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Behaviour of stranded abandoned plastic fishing nets in the equatorial tropics

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Abstract. Abandoned, lost, and discarded fishing gear (ALDFG) is a major contributor to marine debris globally but little is known about its life cycle. The impact of ALDFGs on marine organisms and habitats is especially needed in the biodiverse tropics. Five beached gill nets and one trawl net were observed in-situ over 13 weeks and 2 years, respectively. Biofouling was observed in one gillnet; and three of the gillnets increased in area of substrate covered. The trawl net had disintegrated significantly; only the head, foot, and mounting ropes remained, and these were significantly bio-fouled. The trawl net entangled several colonies of corals and anemones, but most were still alive and had grown over the net; demonstrating that sessile organisms adapt to ALDFGs in their environment. The ALDFGs observed underwent slow rates of degradation, during which they can remain viable traps. Finally, we propose a standard protocol to collect data from ALDFGs, as well as retrieve them and organisms trapped therein.

Key words. ghost fishing, in-situ, life cycle, marine debris, plastic net, Singapore

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INTRODUCTION

Abandoned, lost, and discarded fishing gear (ALDFG) is a significant component of ocean pollution, with recent reports estimating that 5% of all fishing nets and 29% of all fishing lines end up derelict (Richardson et al., 2021). These findings are corroborated by debris surveys within the Great Pacific Garbage Patch in which fishing nets alone accounted for 46% of all debris types (Lebreton et al., 2018). Similarly, in the northeast Atlantic, 55% of all floating plastics is fishing gear (Ostle et al., 2019). Unrecovered ALDFGs remain viable trapping devices when buoyed within the water column, lodged on the seabed, or stranded along shorelines (Gajanur & Jaafar, 2022). Organisms trapped in ALDFGs typically die of starvation. They also attract conspecifics, predators and scavengers that in turn become entangled (Furevik & Fosseidengen, 2000; Davies et al., 2017). These damages that ALDFGs exact on the marine environment are at times irreversible (Gilman et al., 2016). Derelict fishing gear in shallow coastal areas, for example, cause high mortality and morbidity of intertidal biota, and also physical damage to sessile benthic organisms with which they become entangled or lodged (Laist, 1997). Beaches and intertidal areas are locations where ADLFGs and other fishing-related plastic items tend to aggregate, as shown by reports from coastal areas globally (Davies et al., 2017; Stelfox et al., 2019; Daniel et al., 2020; Kaviarasan et al., 2020; Andrade et al., 2022; Gajanur & Jaafar, 2022; Haghighatjou et al., 2022).

The detrimental impacts of ALDFGs on the marine environment have escalated in recent decades due to advances in the fisheries sector. Less expensive fishing gear with improved material durability and design exacerbate the impacts of ALDFGs as they are able to remain as effective trapping devices in the environment for longer periods (Gilman et al., 2016). Plastic ALDFGs are especially prevalent in this regard because they are buoyant, allowing them to be transported far from their source points while continually trapping marine organisms due to material durability and design efficacy (Derraik, 2002; Vance & McGregor, 2019; Gilman et al. 2021).

Plastic debris, including ALDFGs, are also becoming increasingly common in the seabed, making up 80–85% of the seabed debris (Moore, 2008). These degrade and release microplastics into ecosystems (Wright et al., 2021). Microplastics are known to be pervasive and are easily ingested or absorbed by organisms; consequences to these organisms are yet unknown (Andrady, 2000; Wright et al., 2013). Initially, plastic ALDFGs were found to undergo accelerated gain in density due to fouling (Andrady, 2000) and thereafter, sink to the aphotic zone. The fouling colonies eventually die due to a lack of sunlight and the ALDFGs are again buoyant.

The majority of ALDFGs that exist today are of plastic or synthetic materials. Modern plastics can last up to 600 years in marine ecosystems (Macfadyen et al., 2009). An expedition to clean up 18 tons of accumulated trash on Henderson Island, United Kingdom, for example, revealed marked plastic fish bins that originated 5,600 km away. Plastic items from companies that had ceased operation nearly two decades prior were also found (Vance & McGregor, 2019). Furthermore, plastic debris contributes to 88% of all accidental or unintended ingestion and entanglement in marine organisms (Gall &

Thompson, 2015; Duncan et al., 2017; Jepsen & de Bruyn, 2019), including seabirds that mistake plastics for food (Laist, 1997; Gall & Thompson, 2015). Yet, there is very little understanding of the life cycle of non-biodegradable plastic ALDFGs (Gilman et al., 2021).

Information on ALDFG behaviour is lacking in Southeast Asia, a region of high biodiversity, increasingly urbanised coastlines and accelerated fishing effort (Gajanur & Jaafar, 2022). Fishing nets, traps and lines left in marine ecosystems in the Baltic Sea, north-eastern Atlantic and Mediterranean Sea, for example, have been shown to break down between 8 months to 8 years from wave action and biofouling (Brown & Macfadyen, 2007) but neither the material used nor the rate of degradation was considered. This study tracked the in-situ changes in stranded plastic fishing nets within a tropical coastline and considered their trapping efficacy and rates of degradation, providing relevant baseline data to inform protocol for the end-of-life management of stranded ALDFG.

MATERIAL & METHODS

The study was carried out in Singapore, an island state that lies just one degree north of the equator. It is highly urbanised, with most of its coastline being artificial due to being reclaimed land (80% of the coastline), and protected by seawalls and breakwaters (63% of the coastline) (Lai et al., 2015). Despite this, it has a variety of ecosystems on its mainland and offshore islands, from primary forests to mangroves, diverse intertidal spaces, coral reefs, and seagrass habitats. Singapore experiences high and uniform temperatures (31°C to 33°C), raining an average 167 days of the year, and high humidity all year round (60% to 90%), without high month-to-month variation (Fong & Ng, 2012). It is characterised by two monsoon seasons (December–early March and June–September) with moderate to heavy rainfall (240 mm to 320 mm) separated by inter-monsoonal periods, i.e., periods of light rain and wind and scattered thunderstorms (110 mm to 170 mm) (Fong & Ng, 2012). Singapore also experiences mixed semi-diurnal tidal patterns with tidal variation of about 3 meters. Lowest tides typically occur during the spring ebb tides (before sunrise April–August and after sunset October–February) (Fong & Ng, 2012).

Six stranded plastic polymer fishing nets—five gillnets (GN1 to GN5) and one trawl net (TN)— were tracked between January and March 2019 at two sites—Pulau [=Island in Malay] Ubin and Pulau Semakau (Table 1). The gillnets were encountered for the first time as part of this study, but the trawl net had been under observation by citizen scientists since 2017. These nets were within the intertidal zone and accessed fortnightly during spring ebb tides. The substrate of the intertidal area comprised complex matrices of coral rubble, algae, and seagrasses. A total of 11 sampling sessions were carried out over the course of 13 weeks, with each net in this study surveyed a total of four times. During each sampling session, any newly trapped organisms were identified to document the in-situ passive-capture capabilities. Parameters such as area covered by the net, size of mesh, extent of fouling organisms and colour of net material were examined and recorded to determine the behaviour of these stranded nets. Mesh size and area covered by the net were measured using a tape measure, while fouling and net colour was only assessed visually.

RESULTS

Five gillnets (GN1, GN2, GN3, GN4, GN5) were found intact in January 2019, either trapped between rocks, entangled in mangrove tree roots and low-lying branches, or half-buried in sand (Fig. 1). Gillnet lengths ranged from 1.9 m to 4.8 m, with mesh sizes between 5.1 cm and 13.2 cm. Dimensions of each net are detailed in Table 1 and 2. Over 13 weeks, no changes in mesh sizes of these gillnets were detected but three gill nets, GN1, GN2, and GN5, increased in area of substrate covered by 7%, 40% and 44% respectively (Table 2). Biofouling was observed only on one net trapped between rocks (GN4) where accumulation of unidentified algae and staining of net filaments caused the overall net colour to change from white to yellow (week 1 to week 5), and then green (week 8). No accumulation of algae or other fouling organisms were visible for the other four nets (GN1, GN2, GN3, GN5). No organisms were found trapped in any of the five gill nets during the 13 weeks.

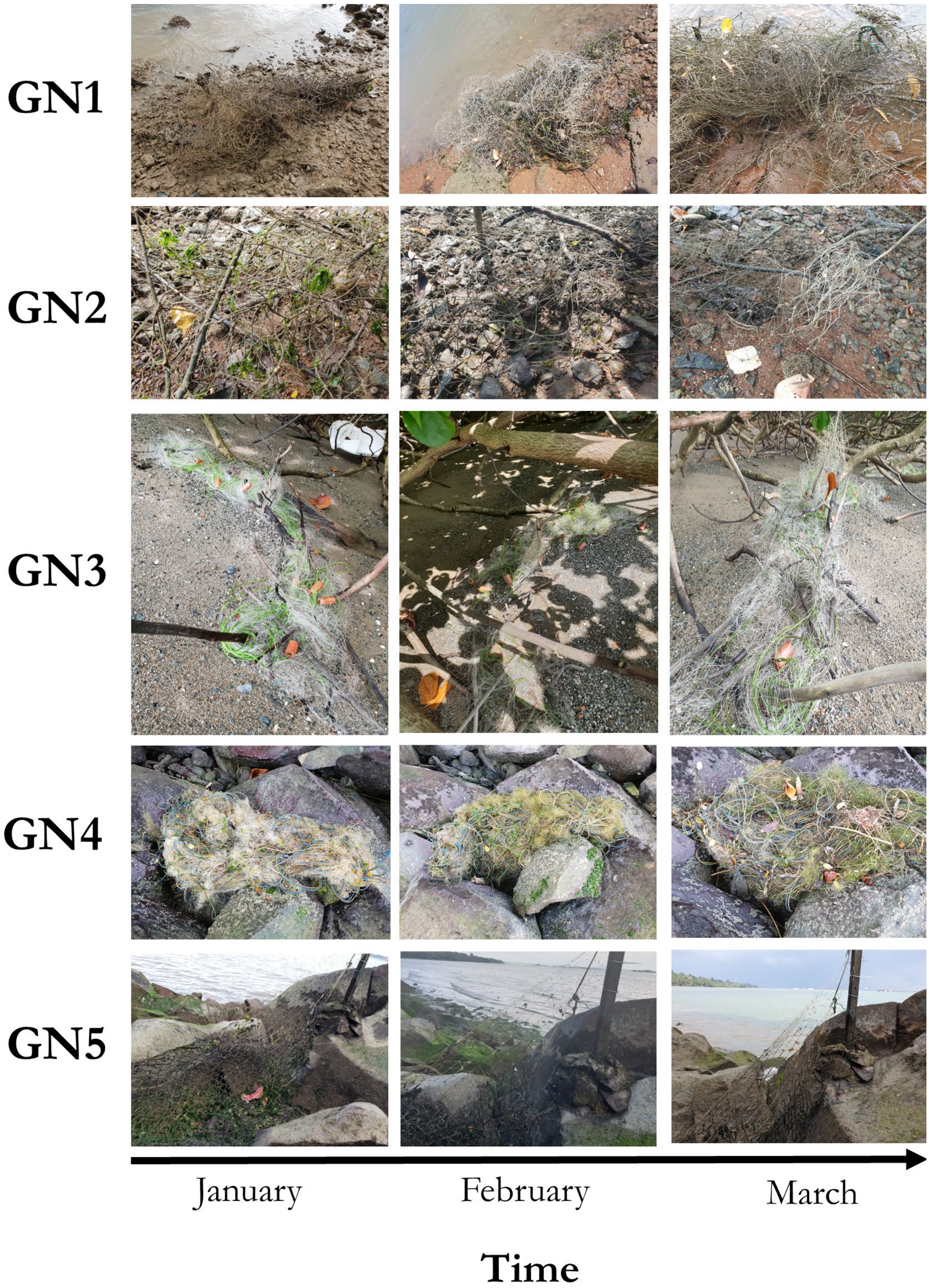

Fig 1. Five gillnets (GN1–GN5) monitored in-situ from January to March 2019. Each row shows the same gillnet over time. (Photographs by: Anya Roopa Gajanur).

The trawl net (TN) was first reported by a citizen science group conducting intertidal surveys in 2017 (Fig. 2) who shared photographs and videos of the net at first encounter. The 200-m trawl net, made of plastic polymers, stretched from one seawall at the shore to the edge of a coral reef over a rubble-algae-seagrass area. Mesh sizes of TN varied between 3 cm and 4 cm. While the exact number was undeterminable, the net had snagged on several hard and soft corals, and sea anemones. Figures 2A and 2B show the net as observed in 2017 when the mesh netting was still visible. In 2019, no mesh netting was observed and only the head, foot, and mounting ropes remained; these were significantly biofouled (Fig. 2C and D). Although the rope was observed to settle over several colonies of soft corals, these colonies were still alive and appeared to have grown over or around these ropes (Fig. 2C).

Table 1. Specific information on five gillnets (GN1–GN5) and one trawl net (TN) monitored in-situ for three months at Pulau Ubin and Pulau Semakau in Singapore.

Name	Location	Latitude	Longitude	Type of Net	Changes to Net Over Time	Status of Net	Mesh Size (cm)	Initial Area Covered by Mesh (m^2)	Final Area Covered (m^2)
GN1	Pulau Ubin (Ketam beach)	1.411212	103.9444	Plastic gillnet	Increase in surface area covered	Half-buried in sand	13.2	2.45	3.43
GN2	Pulau Ubin (Ketam beach)	1.411013	103.9457	Plastic gillnet	Increase in surface area covered	Entangled in tree branches	11.5	0.71	0.76
GN3	Pulau Ubin (Ketam beach)	1.411188	103.9447	Plastic gillnet	Nil	Entangled in tree branches and buried in sand	5.1	0.59	0.59
GN4	Pulau Ubin (Jetty)	1.40209	103.9689	Plastic gillnet	Biofouling (change in colour of net filaments from transparent to green)	Trapped between rocks	12.4	0.23	0.23
GN5	Pulau Ubin (Sungei Ubin)	1.403779	103.9739	Plastic gillnet	Increase in surface area covered	Trapped between rocks	10.2	6.03	8.71
TN	Pulau Semakau (north-east)	1.209287	103.7657	Trawl net	Degradation (mesh disappeared and only the rope remained)	Snagged on corals, anemones, and sponges	Nil	Unable to determine	Unable to determine

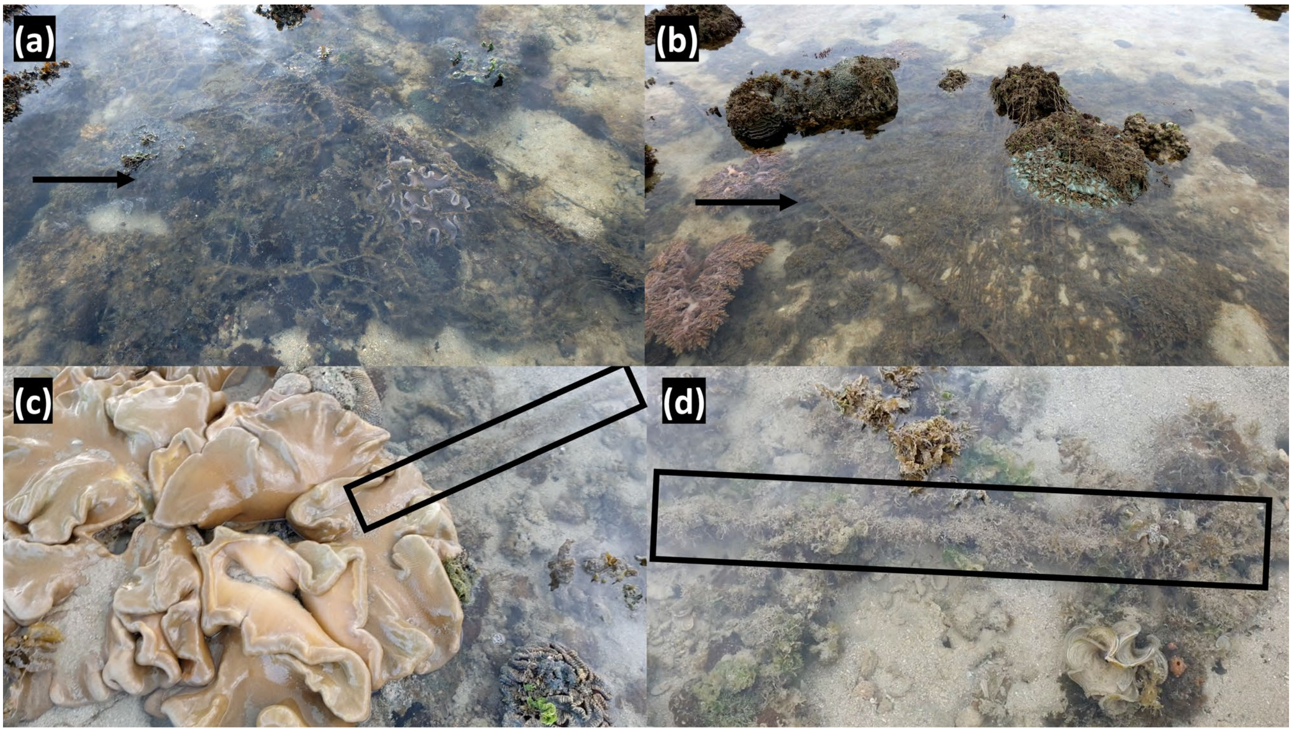

Fig. 2. 200-m trawl net (TN) in 2017 (a and b, photographs by: Ria Tan) and in 2019 (c and d, Photographs by: Anya Roopa Gajanur). Black arrows and boxes point to and demarcate the net.

Table 2. Mesh size (cm) (MS) and Total area covered (m^2) (AC) of gillnets monitored in-situ at Pulau Ubin.

Gear Code	**G1**		**G2**		**G3**		**G4**		**G5**	
Status of gear	Not entangled, buried or trapped.		Entangled with mangrove tree.		Entangled with mangrove tree, half buried.		Trapped between rocks.		Trapped between rocks.	
	MS	**AC**	**MS**	**AC**	**MS**	**AC**	**MS**	**AC**	**MS**	**AC**
Survey 1	13.2	2.45	11.5	0.71	5.1	0.59	12.4	0.23	10.2	6.03
Survey 2	13.2	2.55	11.5	0.71	5.1	0.56	12.4	0.25	10.2	4.02
Survey 3	13.2	2.57	11.5	0.71	5.1	0.58	12.4	0.23	10.2	8.04
Survey 4	13.2	3.43	11.5	0.76	5.1	0.59	12.4	0.23	10.2	8.71
% Change in AC	–	40	–	7	–	0	–	0	–	44

DISCUSSION

Stranded ALDFGs are considered environmental hazards but the opportunity to observe their behaviour in-situ is limited. We observed five stranded gillnets over 13 weeks along intertidal tropical shorelines to determine the trapping capabilities and behaviour. There was accumulation of algae and seaweed for one of the five gillnets while biofouling was not observed for the other four (Fig. 1). The structural framework, including the integrity of the mesh area, remained unchanged in all five stranded gillnets over 13 weeks. However, the area covered by three of the gillnets increased over time (Table 2). As the structural integrity of these nets remained intact, and minimal biofouling was observed, the increase of area covered is unlikely to be the result of material degradation but may be attributed to tidal action.

During this study, all five gillnets neither passively trapped nor entangled marine organisms. In the literature, catch efficiency was seen to rapidly decrease over time as the structural integrity and mesh netting of ALDFGs disintegrate, aided by the accumulation of fouling organisms, in shallow coastal waters (Erzini et al., 1997; Brown & Macfadyen, 2007). The absence of trapped organisms in the intact gillnets we observed is therefore likely because they were partially lodged within or between the substrate and consequently less effective. These nets were also stranded within the upper reaches of the littoral zone where they were exposed for longer durations. The collapsed nets in little to no water further decreased their trapping efficacies. If dislodged, the re-entry of these intact nets into the coastal waters will likely resume ghost-trapping and increase incidences of entanglement (Gajanur & Jaafar, 2022).

The stranded 200-m trawl net was intact in 2017 but only the highly biofouled head, foot and mounting ropes remained in 2019. Significant disintegration occurred over the two years and no organisms were found trapped within the degraded mesh over the course of this study; observations that corroborate reports of other nets with similar overall loss of structural integrity (Erzini et al., 1997; Santos et al., 2003; Brown & Macfadyen, 2007; Ayaz et al., 2010). This trawl net was lodged at the base of a seawall along the shoreline, stretched across the intertidal zone, and ended at the edge of a fringing reef. The ropes of the net had entangled around or rested on hard and soft corals, as well as sea anemones but several of these organisms were alive or had grown over the ropes. Due to the high density of rubble and fast growing macroalgae and seagrass in the area, we were not able to determine if the net had caused the death of anemones or corals prior to our study. However, it is evident that a degree of adaptability is observed in at least some of the organisms entangled by the trawl net. In a few studies, ALDFGs were found to enhance dispersal and shelter capabilities in marine organisms (Kiessling et al., 2015; Angiolillo & Fortibuoni, 2020). However, to determine the adaptation processes of sessile marine invertebrates to ALDFG entanglement, consistent and long-term data is required.

Whether stranded or within the water column, plastic ALDFGs, fishing nets included, disintegrate and release smaller fragments of plastics into the marine environment (Wright et al., 2021; Napper et al., 2022). The intertidal environments are where materials are readily weathered by wave, wind, and sun and are abraded by sand and other benthic substrates (Welden & Cowie, 2017). Through the processes of weathering, abrasion, and biofouling, ALDFGs have been reported to release microplastics at a rate of 0.427 grams per month, with a consequent reduction of up to 1% in weight of polymer ropes (Welden & Cowie, 2017). Another similar study showed approximately 1,277 pieces of microplastics being emitted per meter of beach (Wright et al., 2021). In this study, opportunistic recovery of stranded nets precluded data capture of their initial weight and dimensions. Consequently, the rate of degradation and amount of microplastic released into the environment cannot be conclusively determined. Furthermore, as plastics in the marine environment can take anywhere between four years to over 500 years to fully degrade depending on the type of plastic, size of the object, and conditions of the environment (Chamas et al., 2020), the degradation rate of plastic ALDFGs was unlikely to be measurable for nets monitored in-situ over 13 weeks. Future studies on the rate of introduction of microplastics by ALDFGs and their impact to sessile marine organisms are important as the information aid in protocol development for their responsible use and the management of their eventual disposal (Stead et al., 2020; Wu et al., 2022).

Our findings reveal that beached and stranded gill and trawl nets deteriorate slowly whilst covering larger surface areas as they degrade. Until mesh netting significantly disintegrates, gill nets may continue to trap intertidal and marine organisms. Although no trapped organisms were found in the gill nets from our study, several corals and anemone colonies entangled in the trawl net were alive and had grown over the head ropes. Future studies should focus on long-term in-situ studies on beached ALDFGs to determine the changes in catching and ghost fishing efficiency as well as the adaptability of the marine biodiversity to ALDFGs. Finally, we propose a standard procedure to collect data and parameters of ALDFGs encountered as well as the organisms trapped or entangled within them (see Appendix). The protocol can be adopted and adapted by researchers as well as citizen scientists; and improve data granularity on the regional and global impacts of ALDFGs.

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APPENDIX

Standard ALDFG & Data Retrieval Protocol

This protocol aims to standardise and systematically document and release organisms trapped in ALDFGs along coastlines and underwater; as well as document and remove ALDFGs from the marine habitats. The protocol can be used by researchers and citizen scientists to improve data quality and our understanding of ALDFGs. The following needs to be documented— a) location of the ALDFG, b) the variety and types of ALDFG used and c) organisms trapped within the ALDFG. The ALDFG should be cleared from these areas, with exceptions for organisms that have grown on or around the driftnet i.e., when the gear has integrated into the ecosystem.

Items Needed

Short rulers, long rulers, buckets, large cooler box filled with ice, gloves, scissors or shears and a camera (digital and waterproof would be most convenient). Note that latex gloves offer little protection and are easy to tear. Instead, use thin neoprene or gardening gloves that offer protection as well as flexibility.

Protocol

1. Indicate location, date, time, tidal height, and names of members of the team. Take photos of the general area as well as the net prior to measuring and removing animals.
2. Measure total length of ALDFG – If the ALDFG (especially if it is a net), is partially buried, only measure the portion that is above the substrate. Do not dig up portions that are within the substrate.
3. Measure the mesh size of the ALDFG – if nets are encountered, stretch the mesh and measure the length and width as shown below. Take THREE measurements from THREE different meshes from different parts of the ALDFG. Note that some gill nets have 2-3 layers and the mesh size for each might be different. In such cases, measure 3 mesh sizes from EACH layer.

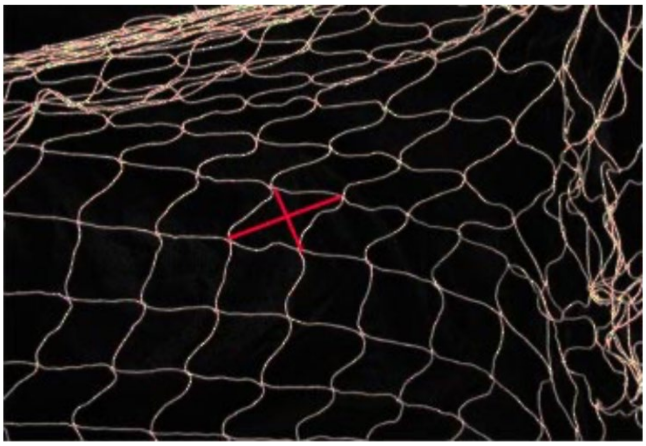

Fig. S1. Illustration on the mesh measurements to be taken when an ALDFG is encountered.

4. If possible, before removing each organism, take a photo.
5. Remove trapped organisms from the ALDFG. You are strongly advised to wear gloves. At this point, you may use scissors to aid in the disentanglement of the organisms.
6. Prepare several buckets with seawater should there be live organisms trapped in the nets. Place live organisms in buckets of seawater. Ensure organisms that might injure others are separated. Ensure water in bucket is oxygenated by means of a pump.
7. For each organism, take several photos. For laterally flattened organisms, take 1 photo of the side and 1 photo of close-up of the head. For dorsally flattened organisms, take 1 photo from the top, 1 photo from the bottom and 1 photo of close-up of the head. Take note of photo sequence so that the specimen to which it belongs can be ascertained.
8. Measure the length of the organism. For crabs, measure the carapace at its widest point. For fish, measure standard length (tip of snout to just before the tail begins) and total length (tip of snout to the end of tail). For shrimps, from tip of snout to end of tail. For horseshoe crabs, take two measurements, one with and one without the tail.
9. If organisms are still alive, proceed to release them. If already dead, place in ice or ice slurry. Freeze organisms as soon as possible if specimens are needed for further studies. Otherwise, please dispose of them responsibly.

Once all the measurements are taken and the organisms either released, iced, or discarded, proceed to remove the ALDFG and responsibly dispose at approved points for trash collection or recycling.