The Journal of Agricultural Sciences - Sri Lanka
Vol. 18, No 2, May 2023. Pp 273-288
http://doi.org/10.4038/jas.v18i2.10259

Potential of Live Rock Culture in Coastal Environments of Sri Lanka Based on Shape, Substrate, and Monsoon Pattern

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Received:04th August 2022 / Accepted: 24th February 2023

ABSTRACT

Purpose: *Live rocks are very important and highly demanded in the global aquarium industry and can be cultured easily without sophisticated techniques or knowledge. Marine Live rock culture may become a conceivable alternative industry among the resource utilizing coastal communities in Sri Lanka. However, it has not been scientifically studied yet.*

Research Method: *Nine types of cement rocks were made by changing three types of shapes and three types of substrates and those were placed in different study locations on the Southern and Eastern coast of Sri Lanka covering all four types of monsoon patterns prevail in the country.*

Findings: *Live species attachments, their attachment rates, and consumer preferences differed with the shape, substrate, monsoon pattern, study location, and growth period in the sea and most of those differences were statistically significant. Consumer preference was mainly dependent on the nature of biota attachments on top of the different rock types. Therefore, their preferences were also changing with the types of rock, monsoon pattern, and location.*

Originality/ Value: *Findings can be effectively utilized for establishing live rock culture as an alternative industry, especially in ecosystems where resources are depleted or degraded.*

Keywords: *Fish tank decoration with live rocks, Aspects of global aquarium industry, Marine attached organism Marine ornamental fishing industry, Novel exporting trends in Sri Lanka.*

INTRODUCTION

The Marine ornamental fish industry in Sri Lanka is almost dependent on species harvested from the wild coral reef ecosystems targeting the export market (Dhanasundara *et al.*, 2020; Rajasuriya, 2009). Nearly 611,310 and 459,425 marine fish individuals have been exported from Sri Lanka in the year 2017 and 2018 respectively to many countries, the USA, Japan, and the UK being the leading destinations. Family Gobiidae, Serranidae, Acanthuridae, and Labridae were the most exported reef fish families from the country while the family Hippolitidae and Rhynchocinedae were the most exported invertebrate families (Dhanasundara *et al.*, 2020). Due to the degradation of those reef ecosystems and the overexploitation with bad practices of collectors, this industry is becoming unsustainable in coastal regions (Fernando *et al.*, 2005; Rajasuriya, 2009). However, farming marine ornamental fishes in captivity is problematic since it requires higher skills and technologies than culturing freshwater ornamental fish (Moe Jr, 2003; Gopakumar, 2006).

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Live rock culturing could be identified as one of the simplest processes when compared to marine fish farming, but it also has a high demand (Moe Jr, 2003; Parks *et al*., 2003). Live rocks are defined as "live specimens of invertebrates, plants, coralline algae, and pieces of corals attached to a rock which are not contained in the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) appendices and which are transferred in moist condition, but not in the water, in enclosures" (CITES, 2000). Due to their biological and aesthetic roles, they are important in the ornamental aquaria industry. Harvesting of live rocks from natural coral reefs causes loss of biodiversity and coral destruction. Accordingly, it is necessary to culture such rocks instead of harvesting them from the natural marine environment (Wabnitz, 2003). Since coastal areas around Sri Lanka are rich in coral reefs and coral biodiversity (Rajasuriya *et al*., 2002; Rajasuriya, 2009), there is a copious possibility to culture live rocks by enriching them with naturally occurring marine algae and invertebrates that associate with coral reefs. They could be produced in this environment with attractive colors, shapes, and features adding higher ornamental values.

Important factors such as the basic information on species attachments, the nature of the attachment of live species on artificial rock types, the effect of monsoon pattern, growth period, appropriate substrates, productive shapes of structures, and variations with the different coastal locations, and the preferences of the consumers can be effectively applied for the implementation of live rock cultures for commercial purposes targeting a prospective profit and conservation-oriented marine ornamental aquaria industry, by eliminating the limitation of lack of basic information. Therefore, this study was conducted to evaluate suitable areas, seasons, growth, shapes, substrates, structures, and the preferences of consumers for marine live rock culturing around Sri Lanka.

MATERIALS AND METHODS

A preliminary study was conducted in the Eastern, Southern, and North-western coastal regions around the country to select the best locations for live rock culture as an industry. When selecting suitable locations, the criteria of minimum interruptions to fishermen, slightest disorders to tourism and other recreational activities, effortless accessibility, existing outer spaces, caring environment, and surrounding biodiversity were considered. Ahangama (AGR), Madiha (MR), and Dondra (DR) reefs on the southern coast and Adukkuparu (AR), Kayankerni (KR), and Pasikudah (PR) reefs on the Eastern coast (Figure 01-a) were selected as appropriate locations. However, a suitable site was not identified from the North-western region based on our criteria to culture live rocks as an industry. Therefore, the Northwestern region was omitted in further studies.

Rounded, semi-branched, and branched (shape) cement rocks were made by changing the particle size (substrate) to very coarse sand (1-2mm), very fine gravel (2-4mm), and fine gravel (4-8mm) respectively. Those nine types of rocks were exhibited as S1P1, S1P2, S1P3, S2P1, S2P2, S2P3, S3P1, S3P2, and S3P3 concerning their Shape (S) and Particle size (P) (Table 01).

Those rock structures were placed on particularly fabricated holding facilities made of concrete stands and metal netting that enclosed wooden frames ensuring consistent height from the bottom in all selected study sites (Figure 01-b and c).

Totally, 45 rock structures as 05 structures of each 09 types (9*5=45 types) were attached to one holding facility, and 03 of such units (3*45=135 types) to cover the full range of the site were positioned for one growth cycle at a monsoon period in a study site. Five (05) Cup-shaped cement rocks per unit were used as controllers.

Hence, four such cycles were conducted covering four monsoon patterns that affect Sri Lanka; 1st Inter Monsoon (March-April), Southwest Monsoon (May-September), 2nd Inter Monsoon (October-November), and Northeast Monsoon (December-February) (Ranatunge *et al.,* 2003; Shelton *et al*., 2022) from 2020 to 2021 since the physical and biological circumstances of the ocean are altering when monsoon patterns are changing (Nurdin *et al*., 2013).

Percents of biota attachments were investigated by counting and image analysis after every 03 months and 06 months growth periods. The attachment nature of organisms on different rock types was statistically evaluated considering the study sites and monsoon patterns. Sensory evaluation was performed after a 06-months growth period as relevant to all types of live rocks and locations for different monsoon patterns.

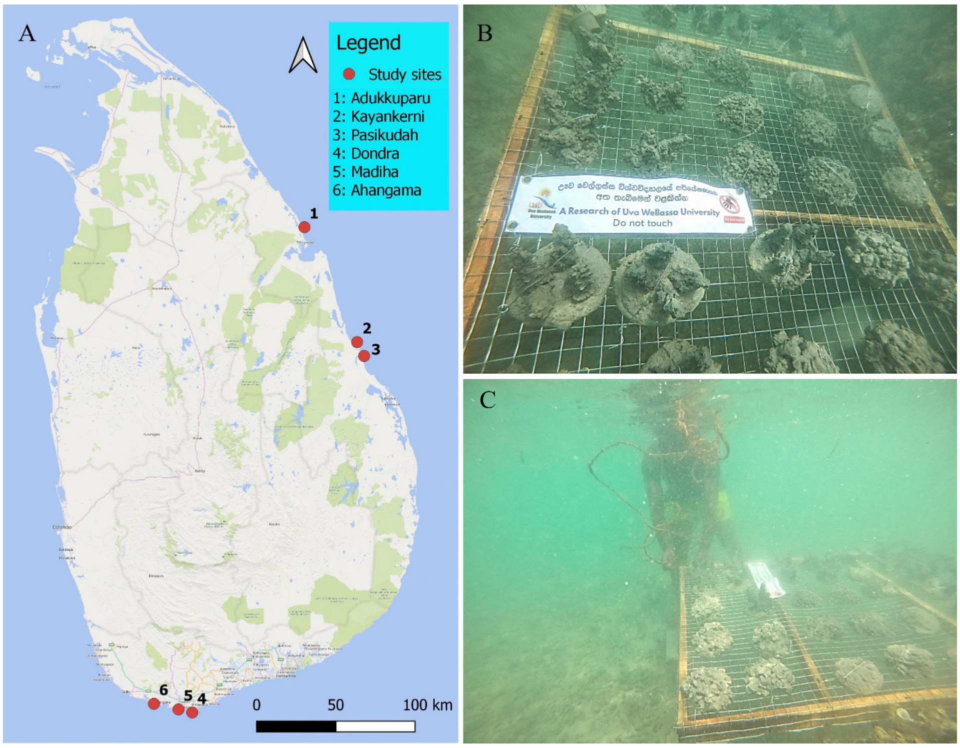

Figure 01: **(A) the map showing all study sites where live rocks were cultured on different coasts of Sri Lanka. (B) and (C) show the initial installation of different types of rocks in the marine environment.**

Table 01: Artificial rock types which were made by changing the shape and particle size

Shape	Particle size	Name code
Rounded	Very coarse sand (1-2 mm)	S1P1
Rounded	Very fine gravel (2-4 mm)	S1P2
Rounded	Fine gravel (4-8 mm)	S1P3
Semi-branched	Very coarse sand (1-2 mm)	S2P1
Semi-branched	Very fine gravel (2-4 mm)	S2P2
Semi-branched	Fine gravel (4-8 mm)	S2P3
Branched	Very coarse sand (1-2 mm)	S3P1
Branched	Very fine gravel (2-4 mm)	S3P2
Branched	Fine gravel (4-8 mm)	S3P3

The benthic environmental surveys of each study location were conducted by using a 50m long Line Intercept Transect (LIT) method (Beenaerts and Berghe, 2005). Underwater videos and photographs of benthic sessile organisms were taken for further analysis (Smith, 1988; Caldwell *et al*., 2016). The abundance and diversity of corals, algae, and seagrass were investigated by calculating Shannon–Wiener Diversity (H'), Simpson's index (d), Pielou's evenness index (J), and Margalef's index-species richness (Zar, 1999).

RESULTS AND DISCUSSION

The gradual growth of microalgae, lichen, and fungi species on artificial cement rocks was observed within 7±1.4 days after they have been placed in different marine environments of all the experimental sites. The time taken for macro species to get attached to cement rocks varied from one month to more than one month. 1% to 20% of macro species have been started to attach to all types of rock structures that were placed during any monsoon period after the first month period and that percentage depended on the monsoon period and the study site. Hence, it is fair to consider commonly that three months as the minimum growth period of any shape of live rocks placed in any monsoon period. However, macro-organisms such as macroalgae, seagrass, cnidarians, molluscs, and echinoderms were attached at a higher rate after the first 03 months period (Table 03 and Table 04). The growth rate of microalgae is relatively high at both high and low substrate concentrations, since microalgae take up nitrogen far faster per unit of biomass than macroalgae, and microalgae have substantially higher empathy for nitrogen than macroalgae (Hein *et al*., 1995). Temperature, light intensity, carbon dioxide, pH, and nutrient composition of the culture media are all elements that influence microalgae cultivation systems. Light and temperature are two of the most critical environmental elements that influence algal growth and biomass output (Li *et al*., 2012; Papapolymerou *et al*., 2019). In the beginning, the cement rocks provide a harsh environment for marine organisms to be attached. Therefore, it can be overcome by lichen and fungi as well since they can easily perform their growth in harsh environmental conditions (Armstrong, 2017; Gostinčar *et al*., 2011; Oksanen, 2006; Slepecky and Starmer, 2009). Here, they could adapt to very high pH levels since newly produce concrete may contain highly alkaline pH levels of more than 13 (Ekström, 2000).

In some cases, these attachments caused the disappearance of the original shape of the placed live rocks due to covering of macro-organisms around it. But, It may gradually reduce the light intensity and inhabit the microalgal growth furthermore (Li *et al*., 2012; Papapolymerou *et al*., 2019). Totally, 25 macro species in AGR, 26 macro species in MR, and 20 macro species in DR have been recorded on all types of live rock structures after 06 months growth period in the sites of the Southern coast (Table 02). On the Eastern coast, 19 macro species in AR, 26 macro species in KR, and 24 macro species in PR were attached after 06 months growth period (Table 02).

Fish species of family Gobiidae and juvenile stages of family Pomacentridae were observed as inhabitants in or on some live rock structures which were covered by macro sessile organisms and sediments after 03 months period. Since many marine fish species belonging to the family Gobiidae can be found resting on a substrate, they were commonly found on live rocks (Greenfield, 2017). Juveniles of the family Pomacentridae were found associated with branched and semi-branched live rocks since they are living in coral habitats (Chase *et al*., 2020; Coker *et al*., 2014).

Most of the time, the attachment nature of micro and macro biota to artificial rock structures after 03 months and 06 months periods which is indicated by table 03, differed with the initiated monsoon patterns and study locations. Those differentiations with respect to 03 months and 06 months growth periods at all the monsoon patterns and study sites were significant ($P<0.05$).

Table 02: List of all species recorded in different study locations after period of six months (AGR-Ahangama, MR -Madiha, DR- Dondra, AR- Adukkuparu, KR- Kayankerni, and PR -Pasikudah).

		Southern coast			Eastern coast		
		AGR	MR	DR	AR	KR	PR
Macro algae	*Halimeda opuntia*	+	+	+	+	+	+
	Halimeda discoidea	+	+	-	+	+	+
	Halimeda gracilis	-	+	-	-	-	-
	Chondrus crispus	-	-	-	-	-	+
	Codium fragile	+	+	-	-	+	+
	Codium geppiorum	+	-	-	-	-	-
	Codium arabicum	+	-	-	-	-	-
	Ulva lactuca	-	+	-	-	+	-
	Ulva fasciata	+	-	+	-	-	-
	Ulva pertusa	-	+	+	-	+	+
	Ulva prolifera	-	-	+	-	-	+
	Chaetomorpha antennina	-	-	-	-	-	+
	Cladophora sericea	-	-	-	-	-	+
	Valoniopsis pachynema	+	-	+	-	-	-
	Caulerpa imbricata	-	+	-	-	+	-
	Caulerpa lentillifera	-	-	-	-	-	+
	caulerpa racemosa	+	+	+	+	+	-
	Caulerpa sertularioides	+	-	-	-	-	+
	Dictyota ciliolate	+	+	+	-	-	-
	Dictyosphaeria versluysii	-	+	-	-	-	-
	Cladophora vagabunda	-	+	+	-	-	+
	Avrainvillea amadelpha	-	-	-	+	+	+
	Bryopsis pennata	+	+	-	-	+	+
	Padina antillarum	-	+	-	+	+	+
	Padina boergesenii	-	+	-	-	+	+
	Sargassum ilicifolium	+	+	-	-	-	+
	Sargassum wightii	-	+	-	-	-	-
	Sargassum turbinatifolium	-	+	-	-	-	-
	Turbinaria ornata	+	-	-	-	-	-
	Colpomenia sinuosa	-	-	-	-	-	+
	Dermonema virens	-	-	-	-	+	-
	Gracilaria crassa	+	-	-	+	-	-
	Gracilaria corticata	+	-	-	-	+	-
	Polyopes sp.	-	-	-	-	-	+
	Hypnea pannosa	+	-	-	+	-	-
	Gelidium sp.	+	-	-	+	+	-
	Pterocladiella sp.	+	-	-	-	-	-
	Botryocladia skottsbergii	-	-	-	-	+	-
	Chondrus crispus	+	-	-	-	+	-
	Asparagopsis taxiformis	-	-	-	+	+	+

		Southern coast			Eastern coast		
		AGR	MR	DR	AR	KR	PR
Sea grass	*Syringodium isoetifolium*	-	-	-	-	-	+
	Thalassia hemprichii	+	+	+	+	-	-
	Halodule uninervis	-	+	-	-	+	-
	Halophila ovalis	-	-	-	-	+	-
	Cymodocea rotundata	+	-	+	+	+	+
Invertebrates	*Sabellaria sp.*	-	-	+	+	+	-
	Semibalanus balanoides	-	+	+	+	-	-
	Tetraclita sp.	-	+	+	+	-	+
	Cellana exarata	+	+	+	+	-	-
	Cellana radians	-	-	+	+	+	-
	Patella vulgata	-	-	+	+	-	-
	Monetaria caputserpentis	-	-	-	-	+	+
	Nerita plicata	+	+	+	-	+	-
	Littorina littorea	-	-	+	+	-	-
	Saccostrea cucullata	-	-	-	+	+	-
	Acanthopleura sp.	-	+	-	-	-	+
	Diadema sp.	+	+	+	-	-	-
	Tripneustes ventricosus	+	+	+	-	-	-
	Actiniaria sp.	-	-	-	-	+	-

+ Present; - Absent

According to figure 02, the relative abundance of macroalgal species was higher than the relative abundance of seagrass and invertebrates in all the sites except in DR. The highest relative abundance of macroalgal species was recorded in PR (79%) while the lowest value was in DR (40%). In DR the relative abundance of invertebrates was the highest (50%) while PR was showing the lowest relative abundance of invertebrates (12.5%). Therefore, the presence of a high relative abundance of invertebrates might have caused a reduction in the abundance of macroalgae by feeding. Many types of marine macroalgae start to colonize in a new substrate after the separation of propagules from the parent plants due to various factors such as grazing and wave actions (Fletcher and Callow, 1992). Since the surrounding environments of all the study sites contain macroalgae with higher diversity (Figure 06), propagules can be easily attached and grow on artificial rock types. However, the relative abundance of seagrass species was the lowest value among all the sites and that was around 10%. Seagrasses require a soft benthic substrate usually made of sand or mud to grow their roots (Erftemeijer and Koch, 2001) and the lower relative abundance of seagrass species recorded may be due to the low level of sediment trapping in live rocks during the 06-month growth period. Therefore, a higher amount of seagrass biomass cannot be expected.

The similarity levels as per the presence of species between every two sites were shown in Figure 03. The similarities were less than 40% according to the Jaccard similarity coefficient (Figure 03). The maximum similarity level was recorded between DR and AR (39.29), though they were situated on two different coasts. The lowest value was between DR and PR (15.79). It indicates that the species compositions on live rocks were different with the study sites. That could be due to the differentiation of species composition in different sites (Premarathna *et al*., 2020; Ramawickrama *et al*., 2020).

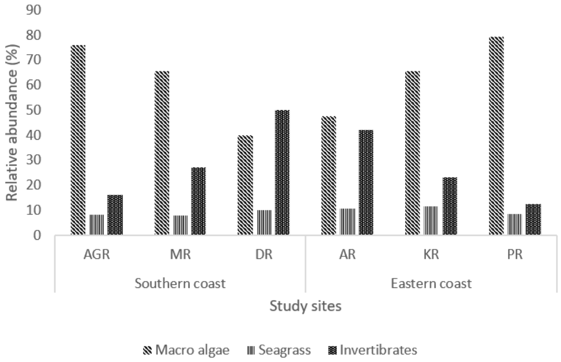

Figure 02: Relative abundance of the type of species recorded in each site (AGR-Ahangama, MR -Madiha, DR-Dondra, AR- Adukkuparu, KR-Kayankerni, and PR -Pasikudah)

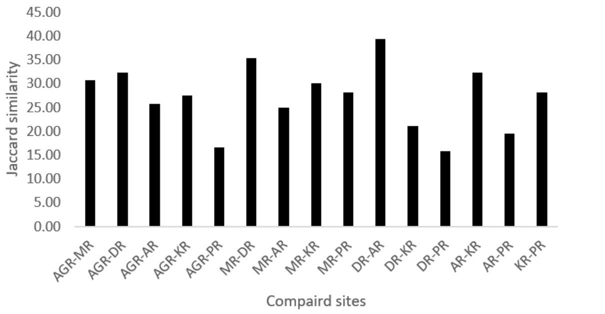

Figure 03: The Jaccard similarity coefficient for every two sites (AGR-Ahangama, MR -Madiha, DR-Dondra, AR- Adukkuparu, KR-Kayankerni, and PR -Pasikudah).

The attached percentages of biota on all types of rock species after three months growth period differed significantly among different study sites ($p<0.05$). It has also significantly differed among different monsoon patterns ($p<0.05$). The attached percentages of biota on all types of rock species after six months growth period differed significantly among different study sites ($p<0.05$), and also among different monsoon patterns ($p<0.05$).

In all the study locations of the Southern coast, the highest attachment rate of combined micro and macro colonies during the first three months period was recorded in the 2nd Inter Monsoon followed by Southwest Monsoon, Northeast Monsoon, and 1st Inter Monsoon (Table 03). However, if they were placed around 06 months period for growing, they had to face two different monsoon periods. Therefore, for the 06 months growth period, the lowest growth rate was observed in live rocks that were initiated with the Northeast monsoon period followed by the 1st Inter Monsoon period. For six months growth period, the culture cycles initiated in other three monsoon periods showed high performance (Table 03). It was also evident that the percentages of macro-organisms are higher in 6 months than in 3 months growth period.

In all the study locations of the Eastern coast, the highest percent cover of combined micro and macro colonies during the first three months period were recorded in the 1st Inter Monsoon followed by Northeast monsoon, Southwest Monsoon, and 2nd Inter Monsoon (Table 04). However, if they were placed around 06 months period for growing, the lowest growth rates could be observed in live rocks that were initiated with the Southeast Monsoon period while other monsoon periods were showing a high performance (Table 04). On the Eastern coast also the percentage of macro-organisms increased with the increased growth period.

Strong monsoon winds blow in from the southwest of the island between May and September (Southwest Monsoon), and from the east of the island between December to February (Northeast Monsoon) bringing heavy rain to that particular part of the country (Department of Meteorology Sri Lanka, 2019; Shelton *et al*., 2022; Wyrtki, 1973). According to Sri Lanka's Department of Meteorology, rainfall during the SWM season exceeds 3000 mm, and that is the highest rainfall value that has been recorded for the year (Department of Meteorology Sri Lanka, 2019). So, there can be higher nutrient accumulations that facilitate algal and plant growth in the coastal areas by terrestrial runoff (Nurdin *et al*., 2013; Shaari *et al*., 2013). Both the 1st Inter-Monsoon and the 2nd Inter-Monsoon are considered the transition periods of a year (Vos *et al*., 2014), and those time durations have differently distributed rainfall over Sri Lanka (Department of Meteorology of Sri Lanka, 2019). During these seasons, the whole landmass gets more than 400 mm of rainfall. However, the 2nd Inter-Monsoon is significant to the climatic system through the phenomena such as cyclones, convectional rain, and tropical depressions in the Bay of Bengal while delivering higher amounts of rain than the 1st Inter-Monsoon (Ranatunge *et al*., 2003). Strong winds and widespread rains are common in such situations, causing floods and landslides (Department of Meteorology of Sri Lanka, 2019; Ranatunge *et al*., 2003). In such situations, heavy terrestrial runoff to the coastal environment can be contributing to the algal and plant growth and subsequence grazing by invertebrates in the coastal regions. Therefore, that would be the main reason for the different growth levels of live rocks in different monsoon patterns and different coasts (Table 03 and Table 04).

Table 03: Percent cover of biota in all types of rock structures after 03 months and 06 months period concerning four different culture cycles based on different monsoon patterns in study locations on the Southern coast (DR-Dondra, MR-Madiha, AGR-Ahangama).

Site	Initiation of culture cycle	% Cover in 3 months			% Cover in 6 months		
		Microcolonies	Macro-organisms	Total	Microcolonies	Macro-organisms	Total
DR	1st Inter Monsoon	45%	05%	50%	75%	20%	95%
	Southwest Monsoon	60%	20%	80%	55%	45%	100%
	2nd Inter Monsoon	60%	25%	85%	60%	40%	100%
	Northeast Monsoon	50%	05%	55%	65%	15%	80%
MR	1st Inter Monsoon	55%	05%	60%	50%	50%	100%
	Southwest Monsoon	70%	20%	90%	70%	30%	100%
	2nd Inter Monsoon	60%	40%	100%	40%	60%	100%
	Northeast Monsoon	65%	05%	70%	80%	10%	90%
AGR	1st Inter Monsoon	50%	05%	55%	60%	40%	100%
	Southwest Monsoon	60%	30%	90%	40%	60%	100%
	2nd Inter Monsoon	60%	35%	95%	45%	55%	100%
	Northeast Monsoon	50%	10%	60%	60%	20%	80%

***Macro-organisms attached over microcolonies were counted as macro-organism percentages.*

Table 04: Percent cover of biota in all types of rock structures after 03 months and 06 months period concerning four different culture cycles based on different monsoon patterns in study locations on the Eastern coast (AR-Adukkuparu, KR-Kayankerni, and PR-Pasikudah).

Site	Initiation of culture cycle	% Cover in 3 months			% Cover in 6 months		
		Microcolonies	Macro-organisms	Total	Microcolonies	Macro-organisms	Total
AR	1st Inter Monsoon	60%	15%	75%	70%	20%	90%
	Southwest Monsoon	50%	05%	55%	65%	15%	80 %
	2nd Inter Monsoon	45%	05%	50%	50%	35%	85%
	Northeast Monsoon	50%	15%	65%	70%	30%	100%
KR	1st Inter Monsoon	55%	25%	80%	60%	35%	95%
	Southwest Monsoon	50%	15%	65%	60%	25%	85 %
	2nd Inter Monsoon	50%	10%	60%	40 %	60%	100%
	Northeast Monsoon	65%	10%	75%	75%	10%	100%
PR	1st Inter Monsoon	60%	35%	95%	45%	55%	100%
	Southwest Monsoon	40%	25%	65%	50%	30%	80%
	2nd Inter Monsoon	40%	20%	60%	45%	40 %	85%
	Northeast Monsoon	50%	40%	90%	40%	60 %	100%

***Macro-organisms attached over microcolonies were counted as macro-organism percentages.*

A higher amount of nutrient runoff with the Southwest Monsoon to the coastal water of the southwestern zone has been observed by Silva *et al*., 2005, and that is strongly suggested for the rapid attachment of microalgae, macroalgae, and other biotas to the live rock structures in all study sites along the Southern coast. Loading of those nutrients at the end of the Southwest Monsoon period and the calm sea condition may highly affect the rapid growth of those biotas on top of the artificial rock structures than in any other monsoon pattern. Further reduction of nutrient levels due to lower amount of terrestrial runoff during the Northeast Monsoon and the 1st Inter Monsoon, may cause to longer growth period observed on live rock structures during those particular seasons. When comparing study locations, MR showed a relatively higher growth rate and higher number of species attachments followed by AGR and DR. MR is situated closer to the Nilwala river mouth, which would be the reason to show a higher growth rate with the help of terrestrial nutrient runoff by the river. Subsequently, the AGR location is closer to the Koggala lagoon mouth which may loading nutrients to the coastal area. Therefore, dissimilarities in the attachment nature were observed in different study sites related to the corresponding monsoon patterns (Figure 04).

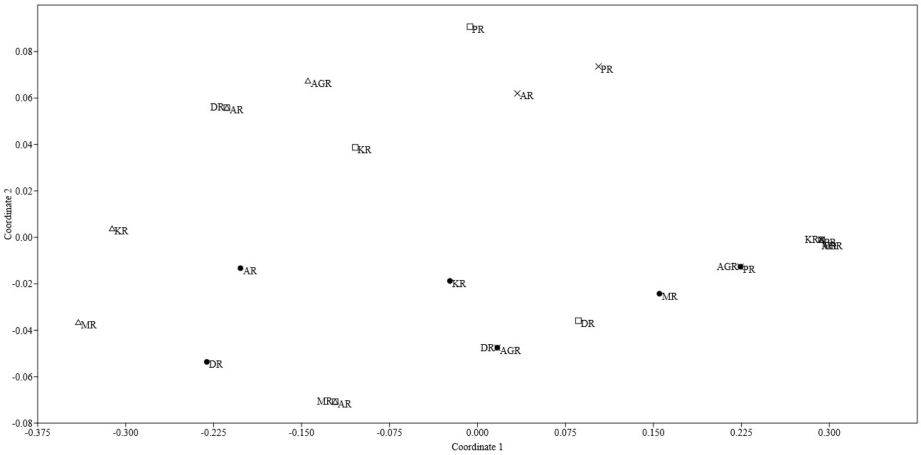

Figure 04: Non-Metric MDS plot for attached microcolonies and macro-organisms after 06 months in different study locations with respect to four monsoon patterns (Dots indicate 1st Inter Monsoon, Squares indicate Southwest Monsoon, Crosses indicate 2nd Inter Monsoon, and Triangles indicate Northeast Monsoon.

The attachment nature of macro-organisms on rocks placed on the Eastern coast also varied according to the affected monsoon pattern. Around 42% of Sri Lankan annual rainfall (1853mm) is received with the Northeast Monsoon from December to February (Zubair and Ropelewski, 2006). During this period, the highest amount of rainfall (around 1200mm) is received to the Northeastern slope of the central highlands (de Silva and Nawala, 2009) which runs off to the eastern coast ultimately by the river systems.

As per the PCA performed related to the micro and macro colonies on different rock types, the highest dissimilarities were observed between rounded and branched types of rocks. However, the dissimilarities with the particle size used for making cement rocks were not prominent (Figure 05).

According to table 05, more species have been recorded on branched rock types. Cement structures made with very fine gravel (2-4mm) substrate had the highest preferences followed by fine gravel (4-8mm) substrate and very coarse sand (1-2mm) substrate. More species have been recorded on rock types made of fine gravels (2-4mm) except the rounded-shaped rocks (Table 05).

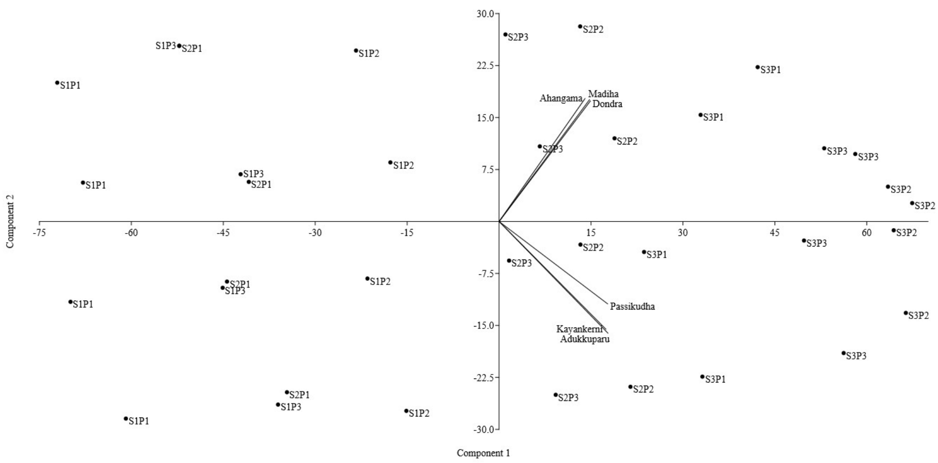

Figure 05: PCA of attached organisms after 06 months in different rock types cultured with respect to four monsoon patterns and study sites.

Table 05: Number of species recorded on different rock types in different study sites

Study site	Total number of species recorded on rock types								
	S1P1	S1P2	S3P3	S2P1	S2P2	S2P3	S3P1	S3P2	S3P3
Ahangama	10	12	15	18	23	20	21	24	24
Madiha	11	13	18	18	24	21	22	26	24
Dondra	8	10	13	12	16	13	15	19	17
Adukkuparu	7	8	11	10	15	14	15	18	16
Kayankerni	10	13	18	19	23	20	21	24	23
Passikudha	9	11	16	17	22	18	20	23	21

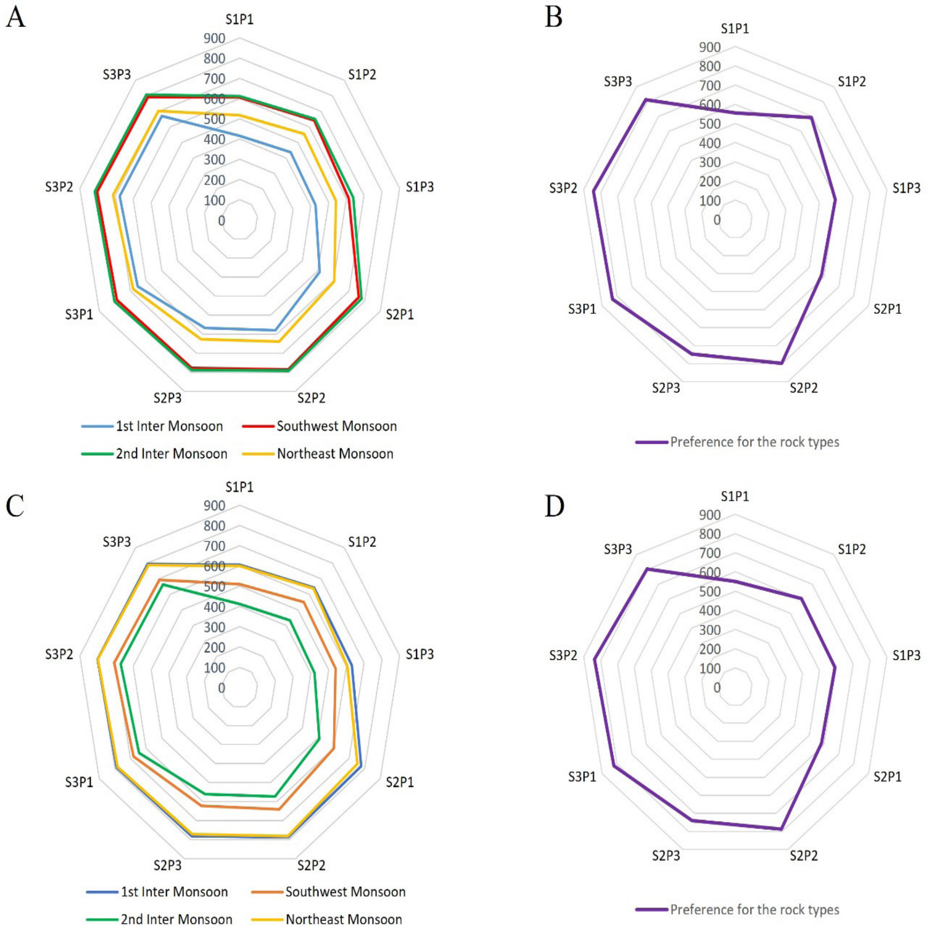

Figure 06: The radar charts show the sum of the ranks achieved by the Friedman tests. (A). 100 volunteer respondents' preferences on live rocks afterward 06 months culture period obtained via 0-10 ranking concerning dissimilar culture cycles at respective monsoon patterns on the Southern coast, (B). 100 volunteer respondents' preferences on live rocks afterward 06 months obtained via 0-10 ranking concerning all culture cycles at all four monsoons on the Southern coast, (C). 100 volunteer respondents' preferences on live rocks afterward 06 months obtained via 0-10 ranking concerning various culture cycles at respective monsoon patterns on the Eastern coast, and (D). 100 volunteer respondents' preferences on live rock structures afterward 06 months were obtained via a 0-10 ranking concerning all culture cycles at all four monsoons on the Eastern coast.

Responders' insights also more or less coincided with the level of biota attachment, types of biota attachment, and the colors given by the attached biota on top of the different rock types (Figure 06). Most preferences were received for branched typed rocks followed by semi-branched and rounded types. Branched types of rocks provide more surface areas and the shape facilitates trapping propagules of macroalgae and larvae of invertebrates than the two other shapes. They also can easily facilitate the trapping of sediments and subsequent growing of seagrass.

Sequentially, culture cycles initiated with the 2nd Inter Monsoon, Southwest Monsoon, Northeast Monsoon, and 1st Inter Monsoon have obtained the preferences of responders for the live rocks cultured on the southern coast (Figure 06).

For the live rocks cultured on the Eastern coast, branched rocks made with very fine gravels (2-4mm) and cultured during the 1st Inter Monsoon period had the highest preferences while rounded rocks made with very coarse sand (1-2mm) and cultured during the 2nd Inter Monsoon period had the lowest preferences by the sensory evaluation (Figure 06).

When considering the diversity of live rocks, it showed a close relationship with the diversity of corals and the diversity of macroalgae of the surrounding environment (Figure 07). Always a higher diversity was recorded when a higher diversity of corals and/or a higher diversity of macroalgae were present in the surrounding environment. When surrounding biodiversity is low, the diversity of attached species on artificial rock types were also low.

Therefore, there is a close relationship between the diversity of attached species on live rocks and surrounding biodiversity. Previous studies recorded that the diversity and distribution of macroalgal species are significantly different among the sites on the Southern coast (Premarathna *et al*., 2020). Different levels of biodiversity and species richness of corals have been recorded on the Eastern coast of Sri Lanka also by Ramawickrama *et al*. (2020).

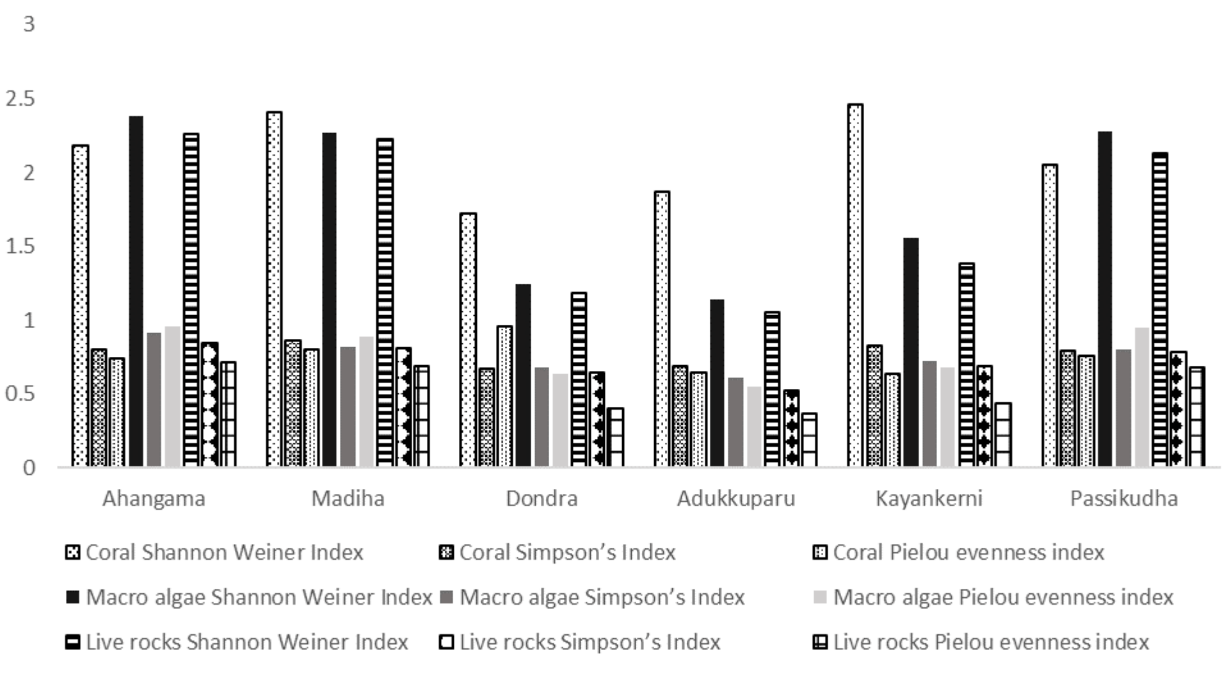

Figure 07: Diversity indices and evenness of live rocks, surrounding coral communities, and macroalgal communities.

CONCLUSIONS

The study concludes that the culture of live rocks can be performed in Sri Lanka. The biota attachment to artificial rocks and becoming live forms (growth rate) depends mainly on the monsoon pattern, shape, substrate, and the location of the initial rock structure placed. The shape of the live rock, level of biota attachment, types of biota attachment, and the colors given by the attached biota are the preferred qualities of the consumers. Branched type live rocks made of very fine gravel (2-4mm) were found to be the best type for live rock culturing. The 2nd Inter Monsoon and 1st Inter Monsoon were the best monsoon periods to initiate live rock culturing on the Southern coast and the Eastern coast, respectively. The diversity of the surrounding marine environment influences the diversity of attached organisms on the live rock types hence selecting a site with high biodiversities such as coral or rocky shore environments is important. However, when initiating live rock culture, sites that are easily accessible; the least disturbances to fishermen, tourists, and recreational activities; well-available space and protection; and sustainability of surrounding biodiversity should be considered.

REFERENCES

Armstrong, R.A. (2017). Adaptation of Lichens to Extreme Conditions. In: Plant Adaptation Strategies in Changing Environment. (Shukla, V., Kumar, S., Kumar, N. Eds.). Springer, Singapore. 1-27. https://doi.org/10.1007/978-981-10-6744-0_1

Beenaerts, N. and Berghe, E.V. (2005). Comparative study of three transect methods to assess coral cover, richness, and diversity. *Western Indian Ocean Journal of Marine Science,* 4(1), 29-38. https://doi.org/10.4314/wiojms.v4i1.28471

Caldwell, Z.R., Zgliczynski, B.J., Williams, G.J. and Sandin, S.A., (2016). Reef fish survey techniques: assessing the potential for standardizing methodologies. *PloS one*, 11(4), 1-14. https://doi.org/10.1371/journal.pone.0153066

Chase, T.J., Pratchett, M.S. and Hoogenboom, M.O. (2020). Behavioral trade-offs and habitat associations of coral-dwelling damselfishes (family Pomacentridae). *Marine Ecology Progress Series*, 633, 141-156. DOI: https://doi.org/10.3354/meps13167

Coker, D.J., Wilson, S.K. and Pratchett, M.S. (2014). Importance of live coral habitat for reef fishes. *Reviews in Fish Biology and Fisheries*, 24(1), 89-126. https://doi.org/10.1007/s11160-013-9319-5

Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES) (2000). Working Group on Trade in Hard Corals (Doc. AC.16.12.1). In: 16th Meeting of the CITES Animals Committee. 6-12. Shepherdstown, USA. https://cites.org/sites/default/files/eng/com/ac/16/16-12-1.pdf

Department of Meteorology (2019) Climate of Sri Lanka, Gov.lk. Available at: http://www.meteo.gov.lk/index.php?option=com_content&view=article&id=94&Itemid=31%20&lang=en&lang=en (Accessed on: June 05, 2022).

de Silva, C.S. and Nawala, N. (2009). Climate Change Effects on the North-East Monsoon and Dry Zone Agriculture in Sri Lanka. In: Proceedings of Global Climate Change and its Impacts on Agriculture, Forestry and Water in the Tropics (Nissanka, S.P., Sangakkara, U.R, Eds.), University of Peradeniya, Peradeniya, Sri Lanka, 32-39.

Dhanasundara, I. P. T. P., Thilakarathne, E. P. D. N., Dias, P. C. B., Egodauyana, K. P. U. T. and Malshani, P. K. T. (2020). Status of the Marine Ornaments Export Industry in Sri Lanka. Proceedings of the International Research Conference of Uva Wellassa University-2020, 94p.

Ekström, T. (2000). Leaching of concrete: experiments and modelling. *Report TVBM (Intern 7000-rapport)*, *7153*.

Erftemeijer, P.L. and Koch, E.W. (2001). *Sediment geology methods for seagrass habitat* (pp. 345-367). Amsterdam, the Netherlands: Elsevier Science.

Fernando, H.J.S., McCulley, J.L., Mendis, S.G. and Perera, K. (2005). Coral poaching worsens tsunami destruction in Sri Lanka. Eos, Transactions American Geophysical Union, 86(33), 301-304. https://doi.org/10.1029/2005EO330002

Fletcher, R.L. and Callow, M.E. (1992). The settlement, attachment and establishment of marine algal spores. *British phycological journal*, *27*(3), 303-329.

Greenfield, D.W. (2017). An overview of the dwarfgobies, the second most speciose coral-reef fish genus (Teleostei: Gobiidae: Eviota). *Journal of the Ocean Science Foundation*, *29*, 32-54. doi: http://dx.doi.org/10.5281/zenodo.1115683

Gopakumar, G. (2006). Culture of marine ornamental fishes with reference to production systems, feeding and nutrition. In: International seminar on ornamental fish breeding, farming and trade, Cochin. http://eprints.cmfri.org.in/8415/

Gostinčar, C., Grube, M. and Gunde-Cimerman, N. (2011). Evolution of fungal pathogens in domestic environments? *Fungal biology*, 115(10), 1008-1018. https://doi.org/10.1016/j.funbio.2011.03.004

Hein, M., Pedersen, M.F. and Sand-Jensen, K. (1995). Size-dependent nitrogen uptake in micro- and macroalgae. *Marine ecology progress series. Oldendorf*, 118(1), 247-253. doi:10.3354/meps118247

Li, Y., Zhou, W., Hu, B., Min, M., Chen, P. and Ruan, R.R. (2012). Effect of light intensity on algal biomass accumulation and biodiesel production for mixotrophic strains Chlorella kessleri and Chlorella protothecoide cultivated in highly concentrated municipal wastewater. *Biotechnology and bioengineering,* 109(9), 2222-2229. https://doi.org/10.1002/bit.24491

Moe Jr, M.A. (2003). Culture of marine ornamentals: for love, for money, and for science. In: Marine ornamental species: collection, culture and conservation. (Cato, J.C. and Brown, C.L. eds. 2008), John Wiley & Sons. 11-28.

Nurdin, S., Mustapha, M. A., & Lihan, T. (2013). The relationship between sea surface temperature and chlorophyll-a concentration in fisheries aggregation area in the archipelagic waters of Spermonde using satellite images. In: AIP Conference Proceedings (1571(1), 466-472. American Institute of Physics.

Oksanen, I. (2006). Ecological and biotechnological aspects of lichens. *Applied Microbiology and Biotechnology*, 73(4), 723-734.86. https://doi.org/10.1007/s00253-006-0611-3

Papapolymerou, G., Karayannis, V., Besios, A., Riga, A., Gougoulias, N. and Spiliotis, X. (2019). Scaling-up sustainable Chlorella vulgaris microalgal biomass cultivation from laboratory to pilot-plant photobioreactor, towards biofuel. *Global Nest Journal,* 20, 37-42. https://doi.org/10.30955/gnj.002777

Parks, J. E., Pomeroy, R. S., & Balboa, C. M. (2003). The economics of live rock and live coral aquaculture. Marine ornamental species: Collection, culture and conservation, 185-206.

Premarathna, A.D., Kumara, A.M.C.P., Jayasooriya, A.P., Jayanetti, D.E., Adhikari, R.B., Sarvananda, L. and Amarakoon, S. (2020). Distribution and diversity of seaweed species in South coastal waters in Sri Lanka. *Journal of Oceanography and Marine Research*, 7, 196. DOI: 10.35248/2572-3103.20.8.196

Rajasuriya, A., Zahir, H., Muley, E.V., Subramanian, B.R., Venkataraman, K., Wafar, M.V.M., Khan, S.M.M.H. and Whittingham, E., 2002. Status of coral reefs in South Asia: Bangladesh, India, Maldives, Sri Lanka. In *Proceedings of the Ninth International Coral Reef Symposium, Bali, 23-27 October 2000,* (Vol. 2, pp. 841-845).

Rajasuriya, A. (2009). Status of the Marine Aquarium Fishery in Galle and Matara Districts. CENARA Reports: Marine Aquarium Fishery, south coast.

Ramawickrama, N.W., Thilakarathne, E.P.D.N., Herath, H.M.T.N.B., Malshani, P.K.T. and Egodauyana, K.P.U.T. (2020). Diversity and the Current Status of Coral Reefs in Eastern Coast of Sri Lanka. Proceedings of the International Research Conference of Uva Wellassa University-2020. 217p.

Ranatunge, E., Malmgren, B. A., Hayashi, Y., Mikami, T., Morishima, W., Yokozawa, M., & Nishimori, M. (2003). Changes in the Southwest Monsoon mean daily rainfall intensity in Sri Lanka: relationship to the El Niño–Southern Oscillation. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 197(1-2), 1-14.

Shaari, F., Mustapha, M.A., Ali, M.M. and Lihan, T. (2013). Chlorophyll-a and nutrient distribution of Pahang coastal waters during southwest monsoon using satellite images. In AIP *Conference Proceedings*. 1571, 493-497. https://doi.org/10.1063/1.4858703

Shelton, S., Pushpawela, B. and Liyanage, G. (2022). The long-term trend in the diurnal temperature range over Sri Lanka from 1985 to 2017 and its association with total cloud cover and rainfall. *Journal of Atmospheric and Solar-Terrestrial Physics*, 227, 105810. https://doi.org/10.1016/j.jastp.2021.105810

Silva, E. I. L., Jennerjahn, T. C., & Ittekkot, V. (2005). Nutrient fluxes into coastal waters via Sri Lankan rivers: a comparison with other Asian rivers. *International Journal of Ecology and Environmental Sciences*, 31(1), 213-221.

Slepecky, R.A. and Starmer, W.T. (2009). Phenotypic plasticity in fungi: a review with observations on Aureobasidium pullulans. *Mycologia*, 101(6), 823-832. https://doi.org/10.3852/08-197

Smith, M.L. (1988). Effects of observer swimming speed on sample counts of temperate rocky reef fish assemblages. *Marine ecology progress series*. *Oldendorf*, 43(3), 223-231. https://doi.org/10.7717/peerj.5378

Vos, A.D., Pattiaratchi, C.B. and Wijeratne, E.M.S. (2014). Surface circulation and upwelling patterns around Sri Lanka. *Biogeosciences,* 11(20), 5909-5930. https://doi.org/10.5194/bg-11-5909-2014

Wabnitz, C. (2003). From ocean to aquarium: the global trade in marine ornamental species (No. 17). 27-51. UNEP/Earthprint.

Wyrtki, K. (1973). Physical Oceanography of the Indian Ocean. In: The Biology of the Indian Ocean (Zeitzschel, B., Gerlach, S.A. Eds.). Ecological Studies, vol 3. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-642-65468-8_3

Zar, J. H. (1999). *Biostatistical analysis*. Pearson Education India.

Zubair, L. and Ropelewski, C.F. (2006). The strengthening relationship between ENSO and northeast monsoon rainfall over Sri Lanka and southern India. *Journal of Climate*, 19(8), 1567-1575. DOI: https://doi.org/10.1175/JCLI3670.1