

Present Status of Marine Invasive Alien Species (MIAS) in selected fishery harbours of the Southern and Western coasts of Sri Lanka: Risks and Potential Management Strategies

P.B. Terney Pradeep Kumara^{1,2*}, M.M. Subasinghe¹, L.L.R.B. De Silva¹, A.J.M. Gunasekara¹

¹ Marine Environment Protection Authority, No.177, Nawala Road, Colombo 05, Sri Lanka

² Department of Oceanography, Faculty of Fisheries and Marine Sciences, University of Ruhuna, Wellamadama, Matara, Sri Lanka.

ABSTRACT

Marine Invasive Alien Species (MIAS) threaten biodiversity, human health and marine industries such as fisheries and tourism. The introduction of alien species from fisheries activities specially through multiday fishing boats, fishing equipment and by catch are poorly studied from Sri Lanka. This study was carried out from March to May 2016, and aimed to investigate the presence of globally known MIAS in Dickovita, Beruwala and Hikkaduwa fishery harbours and adjacent areas in the Southern and Western provinces of Sri Lanka. Phytoplankton, zoo plankton, mobile fauna and sessile fauna were collected through standard sampling procedures and identified as far as possible. Potential pathways and vectors were identified to understand the risks from fishing boats and gears. Six globally known invasive species, all of which were sessile organisms were recorded. They comprised of two oyster species; American cupped oyster (*Crassostrea virginica*), Hooded oyster (*Saccostrea cucullata*), two barnacle species; Australian acorn barnacles (*Eliminus modestus*), Goose neck Barnacle (*Lepas anatifera*), one mollusk species; common periwinkle (*Littorina littorea*) and one algae species; Killer algae (*Caulerpa taxifolia*). It was concluded that the most common and probable pathway for these introductions is hull fouling of multiday fishing vessels. In Sri Lanka *Crassostrea virginica* and *Saccostrea cucullata* are considered as highly potential mariculture species with considerable economic benefits although they are globally known as invasive species. This study provides recommendations on methods of management of hull fouling for the removal of marine invaders.

Key Words: Fishery harbours, Hull fouling, Marine Invasive Alien Species, Sri Lanka

INTRODUCTION

Species which have been transferred outside of its natural geographic range are commonly known as alien or non-native or non-indigenous species. These species are moved intentionally or unintentionally beyond their natural range. Introductions of such species are rising sharply because of increased trade, transport, travel and tourism associated with globalization (IMO, 2010). This situation also provides vectors and pathways for live plants, animals and biological material to cross bio geographical barriers that would usually block their way (Reise et al., 1999).

Marine Invasive Alien Species (MIAS) are recognized as one of the largest threats to global biodiversity. They have transformed marine habitat around the world (Ruiz et al 2000). Ever since people began travelling in ships, they have inadvertently carried “pests” with them, including diseases, rats and largely unnoticed marine organisms. Historical records and studies on modern replicas indicate that wooden sailing ships were often heavily encrusted with fouling organisms (Bax et al., 2003). Many alien species are transferred into marine ecosystems through the ballast water transported during commercial shipping operations and hull fouling (Bax et al., 2003, Carlton, 1999). Anthropogenic vectors for marine invasions other than ballast water and hull fouling include dry and semi-dry ballast, aquaculture and fisheries activities such as intentional release for stock enhancement, unintentional introductions associated with the importation of mariculture species, deliberate introductions of exotic species for mariculture, aquarium trade activities such as intentional or unintentional release of aquatic fauna or flora, recreational water users, and the oil, gas and construction industries (Nicholas et al., 2003; Campbell 1999). Few studies have investigated small boats as vectors of secondary dispersal of invasive species in the marine environment (Darbyson et al., 2009).

Sri Lanka is strategically located in the Indian Ocean close to the path of major sea routes. The world’s busiest international shipping lanes (Sea Lines Of Communications (SLOC’s) as popularly known by seafarers) pass through the Southern coast of Sri Lanka only 5 nautical miles from land and this geographical position has provided ample opportunities to make Sri Lanka an Asian maritime hub. With enhanced shipping activities Sri Lanka will be more prone to contamination by bio fouling organisms and non-native species carried by ship’s ballast water. In addition, multiday boats roaming widely within and beyond the Exclusive Economic Zone (EEZ) of Sri Lanka are likely vectors of secondary dispersal of marine invasive species.

Fishery harbours are more prone to contaminated with MIAS especially by means of fishing crafts and gears. Sri Lanka has 22 major fishery harbours and most of them receive returning multiday boats from distant corners of the Indian Ocean becoming ideal candidates to carry MIAS to Sri Lankan waters, through fouling organisms on hulls. Harbours located on the Southern and Western coast are more susceptible compared to other areas of the country as they cater to higher numbers of multi-day fishing boats. Based on this assumption three fishery harbours of the country were selected for this study to determine the present status and possible risks from MIAS to Sri Lankan marine environment.

METHODOLOGY

2.1 Study Site

Three sites were the fishery harbours of Dickovita, Beruwala and Hikkaduwa and their adjacent areas along the Southern and Western coast of the Sri Lanka during the period of March to May 2016. The sampling sites along the Southern and Western coast of the Sri Lanka are shown in Figure 1.

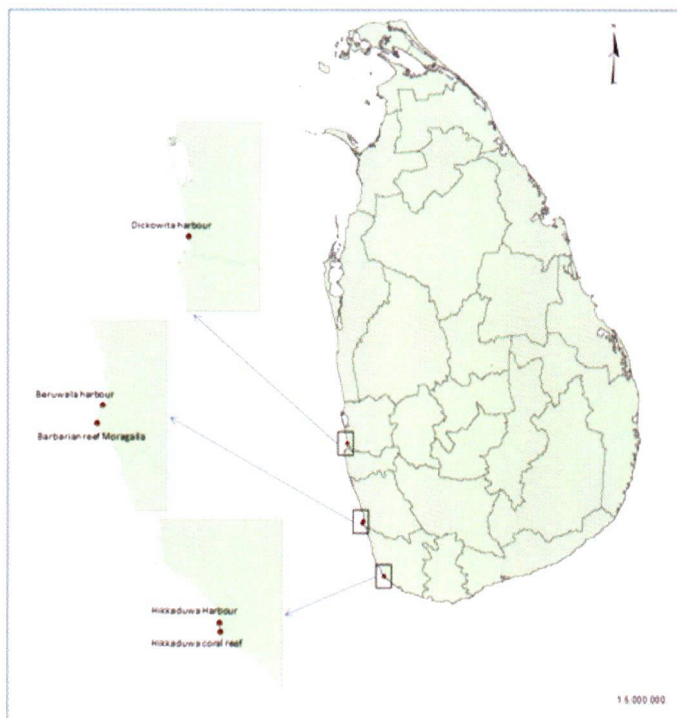


Figure 1: Sampling sites along the Southern and Western coast of the Sri Lanka

2.2 Sample collection and analysis

Sampling was carried out from different locations of each harbour such as piles, banks, submerged structures, breakwaters and rock-wall facings, rocky surfaces, floating devices and boat hulls. Samples from deep areas were collected using Self-Contained Underwater Breathing Apparatus (SCUBA) divers. All the samples were collected from three different depths (0.5 m from the surface of water, $\frac{1}{2}$ of the depth and close to the bottom). Hard substrate organisms (fouling species), phytoplankton, zoo plankton and mobile and sessile fauna were collected randomly using a long armed fabricated scraper.

For each depth level, separate fouling samples were collected for qualitative analysis. All samples were packed in plastic bottles and plastic bags and preserved in 70% alcohol for further laboratory analysis. Specimens were identified to the nearest possible taxonomic level using standard identification guides, keys and available online resources. Direct visual observations and photographic evidence was made in the shallow areas for identification of both mobile and sessile fauna. Qualitative data were collected by underwater visual census through snorkelling and SCUBA diving coupled with underwater photography. In addition techniques such as baited traps and cast nets were also used.

Phytoplankton samples were collected using a plankton net of 20 μm mesh sizes and were preserved in Lugol's solution as per Parsons et al 1984. Phytoplankton identification was conducted to the highest possible taxonomic level using standard available guides and keys

(Newell and Newell 1963; Todd et al, 1991; Jayasiri 2009). A 100 μm mesh size net was towed to collect zooplankton samples and samples preserved in 5% formalin as per Parsons et al., 1984, Goswami 2004 for laboratory analysis and identification (Figure 2).



Figure 2: Sampling of zooplankton and phytoplankton and preserving

RESULTS

Eighty one marine species from Dickovita fishery harbour, 82 species from Beruwala fishery harbor and 60 species from Hikkaduwa fishery harbor were recorded. Twenty three zooplankton, 22 phytoplankton, 14 fish species, 2 invertebrates, 16 zoo bio-foulers and 4 phyto bio-foulers from Dickovita Fishery harbor, Twenty five zooplankton, 17 phytoplankton, 8 fish species, 4 invertebrates, 21 zoo bio-foulers and 7 phyto bio-foulers from Beruwala fishery harbor and Fourteen zooplankton, 19 phytoplankton, 10 fish species, 2 invertebrates, 9 zoo bio-foulers and 6 phyto bio-foulers from Hikkaduwa fishery harbour were recorded (Figure 3).

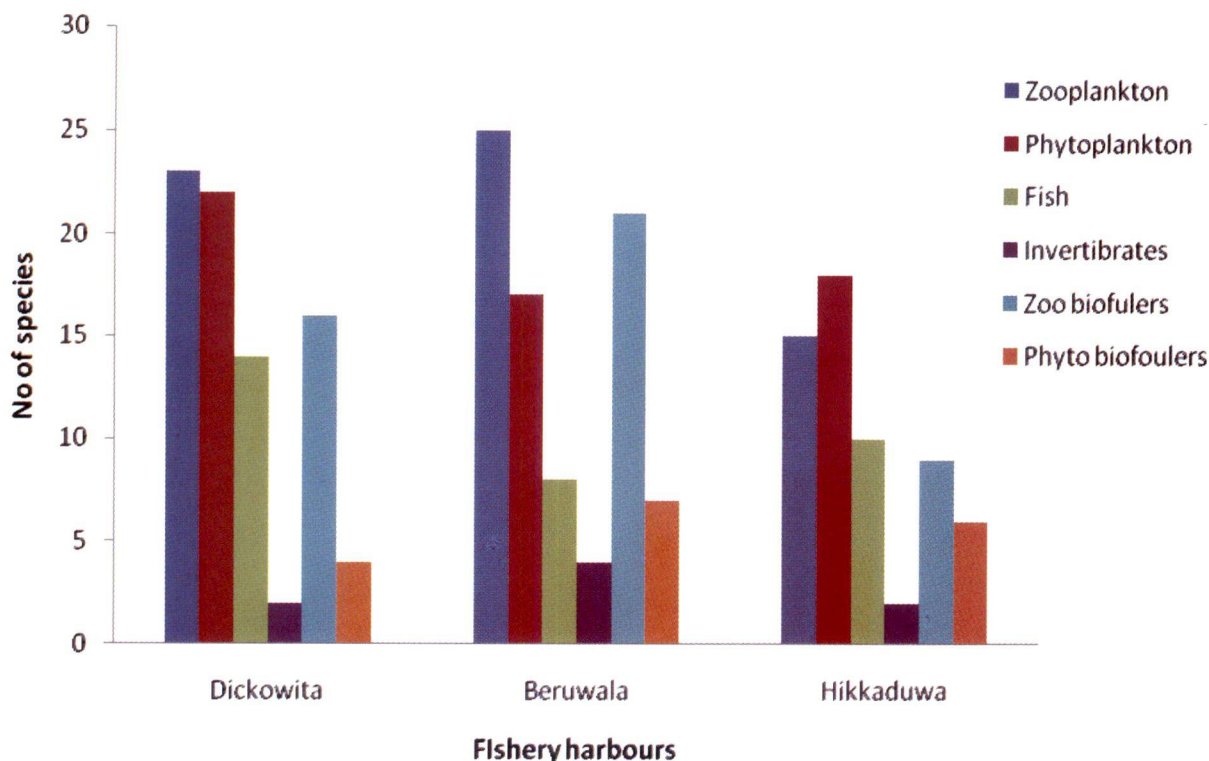


Figure 3: Number of recorded different types of species in fishery harbours of Dickovita, Beruwala and Hikkaduwa

3.1 Species diversity in Dickovita fishery harbour

Twenty three (23) zooplanktons categorized according to phyla Chordata, Echinodermata, Mollusca, Arthropoda, Annelida, Cnidaria, Protozoa and Chaetognatha and twenty two (22) phytoplanktons belonging to Phylum Ochrophyta and Phylum Myxozoa and fourteen (14) species of fish belonging to 9 families were recorded. Of them, 5 species are listed under the Least Concern (LC) category in the IUCN Red List of Threatened Species (IUCN 2012). Under the macro invertebrate category two crab species (Phylum: Arthropoda; Class: Malacostraca; Order: Decapoda; Family: Menippidae, Species: *Menippe rumphii* and one unidentified crab species were recorded.

A total of 20 bio fouling organisms was recorded from Dickowita harbour. Among them were 15 mollusk species, 4 algal species and one species of arthropod. Out of the mollusk species, *Modiolus modiolus* and *Saccostrea sp.* were the most commonly occurring biofouling organisms as they were observed from many sampling sites as large, monospecific aggregations. The only barnacle species, *Balanus perforates* found in the Dickovita fishery harbour and its adjacent areas was the most dominant organisms recorded on hard substrates of this site.

Out of the recorded 15 mollusk species, *Crassostrea virginica* was identified as a globally known invasive species and the algae *Caulerpa taxifolia* (Killer algae) recorded from shallow rock surfaces belonging to Family Caulerpaceae lists as a global invasive species (GISD, 2005).

3.2 Species diversity in Beruwala fishery harbour

Twenty five (25) species of zooplanktons belonging to 8 phyla: Arthropoda, Chordata, Mollusca, Chaetognatha, Cnidaria, Annelida, Protozoa and Echinodermata were recorded. Seventeen (17) phytoplanktons belonging to 3 phyla: Rhodophyta, Ochrophyta and Myzozoa and 12 families; 8 fish species belonging to families: Monodactylidae, Carangidae, Haemulidae, Leiognathidae and Tetraodontidae and four invertebrates were recorded from the area. One mollusc was categorized under Family Lolinidae and three crab species were identified and their taxonomy could not be identified to species level.

A total of 28 bio fouling organisms were recorded from Beruwala fishery harbor during the study period. Among them were, 21 zoo and 7 phyto bio-foulers. It also included 17 species of mollusks, 4 species of barnacles, and 7 species of algae. Among the recorded species *Balanus sp.* and *Saccostrea sp.* were the most commonly found biofouling organisms in large aggregations. Two of them, *Austrominius modestus* (Australian Acorn Barnacle) and *Lepas anatifera* (Goose Barnacles) are globally known invasive species. The algae *Caulerpa taxifolia* (Killer algae) were also recorded as a globally known marine algal invasive species.

3.3 Species diversity in Hikkaduwa fishery harbour

Fourteen (14) zooplanktons belonging to 4 phyla: Arthropoda, Mollusca, Annelida and Protozoa and nineteen (19) phytoplanktons belonging to two phyla: Ochrophyta and Myzozoa were recorded for this study along with 10 species of fish belonging to seven families: Acanthuridae, Apogonidae, Chaetodontidae, Labridae, Lutjanidae, Pomacentridae and Zaclidae. Two unidentified sponge species were recorded from a floating rope.

Fifteen biofoulers were recorded during the study period from Hikkaduwa fishery harbor including nine zoo biofoulers and six phyto biofoulers. Out of the nine zoo bio-foulers 8 were mollusks while the remaining one was a barnacle *Chthamalus montagui* (Star Barnacle). Out of eight mollusk species, two were bivalves and the other six were gastropods belonging to two families. Six species of phyto bio-foulers were recorded belonging to three phyla, Chlorophyta, Ochrophyta and Rhodophyta. *Padina sp.* and *Sargassum crassifolium* were the dominance phyto bio-foulers. Globally Known MIAS *Caulerpa taxifolia* species was found among other chlorophyta species. A single species of barnacle, *Saccostrea cucullata* was the most commonly found fouling organism, occurring in large aggregations at most of the sampling sites.

The recorded zooplankton, phytoplankton, fish, molluscs, barnacles and algae species in each harbour is listed in Table 1, Table 2, Table 3, Table 4, Table 5 and Table 6 respectively.

Table 1 : Zooplankton species recorded during the survey

Phylum	Class	Order	Family	Species	Remarks	Dickowita	Beruwala	Hikkaduwa
Echinodermata	Asteroidea	Forcipulatida	Asteriidae	<i>Asterias sp:</i>		✓	✓	
Athropoda	Crustacea	Calanoida	Calanidae	<i>Calanus sp:</i>		✓	✓	✓
Athropoda	Crustacea	Harpacticoida		-		✓	✓	✓
Athropoda	Crustacea	Cyclopoida		-		✓	✓	✓
Athropoda	Crustacea	Decapoda	Carcinidae	<i>Carcinus maenas</i>		✓	✓	
Athropoda	Crustacea	Decapoda	-	-			✓	
Athropoda	Crustacea	Mysidacea	-	-			✓	
Athropoda	Crustacea	Mysidacea	-	-	<i>Branchyurans larvae</i>		✓	
Athropoda	Crustacea	Calanoida	Centropagidae	<i>Centropages elongatus</i>		✓	✓	✓
Athropoda	Crustacea	Calanoida	Clausocalanidae	<i>Pseudocalanus sp:</i>		✓	✓	✓
Athropoda	Crustacea	-	-	-	<i>Nauplii</i>	✓	✓	✓
Athropoda	Crustacea	-	-	-	<i>Nauplii</i>	✓	✓	✓
Athropoda	Crustacea	Onchypoda	Podonidae	<i>Evadne nordmanni</i>		✓		✓
Athropoda	Crustacea	Cumacea	Poybiidae	<i>Necora puber</i>		✓		
Mollusca	Gastropoda	Littorinimorpha	Gastropods	-	<i>Veliger Larvae (Protoconch)</i>	✓	✓	✓
Cnidaria	Hydrozoa	Siphonophorae	-	<i>Muggiaea atlantica</i>		✓	✓	
Cnidaria	Hydrozoa	Siphonophorae	-	<i>Aglantha digitale</i>			✓	

Cnidaria	Hydrozoa	Limnomedusae	-	-		✓		
Chordata	Appendicularia	Copelata	Oikopleuridae	<i>Oikopleura sp.</i>		✓	✓	
Echinodermata	Ophiuroidea	-	-	-	<i>Ophiopluteus larvae</i>	✓	✓	
Mollusca	Pelicyoda		-	-	<i>Veliger larvae of Bivalv</i>	✓	✓	✓
Annelida	Polychaeta	-	-	-	<i>Polychaeta larvae</i>	✓	✓	✓
Annelida	Polychaeta	-	-	-	<i>Setiger larvae</i>	✓	✓	
Annelida	Polychaeta	Phyllodocida	Syllidae	<i>Autolytus edwardsi</i>			✓	
Annelida	Polychaeta	Phyllodocida	Tomopteridae	<i>Tompteri helgolandica</i>		✓		✓
Chaetognatha	Sagittoidea	Aphragmophora	Sagittidae	<i>Sagitta sp.</i>		✓	✓	
Protozoa	-	Tintinidae		-		✓	✓	✓
Protozoa	-	Foraminifera		-		✓	✓	✓
Protozoa	-	Radiolaria	-	-			✓	
Total Number of species						23	25	14

Table 2 : Phytoplankton species recorded during the survey

Phylum	Class	Order	Family	Species	Dickowita	Beruwala	Hikkaduwa
Ochrophyta	Bacillariophyceae	Bacillariales	Bacillariaceae	<i>Cylindrotheca sp:</i>	✓		
Myzozoa	Dinophyceae	Gonyaulacales	Ceratiaceae	<i>Ceratium furca</i>	✓	✓	✓
Myzozoa	Dinophyceae	Gonyaulacales	Ceratiaceae	<i>Ceratium tripos</i>	✓	✓	✓
Myzozoa	Dinophyceae	Gonyaulacales	Ceratiaceae	<i>Ceratium lunula</i>	✓		
Myzozoa	Dinophyceae	Gonyaulacales	Ceratiaceae	<i>Ceratium fusus</i>	✓	✓	✓
Myzozoa	Dinophyceae	Gonyaulacales	Ceratiaceae	<i>Ceratium horrdum</i>	✓	✓	✓
Ochrophyta	Bacillariophyceae	Chaetocerotanae incertae sedis	Chaetocerotaceae	<i>Bacteriastrum sp:</i>	✓		✓
Ochrophyta	Bacillariophyceae	Chaetocerotanae incertae sedis	Chaetocerotaceae	<i>Chaetoceros sp:</i>	✓	✓	✓
Ochrophyta	Bacillariophyceae	Coscinodiscales	Coscinodiscaceae	<i>Coscinodiscus sp:</i>	✓	✓	✓
Ochrophyta	Bacillariophyceae	Frangilariales	Fragilariaceae	<i>Fragilaria sp:</i>	✓	✓	✓
Ochrophyta	Bacillariophyceae	Hemiaulales	Hemiaulaceae	<i>Cerataulina sp:</i>	✓		
Ochrophyta	Bacillariophyceae	Leptocylindrales	Leptocylindraceae	<i>Leptocylindricus sp:</i>	✓		✓
Ochrophyta	Bacillariophyceae	Melosiraceae	Melosiraceae	<i>Melosira sp:</i>		✓	
Ochrophyta	Bacillariophyceae	Naviculales	Naviculaceae	<i>Navicula sp:</i>	✓	✓	✓
Myzozoa	Dinophyceae	Peridinales	Peridiniaceae	<i>Peridinium sp:</i>	✓	✓	✓
Ochrophyta	Bacillariophyceae	Naviculales	Pleurosigmataceae	<i>Pleurosigma sp:</i>	✓	✓	✓
Myzozoa	Dinophyceae	Prorocentrales	Prorocentraceae	<i>Prorocentrum sp:</i>	✓	✓	✓
Ochrophyta	Bacillariophyceae	Rhizosolaniales	Rhizosoleniaceae	<i>Guinardia sp:</i>	✓	✓	✓

Ochrophyta	Bacillariophyceae	Rhizosolaniales	Rhizosoleniaceae	<i>Rhizosolenia sp:</i>	✓	✓	✓
Ochrophyta	Bacillariophyceae	Rhizosolaniales	Rhizosoleniaceae	<i>Leptocylicndricus sp:</i>		✓	✓
Ochrophyta	Bacillariophyceae	Thalassionematales	Thalassionemataceae	<i>Thalassionema sp:</i>	✓	✓	✓
Ochrophyta	Bacillariophyceae	Thalassiosirales	Thalassiosiraceae	<i>Thalassiosira sp:</i>	✓		✓
Ochrophyta	Bacillariophyceae	Triceratiales	Triceratiaceae	<i>Odontella sp:</i>	✓		
Ochrophyta	Bacillariophyceae	Triceratiales	Triceratiaceae	<i>Triceratium sp:</i>	✓	✓	✓
Total number of species					22	16	19

Table 3 : Fish species recorded during the survey

Phylum	Class	Order	Family	Species	Dickowita	Beruwala	Hikkaduwa
Chordata	Actinopterygii	Perciformes	Acanthuridae	<i>Acanthurus lineatus</i>			✓
Chordata	Actinopterygii	Perciformes	Acanthuridae	<i>Acanthurus spp.</i>			✓
Chordata	Actinopterygii	Perciformes	Apogonidae	<i>Apogon nigrofasciatus</i>			✓
Chordata	Actinopterygii	Perciformes	Carangidae	<i>Caranx sexfasciatus</i>	✓	✓	
Chordata	Actinopterygii	Perciformes	Carangidae	<i>Caranx ignobilis</i>	✓	✓	
Chordata	Actinopterygii	Perciformes	Carangidae	<i>Carangoides gymnostethus</i>	✓		
Chordata	Actinopterygii	Perciformes	Carangidae	<i>Gnathanodon speciosus</i>		✓	
Chordata	Actinopterygii	Perciformes	Chaetodontidae	<i>Chaetodon decussatus</i>			✓
Chordata	Actinopterygii	Perciformes	Haemulidae	<i>Pomadasys guoraca</i>	✓		
Chordata	Actinopterygii	Perciformes	Haemulidae	<i>Pomadasys furcatus</i>		✓	

Chordata	Actinopterygii	Perciformes	Labridae	<i>Thalassoma</i> spp.			✓
Chordata	Actinopterygii	Perciformes	Leiognathidae	<i>Leiognathus</i> spp.		✓	
Chordata	Actinopterygii	Perciformes	Leiognathidae	<i>Leiognathidae insidiator</i>		✓	
Chordata	Actinopterygii	Perciformes	Lutjanidae	<i>Lutjanus gibbus</i>	✓		
Chordata	Actinopterygii	Perciformes	Lutjanidae	<i>Lutjanus fulviflamma</i>	✓		✓
Chordata	Actinopterygii	Perciformes	Lutjanidae	<i>Pristipomoides typus</i>	✓		
Chordata	Actinopterygii	Perciformes	Lutjanidae	<i>Lutjanus biguttatus</i>			✓
Chordata	Actinopterygii	Perciformes	Monodactylidae	<i>Monodactylus argenteus</i>	✓	✓	
Chordata	Actinopterygii	Perciformes	Mugilidae	<i>Mugil cephalus</i>	✓		
Chordata	Actinopterygii	Perciformes	Pomacentridae	<i>Abudefduf vaigiensis</i>	✓		✓
Chordata	Actinopterygii	Perciformes	Pomacanthidae	<i>Pomacanthus annularis</i>	✓		
Chordata	Actinopterygii	Perciformes	Pomacentridae	<i>Abudefduf bengalensis</i>			✓
Chordata	Actinopterygii	Perciformes	Scaridae	<i>Scarus russelli</i>	✓		
Chordata	Actinopterygii	Scorpaeniformes	Scorpaenidae	<i>Pterois</i> spp.	✓		
Chordata	Actinopterygii	Perciformes	Serranidae	<i>Cephalopholis formosa</i>	✓		
Chordata	Actinopterygii	Tetraodontiformes	Tetraodontidae	<i>Arothron hispidus</i>		✓	
Chordata	Actinopterygii	Perciformes	Zanclidae	<i>Zanclus cornutus</i>			✓
Total number of species					14	8	10

Table 4 : Mollusc species recorded during the survey

Phylum	Class	Order	Family	Species	Dickowita	Beruwala	Hikkaduwa
Mollusca	Bivalvia	Pterioida	Anomiidae	<i>Anomia ephippium</i>	✓		
Mollusca	Bivalvia	Arcoida	Arcidae	<i>Ark</i> spp.	✓		
Mollusca	Gastropoda	Caenogastropoda	Cerithiidae	<i>Clypeomorus</i> sp.	✓		
Mollusca	Gastropoda	Caenogastropoda	Cerithiidae	<i>Perpura persica</i>		✓	✓
Mollusca	Gastropoda	Caenogastropoda	Cerithiidae	<i>Clypeomorus batillariaeformis</i>	✓		
Mollusca	Gastropoda	Littorinimorpha	Cypraeidae	<i>Melicerona felina</i>		✓	
Mollusca	Gastropoda	Littorinimorpha	Fissurellidae	<i>Clypidina notata</i>		✓	✓
Mollusca	Gastropoda	Littorinimorpha	Hipponicidae	<i>Sabia conica</i> (<i>Hipponix conicus</i>)			✓
Mollusca	Gastropoda	Littorinimorpha	Littorinidae	<i>Nodilittorina quadricincta</i>		✓	
Mollusca	Gastropoda	Littorinimorpha	Littorinidae	<i>Littoraria intermedia</i>		✓	
Mollusca	Gastropoda	Littorinimorpha	Littorinidae	<i>Littorina littorea</i>		✓	
Mollusca	Gastropoda	Littorinimorpha	Littorinidae	<i>Littoraria undulata</i>		✓	
Mollusca	Gastropoda	Littorinimorpha	Lottiidae	<i>Patelloida sriata</i>		✓	
Mollusca	Gastropoda	Neogastropoda	Muricidae	<i>Drupella margariticola</i>	✓	✓	
Mollusca	Gastropoda	Neogastropoda	Muricidae	<i>Thais tissoti</i> (<i>Semiricinulatissoti</i>)	✓	✓	
Mollusca	Gastropoda	Neogastropoda	Muricidae	<i>Perfura bufo</i>		✓	
Mollusca	Gastropoda	Neogastropoda	Muricidae	<i>Tenguella granullata</i>			✓
Mollusca	Bivalvia	Mytilida	Mytilidae	<i>Modiolus modiolus</i>	✓	✓	
Mollusca	Bivalvia	Mytilida	Mytilidae	<i>Brachidontes variabilis</i>	✓		
Mollusca	Bivalvia	Mytilida	Mytilidae	<i>Septifer bilocularis</i>	✓	✓	✓
Mollusca	Gastropoda	Archaeogastropoda	Nacellidae	<i>Cellana rota</i>	✓	✓	✓
Mollusca	Bivalvia	Ostreida	Ostreidae	<i>Saccostrea scyphophilla</i>	✓	✓	
Mollusca	Bivalvia	Ostreida	Ostreidae	<i>Saccostrea cucullata</i>	✓	✓	✓

Mollusca	Bivalvia	Ostreida	Ostreidae	<i>Crassostrea virginica</i>	✓		
Mollusca	Bivalvia	Ostreida	Ostreidae	<i>Morula serrialis</i>		✓	
Mollusca	Gastropoda	Caenogastropoda	Potamididae	<i>Pirenella cingulata</i>	✓		
Mollusca	Gastropoda	Neogastropoda	Rapaninae	<i>Mancinella alouina</i>	✓		
Mollusca	Gastropoda	Pulmonata	Siphonariidae	<i>Siphonaria acmaeoides</i>			✓
Total number of species					15	17	8

Table 4 : Barnacle species recorded during the survey

Phylum	Class	Order	Family	Species	Dickowita	Beruwala	Hikkaduwa
Arthropoda	Maxillopoda	Sessilia	Austrobalanidae	Austrominius modestus/Eliminus modestus		✓	
Arthropoda	Maxillopoda	Sessilia	Balanidae	<i>Balanus perforates</i>	✓		
Arthropoda	Maxillopoda	Sessilia	Balanidae	<i>Balanus crenatus</i>		✓	
Arthropoda	Maxillopoda	Sessilia	Balanidae	<i>Balanus balanus</i>		✓	
Arthropoda	Maxillopoda	Sessilia	Chthamalidae	<i>Chthamalus montagui</i>			✓
Arthropoda	Maxillopoda	Lepadiformes	Lepadidae	<i>Lepas anatifera</i>		✓	
Total number of species					1	4	1

Table 5 : Algae species recorded during the survey

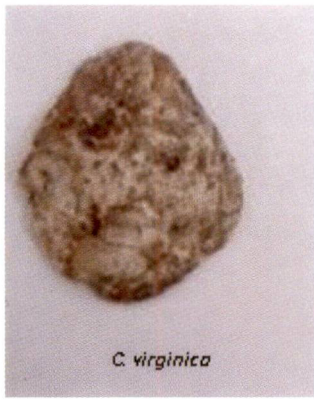
Phylum	Class	Order	Family	Species	Dickowita	Beruwala	Hikkaduwa
Chlorophyta	Ulvophyceae	Bryopsidales	Caulerpaceae	<i>Caulerpa racemosa</i> var <i>racemosa</i>		✓	
Chlorophyta	Ulvophyceae	Bryopsidales	Caulerpaceae	<i>Caulerpa peltata</i>			✓
Chlorophyta	Ulvophyceae	Bryopsidales	Caulerpaceae	<i>Caulerpa taxifolia</i>	✓	✓	✓
Rhodophyta	Florideophyceae	Ceramiales	Ceramaceae	<i>Centroceras</i> sp.		✓	
Chlorophyta	Ulvophyceae	Cladophorales	Cladophoraceae	<i>Rhizoclonium africanum</i>		✓	
Chlorophyta	Ulvophyceae	Cladophorales	Cladophoraceae	<i>Chaetomorpha</i> sp.		✓	
Ochrophyta	Phaeophyceae	Dictyotales	Dictyotaceae	<i>Dictyota ciliolata</i>	✓		
Ochrophyta	Phaeophyceae	Dictyotales	Dictyotaceae	<i>Padina minor</i>	✓		
Ochrophyta	Phaeophyceae	Dictyotales	Dictyotaceae	<i>Padina antillarum</i>			✓
Rhodophyta	Florideophyceae	Nemaliales	Galaxauraceae	<i>Galaxaura rugosa</i>			✓
Rhodophyta	Florideophyceae	Gracilariales	Gracilariaceae	<i>Gracilaria corticata</i>	✓		
Chlorophyta	Ulvophyceae	Bryopsidales	Halimedaceae	<i>Halimeda opuntia</i>			✓
Ochrophyta	Phaeophyceae	Fucales	Sargassaceae	<i>Sargassum crassifolium</i>			✓
Chlorophyta	Ulvophyceae	Ulvaes	Ulvaceae	<i>Ulva lactuca</i> (<i>Ulvafasciata</i>)		✓	
Chlorophyta	Ulvophyceae	Ulvaes	Ulvaceae	<i>Ulva compressa</i>		✓	
Total number of species					4	7	6

DISCUSSION

Six globally known MIAS were found during this study and all of them were biofoulers on hard substrates. Two oyster species (Family:Ostreidae), two barnacle species (families Austrobalanidae and Lepadidae),one mollusk species (Gastropoda) belonging to Family Littorinidae and one algae species belonging to Family Caulerpacae.were the identified globally known invasive species (Figure 4). More details of the recorded MIAS are shown in Table 4.

Table 4: Globally listed invasive alien species recorded in Sri Lanka

Species	Common name	Recoded site	Possible vector	Reference
<i>Crassostrea virginica</i>	American cupped Oyster	Dikovita	Ships/ Vessels hull fouling	Invasive Species Compendium of www.cabi.org
<i>Saccostrea cucullata</i>	Hooded oyster	Dikowita , Hikkaduwa		Invasive Species Compendium of www.cabi.org
<i>Austrominius modestus/</i> <i>Eliminus modestus</i>	Australian acorn barnacles	Beruwala	Ships/ Vessels hull fouling	Global Invasive Species Database, Invasive Species Compendium of www.cabi.org NOBANIS- Marine invasive species in Nordic waters - Fact Sheet
<i>Lepas anatifera</i>	Goose neck Barnacles	Beruwala	Floating devices Ships/ Vessels hull fouling	NOBANIS – Invasive Alien Species Fact Sheet – www.nobanis.org
<i>Littorina littorea</i>	Common periwinkle	Beruwala	Ships/ Vessels hull fouling	Global Invasive Species Database, Invasive Species Compendium of www.cabi.org
<i>Caulerpa taxifolia</i>	Killer algae	All harbours	Native to Indian Ocean	Global Invasive Species Database

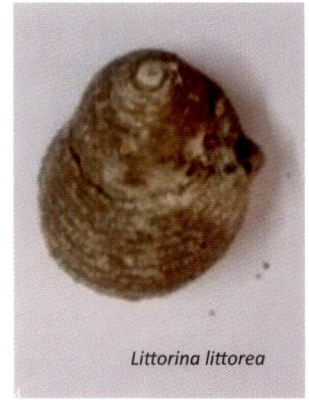


C. virginica

(a)



(b)



Littorina littorea

(c)

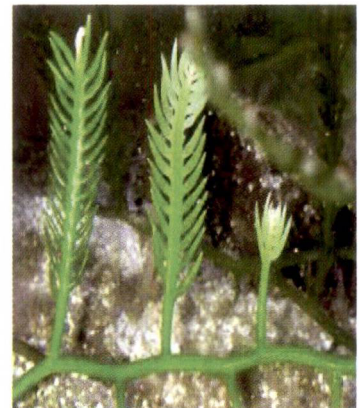


(d)



Saccostrea cucullata

(e)



(f)

Figure 4: Recorded Globally Known Invasive Alien Species during the study (a) *Crassostrea virginica* (b) *Lepas anatifera* (c) *Littorina littorea* (d) *Eliminus modestus* (e) *Saccostrea cucullata* (f) *Caulerpa taxifolia*

All MIAS recorded from this study are possible contaminants through fouling of ships and boats. *Crassostrea virginica* (American Cupped Oyster) naturally occurs in the Gulf of St. Lawrence, Canada, along the Atlantic coast of the United States to the Gulf of Mexico to the Yucatan Peninsula, Mexico and to the West Indies and the coast of Brazil and has been introduced into many non-native areas, but there are no data to support invasiveness (NOAA, 2005). *Austrominius modestus* / *Eliminus modestus* (Australian Acorn Barnacle) is native to Australia. It was first seen in British waters, in Chichester Harbour, during the Second World War (NOBANIS, 2010). It was believed to have arrived on the hulls of ships, or possibly the larval stages travelled in bilge water (NOBANIS, 2010). However, ballast and bilge waters were not sampled during this study restricting the exploration of possible pathway and vector specific details of the introduction to Sri Lanka waters. *Lepas anatifera* (Goose neck barnacle) was found, often in large numbers. They attached by their flexible stalks into floating timber, hulls of fishing vessels, ships, piers, pilings, seaweed and various sorts of flotsam and known to disperse long distances. This is a cryptogenic species with unknown area of origin and common

in warmer waters of subtropical and tropical seas. During this study, *L. anatifera* was recorded from the hulls of multiday boats coming from the Andaman Islands in the Eastern Indian Ocean.

Invasive Species Compendium (www.cabi.org) has categorized *Saccostrea cucullata* as an invasive species. But this oyster species is known to be native to the Indian Ocean and tropical West Pacific Ocean. It is also found in Australia, New Zealand, Red Sea and favours rocky habitats in the intertidal zone, and is part of the fouling community and is found on harbour walls, pilings, and other underwater structures (Mitra and Choudhury, 1993). In India, it is one of the most commercially exploited oyster species. *Littorina littorea* (Common Periwinkle) is native to the Northeastern coasts of the Atlantic Ocean, including Northern Spain, France, England, Scotland, Ireland, Scandinavia, and Russia (Benson, 2008). They have been introduced to North America by rock ballast in the mid 19th century and are invasive in North America with a current range from Red Bay, Labrador, to Lewes, Delaware (Chapman et al., 2007).

Caulerpa taxifolia (Killer Algae) is green algae. It is widespread in tropical habitats and its Mediterranean clone may have originated in Australia. An invasive strain of this alga occurs in the Mediterranean, California, Japan, Australia, and Monaco regions. The species were spread widely through the aquarium trade, was unintentionally introduced into the Mediterranean in 1984 and has since spread from Cyprus to Spain and even into the Canary Islands (Verlaque et al., 2004). This species is considered as habitat modifier and ecosystem engineer (Klein & Verlaque 2008) and forms compact multilayered mats forming 'web-like green meadow' contributing to large-scale landscape modification, even in highly diverse, native macroalgal assemblages with dense coverage (Piazzi et al 2001, Piazzi et al 2003). Further, the most potent of its repellent endotoxins, Caulerpenyne, is toxic to molluscs, sea urchins, herbivorous fish, at least during summer and autumn when metabolite-production peaks. *Caulerpa taxifolia* is associated with reduction of species diversity and richness of native hard substrate algae and, under certain conditions, out competes *Cymodocea nodosa* and *Posidonia oceanica* (Villele et.al., 1995, Ceccherelli et al., 1999). However, it is known that *Caulerpa taxifolia* is native to the Indian and Pacific Oceans and therefore its invasiveness in Sri Lankan water has to be further studied. Tropical invasive algae such as *Gracilaria*, *Hypnea*, and *Sargassum* are widely available in Sri Lankan waters and need further investigation for better understanding their current status and threats to other organisms.

Although all of the above species are listed as globally known invasive species, we could not find sufficient evidence to confirm their introduction pathways and level of invasiveness during the current study. In addition to that, there is no baseline information on the indigenous or endemic marine species of Sri Lanka, which prevented the comparison of current findings to previous records. In addition to shipping activities, other processes such as trans-boundary circulation of floating debris through water currents contributes to the introduction of alien invasive species into new marine environments. The possible pathways and potential management strategies the MIAS recorded for this study are provided in Table 5.

Table 5: Possible pathways and Potential management strategies

Species	Pathways	Vectors	Management information
<i>Crassostrea virginica</i>	Shipping/Fishery	Hull fouling	Manual removal Use as a Food source Use as an animal feed Use as a Fertilizer
<i>Saccostrea cucullata</i>	Shipping/Fishery	Hull fouling	Manual removal Use as a Food source Use as an animal feed Use as a Fertilizer
<i>Eliminus modestus</i>	Shipping/Fishery As epifauna on shellfish Floating debris	Hull fouling Fishing gears Discarded plastic debris	Manual removal Scraping of hulls and fishing gears
<i>Lepas anatifera</i>	Shipping/Fishery As epifauna on shellfish Floating debris	Hull fouling Fishing gears Discarded plastic debris	Manual removal Scraping of hulls and fishing gears
<i>Littorina littorea</i>	Shipping/Fishery	Hull fouling	Manual removal Biocides Introduction of bio-control agents
<i>Caulerpa taxifolia</i>	As epifauna on shellfish Floating debris	Hull fouling Fishing gears Discarded plastic debris	Manual removal Use as an animal feed Use as a Fertilizer Introduction of bio-control agents

CONCLUSIONS

The findings of this study show that there were six non indigenous species (3 bivalve species, 2 cryptogenic barnacle species and 01 algae species) that are globally known as MIAS. However, it is very likely that a common and most probable pathway for the MIAS are multiday fishing routes while the most common vector is the hull fouling. In Sri Lanka, the only available management actions for the above recorded species are manual removal by scraping from boat hulls and disposing the scrapped materials using appropriate methods. However, it is evident that most of the hull cleaners dispose their scappings into harbour basins, or dump on Jetties without disposal them in more systematic way. This boosts the spread of hull fouling organisms in harbours and adjacent environments. The use of biocides and the introduction of bio-control agents have been considered as possible methods for the removal of marine invaders. However, in Sri Lanka, such options are very rarely applied in the fisheries sector. Although there are number of ecological and economical hazards from MIAS, *Crassostrea*

virginica and *Saccostrea cucullata* are considered as a high potential mariculture species in Sri Lankan aquaculture industry with considerable economic benefits. Therefore promotion of some species as potential food species and encourage wild collection might provide viable solutions to control such species to a large extent.

However, it is appropriate to note that though the number of globally known MIAS were recorded in Sri Lanka, their invasiveness in the Sri Lanka has not been established. Hence, further studies are highly encouraged on marine indigenous species, native species, invasive species, their invasiveness and impacts on native biodiversity and socio economic of Sri Lanka.

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