 414:012020.
Siti Dina R. P., Ahmad F. M., Abdullah S., 2016 Life cycle assessment of cockles (*Anadara granosa*) farming: A case study in Malaysia. EnvironmentAsia 9(2):80-90.
Spångberg J., Jönsson H., Tidåker P., 2013 Bringing nutrients from sea to land - mussels as fertiliser from a life cycle perspective. Journal of Cleaner Production 51:234-244.
Srisunont C., Nobpakhun Y., Yamalee C., Srisunont T., 2020 Influence of seasonal variation and anthropogenic stress on blood cockle (*Tegillarca granosa*) production potential. Journal of Fisheries and Environment 44(2):62-82.
Tamburini E., Fano E. A., Castaldelli G., Turolla E., 2019 Life cycle assessment of oyster farming in the Po delta, northern Italy. Resources 8(4):170.
Tamburini E., Turolla E., Fano E. A., Castaldelli G., 2020 Sustainability of mussel (*Mytilus galloprovincialis*) farming in the Po River delta, northern Italy, based on a life cycle assessment approach. Sustainability 12(9):3814.
Tatsuya Y., 2020 Status of blood cockle, *Tegillarca granosa* (Linnaeus, 1758), aquaculture and sustainable production in Selangor, Malaysia. Malaysian Fisheries Journal 19:1-20.
Teillard F., de Souza D. M., Thoma G., Gerber P. J., Finn J. A., 2016 What does Life-Cycle Assessment of agricultural products need for more meaningful inclusion of biodiversity? Journal of Applied Ecology 53(5):1422-1429.
Turolla E., Castaldelli G., Fano E. A., Tamburini E., 2020 Life cycle assessment (LCA) proves that Manila clam farming (*Ruditapes philippinarum*) is a fully sustainable aquaculture practice and a carbon sink. Sustainability 12(13):5252.
Van der Giesen C., Cucurachi S., Guinée J., Kramer G. J., Tukker A., 2020 A critical view on the current application of LCA for new technologies and recommendations for improved practice. Journal of Cleaner Production 259:120904.
Vélez-Henao J. A., Weinland F., Reintjes N., 2021 Life cycle assessment of aquaculture bivalve shellfish production – a critical review of methodological trends. The International Journal of Life Cycle Assessment 26:1943-1958.
Wu F., Wang Y., Leung J. Y. S., Huang W., Zeng J., Tang Y., Chen J., Shi A., Yu X., Xu X., Zhang H., Cao L., 2020 Accumulation of microplastics in typical commercial aquatic species: A case study at a productive aquaculture site in China. Science of The Total Environment 708:135432.
Yurimoto T., Kassim F. M., Fuseya R., Man A., 2014 Mass mortality event of the blood cockle, *Anadara granosa*, in aquaculture ground along Selangor coast, Peninsular Malaysia. International Aquatic Research 6:177-186.
Ziegler F., Winther U., Hognes E. S., Emanuelsson A., Sund V., Ellingson H., 2013 The carbon footprint of Norwegian seafood products on the global seafood market. Journal of Industrial Ecology 17(1):103-116.
*** AGC, 1990 [Fisheries regulation (marine culture system) 1990]. P.U. (A) 131, Fisheries Act 1985, Act 317, Federal Government Gazette, Attorney General's Chambers (AGC), Malaysia. [In Malay].
*** AGC, 2002 [Fisheries regulation (conservation and cockle culture) 2002]. P.U. (A) 405/2002, Fisheries Act 1985, Act 317, Federal Government Gazette, Attorney General's Chambers (AGC), Malaysia. [In Malay].
*** AGC, 2012 [Fisheries (Fish disease control compliance to import and export) Regulation 2012]. P.U. (A) 95, Fisheries Act 1985, Act 317, Federal Government Gazette, Attorney General's Chambers (AGC), Malaysia. [In Malay].
*** CEMACS (Centre for Marine and Coastal Studies, University of Science Malaysia), 2022 Blood cockles are getting more expensives, Penang char kuey teow losses its savoriness. Available at: https://cemacs.usm.my/index.php/en/about-us/latest-news/148-blood-cockles-is-getting-more-expensives-penang-char-kuey-teow-losses-its-savoriness
*** DOFM (Department of Fisheries Malaysia), 2001 [Fisheries annual statistic 2001]. Department of Fisheries Malaysia. Available at: http://www.dof.gov.my. [In Malay].

*** DOFM (Department of Fisheries Malaysia), 2020 [Fisheries annual statistic 2020]. Department of Fisheries Malaysia. Available at: http://www.dof.gov.my. [In Malay].
*** DOFM (Department of Fisheries Malaysia), 2021 [Standard operating procedure]. National Shellfish Sanitation Programme (N.S.S.P), SOP-DOF-BP1-1BB3, Fisheries Biosecurity Division, Department of Fisheries Malaysia. [In Malay].
*** EP (European Parliment), 2022 Circular economy: definition, importance and benefits. Article 14:41. European Parliament. Available at <https://www.europarl.europa.eu/news/en/headlines/economy/20151201STO05603/circular-economy-definition-importance-and-benefits>
*** FAO, 2022a The state of world fisheries and aquaculture 2022. Available at: https://www.fao.org/3/cc0461en/online/sofia/2022/aquaculture-production.html
*** FAO, 2022b Top 10 species groups in global, regional and national aquaculture 2020. Supplementary materials to the factsheet on Top 10 species groups in global aquaculture 2020. Available at: https://www.fao.org/3/cc0681en/cc0681en.pdf
*** FAO, WOAH, UNEP, WHO, 2021 Tripartite and UNEP support OHHLEP's definition of "One Health", Joint News Release 1 December 2021, The Food and Agriculture Organization of the United Nations (FAO), the World Organisation for Animal Health (WOAH), the United Nations Environment Programme (UNEP) and the World Health Organization (WHO). Available at: https://www.who.int/news/item/01-12-2021-tripartite-and-unep-support-ohhlep-s-definition-of-one-health
*** GOM 1985 [Fisheries act (Act 317)]. Department of Fisheries Malaysia, Government of Malaysia (GOM). [In Malay].
*** Malik M. A., 2017 With production plummeting, cockles no longer cheap seafood indulgence. New Strait Times, Available at: https://www.nst.com.my/news/nation/2017/10/290899/production-plummeting-cockles-no-longer-cheap-seafood-indulgence
*** The Star, 2009 Suspected cockle seed smugglers nabbed. Available at: https://www.thestar.com.my/news/nation/2009/04/02/suspected-cockle-seed-smugglers-nabbed
*** Utusan Malaysia, 2022 [Two 25 kg sacks of baby clams were confiscated]. Available at: http://www.utusan.com.my/terkini/2022/02/dua-guni-anak-kerang-25-kg-dirampas/. [In Malay].
*** WHO (World Health Organization), 2022 One Health fact sheet. Available at: https://www.who.int/news-room/fact-sheets/detail/one-health
*** World Bank, UNDESA, 2017 The potential of the Blue Economy: Increasing long-term benefits of the sustainable use of marine resources for small island developing states and coastal least developed countries. World Bank and United Nations Department of Economic and Social Affairs (UNDESA), Washington D. C., 50 p.

Received: 06 September 2022. Accepted: 11 November 2022. Published online: 03 February 2023.
Authors:
Siti Dina Razman Pahri, Centre for Research in Development, Social and Environment, Faculty of Social Sciences and Humanities, Universiti Kebangsaan Malaysia, 43600 Bangi, Selangor, Malaysia, e-mail: sitidina@ukm.edu.my
Raja Yana, Department of Fisheries Malaysia, Ministry of Agriculture and Food Security, Wisma Tani, Precinct 4, 62628 Putrajaya, Malaysia, e-mail: rajayana@dof.gov.my
Muhammad Danial Abdullah, Department of Fisheries Malaysia, Ministry of Agriculture and Food Security, Wisma Tani, Precinct 4, 62628 Putrajaya, Malaysia, e-mail: danial@dof.gov.my

How to cite this article:
Pahri S. D. R., Yana R., Danial M. A., 2023 Sustainable management of blood cockles (*Tegillarca granosa*) industry in Malaysia from the life cycle assessment perspective: A review. AACL Bioflux 16(1):436-446.