Ghost Nets

Needs Analysis and Feasibility Study for Northern Australia

Final Report July 2021

TierraMar

SMaRT@UNSW
Sustainable Materials Research & Technology

Disclaimer

This report has been commissioned by the Department of Agriculture, Water and the Environment (DAWE) to seek information to facilitate the improved removal and processing of Abandoned, Lost or Discarded Fishing Gear (or ghost nets) from Australia's northern waters that will help identify activities that will provide the greatest net benefit for the investment made, and directly inform the investment in new infrastructure and/or coordinated services. It is solely for the use of DAWE. TierraMar Ltd does not accept any responsibility to any other party to whom this report may be shown or into whose hands it may come. No representation or warranty (express or implied) is given as to the accuracy or completeness of the information contained in this report, and, to the extent permitted by law, TierraMar Ltd, its members, employees and agents accept no liability, and disclaim all responsibility, for the consequences of you or anyone else acting, or refraining to act, in reliance on the information contained in this report or for any decision based on it. The information provided in this report is based on the best information and documentation available at the time of preparation. The views and opinions expressed in this publication are those of the author and do not necessarily reflect those of DAWE.

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We acknowledge

the Traditional Custodians upon whose ancestral lands we live and work. We pay respect to their Elders, past, present and emerging, and acknowledge the continuing connection that Aboriginal and Torres Strait Islander peoples have to the land, sea, sky, and waterways. Sovereignty was never ceded.

CONTENTS

List of Acronyms

ABF	Australian Border Force www.abf.gov.au
AFMA	Australian Fisheries Management Authority www.afma.gov.au
ALDFG	Abandoned, Lost or Discarded Fishing Gear
AMDI	Australian Marine Debris Initiative http://amdi.tangaroablue.org
AMSA	Australian Maritime Safety Authority www.amsa.gov.au
CSIRO	Commonwealth Scientific and Industrial Research Organisation www.csiro.au/en
DAWE	Department of Agriculture, Water and the Environment www.awe.gov.au
EEZ	Australian Exclusive Economic Zone
EPBC Act	Environment Protection and Biodiversity Conservation Act 1999
FAD	Fish Aggregating Device
FTIR	Fourier-transform infrared spectroscopy
GGGI	Global Ghost Gear Initiative www.ghostgear.org
GNA	Ghost Nets Australia www.ghostnets.com.au
MBC	Maritime Border Command www.abf.gov.au/about-us/what-we-do/border-protection/maritime
MSC	Marine Stewardship Council www.msc.org/en-au
NPF	Northern Prawn Fishery http://npfindustry.com.au
SMaRT@UNSW	University of New South Wales Centre for Sustainable Materials Research and Technology www.smart.unsw.edu.au

Executive summary

Globally, ghost nets (also known as abandoned, lost or otherwise discarded fishing gear (ALDFG)) are a major sea-based source of marine debris. These nets are the most harmful type of marine debris, entangling and killing marine wildlife and can persist for decades. Ghost nets have been a major issue in northern Australia, particularly in the Gulf of Carpentaria for many years with over 15,000 nets reported since 2004.[1]

The prevailing currents and conditions in the Arafura and Timor Seas and the Torres Strait make the Gulf of Carpentaria a global ghost net and marine debris 'hot spot'. Although this area is remote and sparsely populated, it has one of the highest rates of ghost nets and marine debris accumulation in Australia. Much of the debris is marine based, coming from sources outside of Australian waters.

Stopping the ghost nets and other marine debris, most of which is plastic, at source is the priority but will take some time and is outside of the scope of this study. Working through regional partnerships such as the Arafura and Timor Sea Ecosystem Action Program (ATSEA) to develop and implement a regional marine debris and ghost net action plan and establish a regional monitoring network in partnership with Indonesia, Timor-Leste and Papua New Guinea will be key.

Finding sustainable and pragmatic solutions to the ghost nets and marine debris challenges in northern Australia, beyond stopping the situation at its source, is centred around overcoming the vast distances for retrieval, transport and disposal/processing. Ranger groups have limited resources and infrastructure available to them. The harshness of conditions and the remoteness and unpredictability of where nets and other marine debris wash up on beaches makes a challenging combination of problems to overcome. In most cases, there are limited or no domestic waste collection services, sorting and processing facilities or recycling schemes. This is primarily due to the high transport costs and inability to achieve the economies of scale needed to make these types of services and programs economical. It makes for a complex situation requiring highly tailored, integrated, and fit for purpose solutions. As the scale of the issue continues to increase across northern Australia, finding potential solutions that can assist in streamlining processes is key. This includes reducing inefficiencies from double handling of the nets and debris and the need for intensive labour as well as finding economical options for disposal for ghost nets.

To address the challenge of ghost nets especially in the Gulf of Carpentaria, the Australian Government is implementing the Ghost Nets Initiative, that will run until June 2024.[2]

As part of the initiative, Parks Australia will be introducing a suite of new ghost net projects focusing on the Gulf of Carpentaria, commencing in the second half of 2021.

This report provides a regional infrastructure needs analysis and feasibility study to help identify activities that will boost capacity for collection, transport and responsible disposal of ghost nets and marine debris. It seeks to provide guidance to inform investment in new infrastructure and coordinated services through the Ghost Nets Initiative for northern Australia. This work has been undertaken using a combination of desktop research, materials analysis, and stakeholder consultation with government, community, industry, and non-government organisation stakeholders. The focus has been on listening to those stakeholders in the Gulf of Carpentaria to understand key challenges, issues and needs.

Options identified, particularly in relation to opportunities towards achieving impact at scale, are provided following an assessment against key fundamental criteria as outlined below to ensure what is proposed is pragmatic and practical.

For ghost nets and marine debris in northern Australia, finding the economies of scale needed for self-sustaining solutions is critical. Reducing reliance on Government support to clean-up and dispose of the debris is dependent upon being able to produce high quality valuable products that reflect the unique cultural and artistic values and the strong connection to country of Indigenous communities in the region. It is imperative that any investments made do not place increased burden on Rangers without the necessary resources (human and financial) to increase workloads.

For each stage of the ghost net/marine debris impact pathway, options considered most suitable for addressing the situation in the Gulf of Carpentaria, incorporating the priorities identified by key stakeholders, are summarised on the following pages.

Social Criteria

- **Social Licence/Culturally Appropriate:** Social licence to operate and cultural appropriatness
- **Suitable infrastructure and Systems:** Support Systems and infrastructure available, including skills/labour
- **Benefits to communities:** Benefits return to communities including potential for job creation, increased income, fee for service for Rangers

Environmental Criteria

- **Scale:** Appropriate geographic scale eg community, regional, state
- **Risk:** Risk to environment, climate and people (safety and operations)

Economic Criteria

- **Cost effectiveness**: Cost effectiveness, including set up, labour, running costs, maintenance
- **Sustainable**: Financial sustainability and life cycle considerations, including ongoing profiability, overcoming economies of scale
- **Fit for purpose**: End products are fit for purpose, have available markets and meet performance requirements
- **Adaptable:** Ability to deal with the difficult nature of the material (mixed, contaminated, degraded)

Ghost net interception, tracking and retrieval (in-water)

- Any expansion of the tracking trial to other parties, such as Northern Prawn Fishery vessels would best be done after the trial has run its course and the technology has been tested and proven.
- Consider using solar powered tracking devices where it is likely retrieval will be beyond the 3 months life of the current batteries being used in tracking devices during the Australian Government trial.
- Tracking and retrieving multiple nets (or other hazards such as shipping containers) in proximity could increase cost efficiency when tendering for retrieval.
- Satellite imagery via remote sensing technology may be feasible for detecting marine debris densities on beaches. This would need to be closely tied to Ranger retrieval activities to justify costs and be delivered in partnership with Ranger groups in a way that complements their activities. With technology advancing rapidly and some ghost nets being multiple kilometres long, imagery may be able to detect and track them shortly, so it will be important to follow developments with remote sensing capability.
- Drones could be used by Ranger groups to inspect nets close to shore prior to washing up on beaches or for doing a rapid assessment of local beaches to prioritise areas prior to conducting clean ups. With the technology advancing rapidly, drones may also be useful for broader mapping of ghost nets, identifying nets entangled on the seabed and where live animals are entangled and require rescuing. These should be investigated in consultation with Ranger groups.

Olive Ridley turtle caught in ghost nets. Photo by Jane Dermer.

Clean-ups and removal (ghost nets and marine debris) (land-based)

- Provide additional resources to support dedicated clean-up teams within Ranger groups as required. These could be supported using a fee for service model.
- Upgrade hand tools for cutting, provide collection equipment like rakes and picks, and modify vehicles to have the necessary infrastructure to increase carrying capacity for transport and storage that are fit for purpose to increase clean-up efficiency. Each Ranger group has specific needs based on the conditions they work in for marine debris/ghost net removal and therefore there is no single solution for all.
- Beach cleaning machines (either sieve or 'picker' mechanisms) may aid in clean-ups in some locations where beaches are easily accessed and flat, where Rangers have highlighted them to be potential options. A trial should be conducted however prior to purchase to ensure they are fit for purpose.
- Stockpiled ghost nets could be stored in shipping containers to reduce degradation and formation of microplastics and prevent rats once brought back to a Ranger base.
- A landing barge could be used to transport equipment or beach cleaning vehicles to a beach for some Ranger groups that currently do not have barges. The size of the Gulf and water conditions mean that multiple local transport options that suit conditions are preferable compared to one service for the entire region. Boat/barge hire/purchase, fuel, and crew cost must be considered.
- Further investigation is warranted on air boats to establish whether they are fit for purpose and may assist some Ranger groups to improve efficiencies of clean-ups.
- To reduce bulk, fit for purpose mobile compactors/baling machines to use when collecting marine debris and ghost nets or undertaking preliminary sorting, could assist in improving cost efficiencies, reduce bulk and the amount of handling required. This would require some sorting being undertaken by either Rangers or those engaged to undertake baling and compacting process.
- To support the annual clean ups that take place around the Gulf organised by various Ranger groups with their NGO partners, a Gulf wide Clean Up Blitz involving Governments, Ranger groups, NGOs, industry, and communities could take place at identified hotspot areas once or twice a year. This could include use of government infrastructure from Defence and potentially fishing industries in the off-season to provide necessary resources and support to help clean up the more remote hotspot areas as well as remove collected marine debris and ghost nets from collection points to transfer or disposal hubs.

Responsible disposal

» Work with local and state governments working on municipal waste management and recycling schemes for northern Australia, to explore opportunities for marine debris and ghost nets. Consolidation of different waste streams within regions for more efficient transportation and processing will be important to achieve economies of scale.

» Remanufacturing and to a lesser extent extrusion and injection moulding are considered the most feasible options for disposal. In addition to continuing ghost net art weaving, these options would allow for the expansion of art activities to use Green Ceramics™ and other methods such as 3D printing to maximise opportunities for communities to tell their stories to a broader audience of their connection to country and sell a wider range of products in large urban markets. For example, development of a range of high-quality homeware and building products, reflecting the unique cultures, artistic values and connections to country could be produced from ghost nets and marine debris coming out of northern Australia using cost effective MICROfactorie™ solutions for re-manufacturing (Green Ceramics™) and thermo-mechanical recycling (extrusion and injection moulding for higher quality end of life fishing net only). Prototyping of suitable material pathways to develop products with a ready market should be undertaken however as a key step. A market survey is a pre-requisite to developing the prototypes.

» Undertake a coordinated pilot program to establish a suitable modular recycling pathway for the Gulf of Carpentaria, utilising the prototyped products developed and informed by market opportunities. This could include establishing regional hubs for sorting and aggregation of marine debris and ghost nets and designing and then trialling cost effective logistic options for those Ranger groups and communities keen to participate to transport nets and marine debris from communities to collection points for re-processing. Identifying and working with a suitable supply chain to develop a business model that will provide cost effective and economically viable business and job opportunities for Ranger groups, communities, artists, and industry to share in the benefits will be a first key step.

» Low quality marine debris and nets that are highly degraded should be taken to landfill as a first option unless municipal waste management can provide alternate solutions. Where no other options are viable, provide support to improve the safety and efficiency of burning marine debris and ghost nets by reviewing methods, providing training in safety protocols, and using portable incinerators, rather than open burning.

Eastern Long Necked Turtle sculpture made from ghost net.
Photo by Patrick Rodriguez.

Capacity building, training and knowledge sharing

- A knowledge sharing program would allow Ranger groups to learn from the successes of others and build the capacity of Ranger and Junior Ranger programs. Learning exchanges could also be considered (subject to COVID19 restrictions) for art communities/centres who expressed a desire to learn from each other.
- Work with local and state governments working on waste management and recycling schemes for northern Australia to explore opportunities for sharing resources with respect to education and training on plastic recycling. Undertake education programs for Rangers and communities on establishing plastic recycling programs for those Rangers and in those communities that want to participate. This may provide opportunity to extend any recycling scheme to also include domestic plastic recycling.
- The GhostNets Australia Net ID kit and other information kits produced by NGOs on net identification and how to conduct marine debris clean ups should be reviewed to determine which are the most useful and then updated to reflect latest information as required. This update could include for example, new net examples that have been identified by NGOs such as Sea Shepherd, and practical material science on plastic chemistry and processing requirements. These kits should be supplemented with new innovative tools such as handheld classification units and accompanying plastics identification apps and broader community capacity materials. This will allow Rangers to improve knowledge with respect to separation without adding significant additional time pressures. It will also provide opportunity to engage communities, particularly schools in increasing knowledge on opportunities available from recycling, and increase capacity towards encouraging recycling within communities.
- A joint focus on supporting turtle conservation may be a way to bring stakeholders together, given recent research emerging showing the impact marine debris is potentially having on turtles nesting as well as the sex ratio of hatchlings.

Data collection, management and reporting

- Update and roll out ghost net and marine debris identification resources, with associated training and on-ground capacity building.
- Expand knowledge and understanding of the scale of microplastics in the Gulf of Carpentaria and northern Australia.
- Expand knowledge and understanding of marine debris accumulation points across northern Australia outside of well documented areas such as the Gulf of Carpentaria. An appropriate sampling regime would be required as a pre-requisite.
- A data management strategy is required for developing a consistent approach to data collection and management for Australia. Identifying the key questions needing answers to strengthen decision making should drive what data requires collection, how it could most cost effectively be collected, by who and how often. For example, the location of the net, type, and information to identify source are the priorities for consideration of source identification. Weight of material collected, and the clean-up time contribute to understanding of clean-up effort and efficiency. Debris type and density from a representative sample of beaches are needed to track changes in debris load at a location over time.
- The Australian Government commitment to establish a national monitoring protocol and database for plastic pollution could potentially include data capture for ghost nets and marine debris. It should provide a centralised open access database that consolidates all other databases and provides on-water net tracking locations and a monitoring and reporting function that communicates with government agencies.
- Streamline data collection for Ranger groups to improve the ease of collection, and data collection quality and regularity. Should a recycling pathway be established, data collection could be undertaken by others down the supply chain, rather than by Rangers, for example those at transfer and sorting stations.
- Through ATSEA, establish and implement a regional marine debris and ghost net action plan and monitoring network in partnership with Indonesia, Timor-Leste and Papua New Guinea.

The unique situations and challenges that each Ranger group faces will determine the best pathway for ghost nets and marine debris found in northern Australia. There is unlikely to be a single clean-up, retrieval and disposal solution for northern Australia, however sub-regional solutions may be possible.

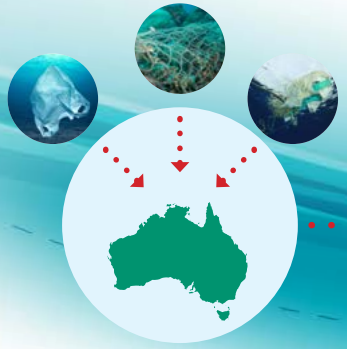
A sub-regional approach (splitting the Gulf into the Queensland and Northern Territory sides) may be achievable if economies of scale and inefficiencies can be addressed through a sound business model that shares benefits and can be self-sustaining beyond the life of Australian Government Ghost Nets Initiative investment. Undertaking a coordinated pilot program to establish a suitable modular recycling pathway for the Gulf of Carpentaria, utilising prototyped products and informed by market opportunities, will provide opportunity to learn and refine and determine how best to structure it.

The most viable technologies suitable for the Gulf were found to be re-manufacturing (Green Ceramics™), complemented with limited thermo-mechanical recycling (extrusion and injection moulding) which will require specialised infrastructure. As a part of a pilot, any approach would need to be framed within the broader waste management and recycling strategies and plans for regional and remote areas being developed by state, territory and federal governments to build economies of scale.

Sea Shepherd and the Dhimurru Aboriginal Corporation beach clean up 2019, photo by Eliza Muirhead (Sea Shepherd Australia)

Finding Solutions for Ghost Nets across Northern Australia

Ghostnets and marine debris enter the ocean mostly from overseas sources.



Solution

Source control and international cooperation are needed.

DETECT

Ghost nets and marine debris enter the Gulf of Carpentaria, moved by ocean currents, wind and storms

Problem

Nets continue to fish and can bring invasive species and biosecurity risks to Australia

Solution

Ghost nets can be tracked before they wash up on beaches

Solution

Coordinated data collection and management, and new partnerships

COLLECT

Most ghost nets are found washed up and require great efforts to clean them up and remove them from the beach

Problem

Nets cause entanglement of marine wildlife, like turtles, sharks and rays.

Solution

Ghost nets can be intercepted and retrieved before they wash up on beaches*

Solution

Improving clean up efficiency with fit for purpose technology and increased capacity

DISPOSE

Finding solutions for responsible disposal is key

Problem

Nets are usually either taken to landfill or burned on site. Storage and transport are challenges given how big the nets can be, the long distances to travel and remoteness of beaches

Solution

Fit for purpose and financially sustainable solutions through recycling and remanufacturing technologies.

Solution

Data management and capacity building

* AFMA on water net retrival.
Photo by Australian Marine Fisheries Authority.

2. Introduction

Globally, ghost nets (also known as abandoned, lost or otherwise discarded fishing gear (ALDFG) are a major sea-based source of marine debris.[3] These nets are the most harmful type of marine debris, entangling and killing marine wildlife and can persist for decades.[4]

As much as 70 percent of floating macroplastic by weight in our oceans globally, is attributed to ghost nets and other ALDFG, with a recent study from the 'Great Pacific Garbage Patch' in the North Pacific Ocean reporting ALDFG made up 46% of the 79,000 tons of plastic observed.[5,6] Ghost nets have been a major issue in northern Australia, particularly the Gulf of Carpentaria for many years. Marine debris has been reported in the Gulf of Carpentaria region since about 1993.[7] Since 2004, over 15,000 nets have been recorded in GhostNets Australia (GNA) or other databases.[8] Foreign fishing debris (nets, rope and gear) is the major source of marine debris (63%) across northern Australia, with 95% of all identified net sourced from Taiwan, Indonesia, Thailand and Korea.[9]

Given the nature of ghost nets to continue fishing, they are of particular concern for target species as well as non-target species such as large, long-lived and slowly reproducing threatened, endangered and protected species like marine turtles, marine mammals, sharks and rays. All six marine turtle species found in Australian waters are listed under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) and four of the six - olive ridley, hawksbill, green and flatback turtles have been found entangled in derelict fishing gear. We know from modelling work undertaken by CSIRO and GNA, that between 4,866 and 14,600 turtles are estimated to be caught in ghost nets annually in the Gulf of Carpentaria, assuming nets drift for 1 year.[10]

GNA, funded through the Australian Government from 2004 until 2016, worked with Indigenous Rangers and other stakeholders to understand the scale and geographic extent of the ghost nets issue in northern Australia. The program also worked to understand where the nets were coming from and why, and to clean up the nets that washed up on beaches. Following the end of GNA funding, Ranger groups have continued to work on country, cleaning beaches and collecting nets and other fishing gear that washes up to reduce impacts on marine wildlife, their environment, and their communities. Marine turtles, marine mammals and sharks and rays and coastal and marine environments are culturally important for Indigenous communities in the Gulf. Over the last 15 years, while ghost nets have continued to wash up, increasing volumes of plastic debris, particularly land sourced garbage such as single use plastics like bags and bottles, oil cans, containers, thongs and lighters, have increased across northern Australia.

This is of great concern for many stakeholders in the Gulf, given the increasing scale of the issue, the impacts to marine wildlife and environments and the significant quantities of microplastics resulting. Many governments, non-government and industry stakeholders are now also working with Ranger groups and communities to address marine debris (e.g. through beach clean-ups and management of litter and illegal dumping). Ranger groups have several programs running throughout the year including biosecurity and coastal surveillance, turtle monitoring, feral animal control, and controlled burning. Schedules are tight and beach clean-ups are done in the small available times between other activities, or where they are provided financial support to do so.

In 2003, 'Injury and fatality to vertebrate marine life caused by ingestion of, or entanglement in, harmful marine debris' was listed as a key threatening process under the EPBC Act.[11] The *Threat abatement plan for the impacts of marine debris on the vertebrate wildlife of Australia's coasts and oceans*, updated in 2018, incorporates actions needed to abate the listed key threatening process, particularly actions to develop understanding about microplastic impacts and the potential role of new technologies in waste management.[12]

The actions are intended to be feasible, effective, and efficient, as required by the EPBC Act. The plan binds the Commonwealth and its agencies to respond to the impact of marine debris on vertebrate marine life, and identifies the research, management and other actions needed to reduce the impacts of marine debris on affected species.

Stopping the ghost nets and other marine debris at source is a priority and will take some time and is beyond the scope of this study. Several organisations globally are working on these issues, including the Global Ghost Gear Initiative (GGGI) and the Ocean Conservancy. The greatest challenge with respect to finding workable solutions to cleanup and dispose of ghost nets and marine debris in northern Australia relates to overcoming the vast distances, both for retrieval, transport, and disposal/processing. Even now with several profitable options existing for processing ghost nets globally, the choice of options for the Gulf has been limited to leaving it in situ, burning or where possible taking it to landfill. Ranger groups have limited resources and infrastructure available to them. The harshness of conditions and the remoteness of where the nets and other marine debris are washing up on beaches (in some cases it can be hundreds of kilometres away from the main townships) makes a challenging combination of problems to overcome.

To address the challenge of ghost nets and plastic debris in the waters and on beaches of northern Australia and especially the Gulf of Carpentaria, the Australian Government is implementing a new *Ghost Nets Initiative*, that will run until June 2024.[13] As part of the initiative, Parks Australia will be introducing a suite of new ghost net projects focusing on the Gulf of Carpentaria, commencing in the second half of 2021.

2.1 Key ghost net and marine debris interception points

The prevailing currents and conditions in the Arafura and Timor Seas and the Torres Strait mean that marine debris accumulates in the Gulf of Carpentaria, which is recognised as a global ghost net and most likely a marine debris 'hot spot'.[14] Although this area is remote and sparsely populated, it has one of the highest rates of marine debris accumulation in Australia. Much of this debris is marine based, coming from sources outside of Australian waters. While ghost nets and other ALDFG can be seen across all of northern Australia, Figure 1 shows the hotspots areas where nets have been found based on GNA data from clean-ups by Ranger groups between 2004 and 2012. The hotspot areas are the northern and western side of Cape York Peninsula in Queensland and northeast Arnhem and south of Gove Peninsula in the Northern Territory.[15]

A recent review of known hotspots undertaken by CSIRO looking at aerial survey results from 2004, 2017, 2019 and 2020 found similar results. Their review predicted the highest number of nets per kilometre to occur in the northern part of western Cape York Peninsula, including: the QLD coastline passing Vrilya Point, Cotterell Creek, Doughboy River, MacDonald River, Horn Island, Peak Point/Punsand, Jardine River, Weipa, Mapoon and Boyd Point and Aurukun, Norman Creek; and in the NT, south of the Gove Peninsula around Cape Barrow and Numbulwar.[16] Both CSRIO and GNA noted the southern portion of the Gulf of Carpentaria, near the QLD/NT border, contains the fewest nets although CSIRO reported that there appears to be an accumulation of nets detected in recent surveys, most likely due to the limited clean-up efforts that have occurred there over time.

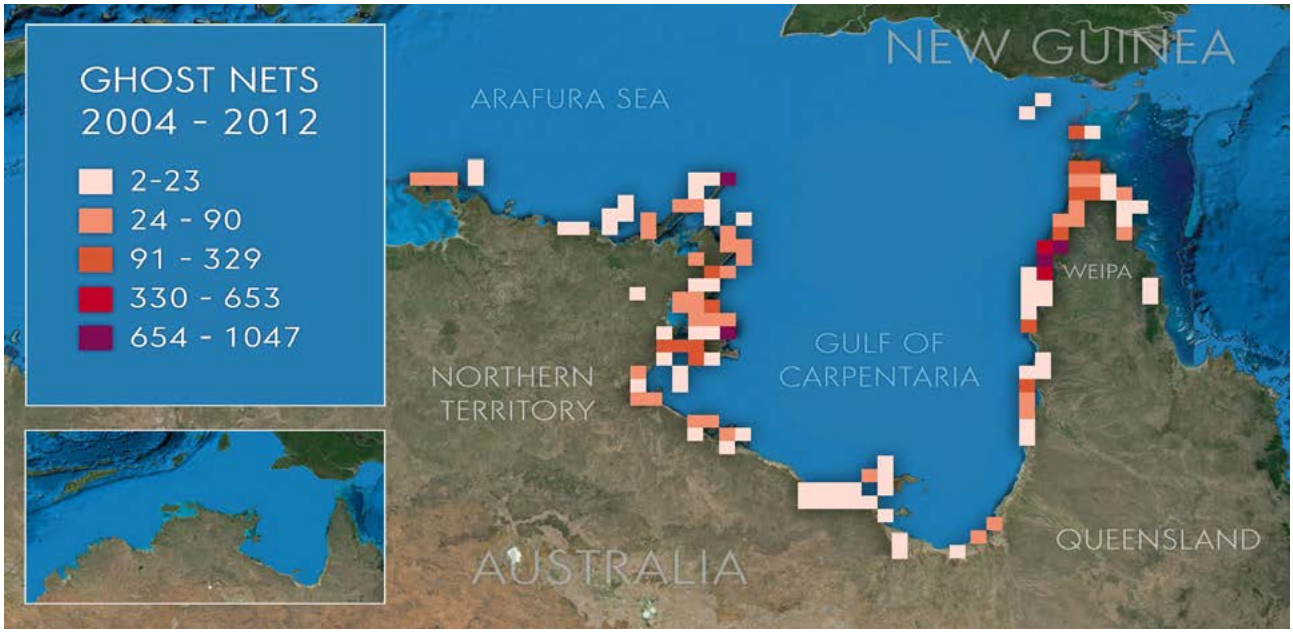


Figure 1 **Concentrations of ghost nets cleaned up by Rangers between 2004 and 2012 (GNA database).**

From discussions with those Ranger groups consulted during this feasibility study, key hotspot areas were identified as: Wessel Island Group (particularly the northern part such as Martjanba Island), Elcho Islands Group, Inglis Island in the Marthakal IPA area, Cape Arnhem, Groote and Nhulunbuy and Dhimurru IPA area, Croker and Goulburn Islands and the outstations on Cobourg Peninsula and Numbulwar in the NT; and Flinders Beach in Mapoon, and Pennefather Beach near Napranum in QLD. These areas also correspond with the GNA and CSIRO findings. Not all Ranger groups were interviewed for this study, so it is likely there are other areas that are hotspots.

Most ghost nets are retrieved once they have washed up on beaches and in mangrove areas making collection sometimes difficult, due to the large size of some nets. Potential net interception points for in-water retrievals with appropriate vessels and equipment, by monitoring the oceanographic currents using satellite technology once it becomes available, adjacent to these hotpot areas would significantly reduce pressure on Ranger groups in clean-up efforts. This however may prove difficult to coordinate.

2.2 Existing port infrastructure, beach access points and potential landing areas

Figure 2 shows the key port infrastructure sites across the Gulf of Carpentaria, the Torres Strait and NT. Sea Swift operates a regular barge service that operates across most of these ports and between Darwin and Cairns.

There are seven key deep-water ports within the Gulf of Carpentaria and Torres Strait:[17,18]

- **Weipa (Amrun Port), QLD** - Approximately 200km south from the tip of Cape York on the west coast of the Cape York Peninsula and 800km by road from Cairns. Serviced by Sea Swift
- **Skardon River, QLD** - Approximately 140 km south from the tip of Cape York on the west coast of the Cape York Peninsula. It has a barge ramp that services the Bauxite Hills Mine, managed by Ports North. Serviced by Seas Swift by booking only.
- **Thursday Island (and Horn Island**), **QLD** - Community port in the Torres Strait. Serviced by Sea Swift.
- **Karumba, QLD** - Situated in the south-east corner of the Gulf of Carpentaria at the mouth of the Norman River and 530km west of Cairns. Serviced by Sea Swift by booking only.
- **Gove Harbour/Nhulunbuy**, **east Arnhem NT** - Servicing major bauxite resources and aluminium refineries. Boat ramp and wharf managed by Sea Swift.
- **Groote Eylandt (Milner Bay) NT** - Serviced by Sea Swift. Milner Bay Port Facility, operated by GEMCO (Groote Eylandt Mining Company Pty Ltd).
- **Elcho Island, Marthakal, NT** - Serviced by Sea Swift, Elcho Island, located in the Arafura Sea off the coast of northeast Arnhem.

Google Earth Image Landsat/Copernicus

Figure 2 Key Ports across the Gulf of Carpentaria and Torres Strait

There are also seven locations in the Gulf of Carpentaria that are either recognised ports or have commercial barge service operated by Sea Swift.[19] There are around 10 additional locations in the Torres Strait that are serviced by commercial barge (not listed).

- **Yirkalla, NT** - Situated on the Gove Peninsula, east Arnhem, around 18km southeast of Nhulumbuy, has a commercial barge scheduled service.
- **Milyakburra (Bickerton Island), NT** - Located 13km west of Groote Eylandt, has a commercial barge scheduled service
- **Numbulwar, NT** - Located at the mouth of the Rose River on the western coast of the Gulf of Carpentaria, has a commercial barge service from Darwin.
- **Arukun, QLD** - Located on the west coast of Cape York, approximately 200km south of Weipa, has a scheduled barge service in the wet season only.
- **Seisia, Torres Strait QLD -** Most northerly point of Australia serviced by Sea Swift.
- **Burketown, QLD** - Is a declared port, although it has no commercial activity. Town is located around 30km inland, and 227km west of Normanton.
- **Mornington Island, QLD** - Within the Wellesley Islands group, has a commercial barge service.

Between Torres Strait and Cairns, there are also ports not included in the scope of this project at Quintell Beach, Cape Flattery and Cooktown. Between Elcho Island and Darwin there are number of locations with regular barge service, such as Croker Island, Goulburn Island, Maningrida, Milingimbi Island and Warruwi.

In addition, Ranger groups can and do land barges at various beaches depending on the conditions and time of the year. Some beaches can be accessed by vehicles where local road networks exist, while others are generally accessed by small vessels. In some cases, Ranger operated six metre barges will sit offshore and smaller vessels come into the beach such as occurs in Mapoon and Pompuraaw due to extended shallow water. Beaches in the NT when exposed to southeast winds are not accessible due to the swell. This is the same case on western Cape York when there are strong northwest winds. For western Cape York generally, most clean up activity occurs after monsoon season and northwest winds drop off. Monsoon season is most windy December to April, with cyclone season November to April.

Sea Shepherd and the Dhimurru Aboriginal Corporation beach clean up 2019,
photo by Eliza Muirhead (Sea Shepherd Australia)

3. Objectives and approach

3.1 Objective and scope

To facilitate the improved removal and processing of ghost nets and other types of ALDFG and marine debris from Australia's northern waters, TierraMar, working in partnership with the University of NSW Centre for Sustainable Materials Research and Technology (SMaRT@UNSW) have been contracted by Parks Australia to conduct a regional infrastructure needs analysis and feasibility study on the issue. The purpose of the study is to help identify activities that will provide the greatest net benefit for the investment made. This work provides guidance and stakeholder input on options for investment in infrastructure and coordinated services to boost capacity for collection, transport and responsible disposal of ghost nets and marine debris.

While the focus is on ghost nets, it has been important to also consider marine debris more broadly in the Gulf of Carpentaria. This is because this is also a major issue and the marine debris hotspots tend to be in the same locations as the nets. To that end, solutions provided cover both ghost nets and marine debris.

3.2 Approach

This needs analysis and feasibility study has been undertaken using a combination of desktop research, materials analysis, and stakeholder consultation with government, community, industry, and non-government organisation stakeholders. The focus has been on listening to stakeholders in the Gulf of Carpentaria to understand key challenges, issues and needs. The desktop analysis included an extensive review of relevant peer review journals, published reports and documents and web-based searches on existing solutions and market ready technology that could potentially be suitable for northern Australia. This included consideration of available and best-practice infrastructure and services for the retrieval and responsible disposal of ghost nets from international case studies, where relevant to the Australian context. Stakeholder consultation included three stakeholder workshops as well as interviews with a cross-section of the stakeholder groups to understand key issues and challenges, needs and priorities and potential solutions (refer Annex 3 for those consulted). Materials analysis of samples of ghost nets received from various stakeholder groups was also undertaken, using fourier-transform infrared spectroscopy (FTIR). This technique measures the reflectance of an object on an infrared spectrum of absorption or emission. Once a sample is scanned, the local database provides the closest match to identify the spectral reading to determine what it was made of (refer Annex 2 for results).

From these activities, a shortlist of potential investment options were identified that sought to specifically address the needs and potential gaps in infrastructure, technology, capacity and data collection and management identified by stakeholders.

This provided opportunity to indicate where spending on new technologies, infrastructure, and services to improve ghost net interception, removal/retrieval, and responsible disposal would be most useful and cost effective.

Key areas covered included:

- Market-ready technologies for improved detection and tracking of ghost nets in water, including but not limited to transponders or other remote sensing technologies (such as drones);
- Potential net interception locations at sea, based on known oceanographic currents, ghost net accumulation points, and available port infrastructure;
- Existing port infrastructure, beach access points and landing areas for barges, which may impact the suitability of potential new technologies, infrastructure and/or services;
- Market-ready technologies that may be used to improve efficiency of beach-based marine debris clean-ups;
- Potential disposal techniques for ghost nets, considering existing stockpiles, environmental impacts, and potential biosecurity risks (for example, burning in situ on beaches, transfer to land fill, recycling or potential waste-to-energy treatment); and
- New market-ready technologies that can be piloted, such as mobile recycling plants or other options for turning ghost nets into commercially viable products with zero residual solids as a means for diverting these away from landfill.

3.2.1 Key considerations for options analysis

To develop investment options, consideration was given to: potential service providers and suppliers that could offer access to useful expertise, technologies, processes, markets, and supply chains; plausible material pathways and solutions; stress testing of the circularity framework by applying high level financial analysis to identify the key commercial levers, strengths and weaknesses of the opportunities; and assessing the risks relating to the suggested pathway(s) to identify potential weaknesses in the solution(s), including the extent and impact of the risks. In identifying investment options, the following social, environmental, and economic criteria outlined in Figure 3 were used to benchmark those considered most fit for purpose:

Also included is a discussion on existing datasets of observed and/or retrieved ghost nets in northern Australia, and suggested options for improving data collection and management. This includes but is not limited to the use of the GNA ghost net identification (ID) toolkit and other materials, a standardised methodology for data collection, and reporting mechanisms.

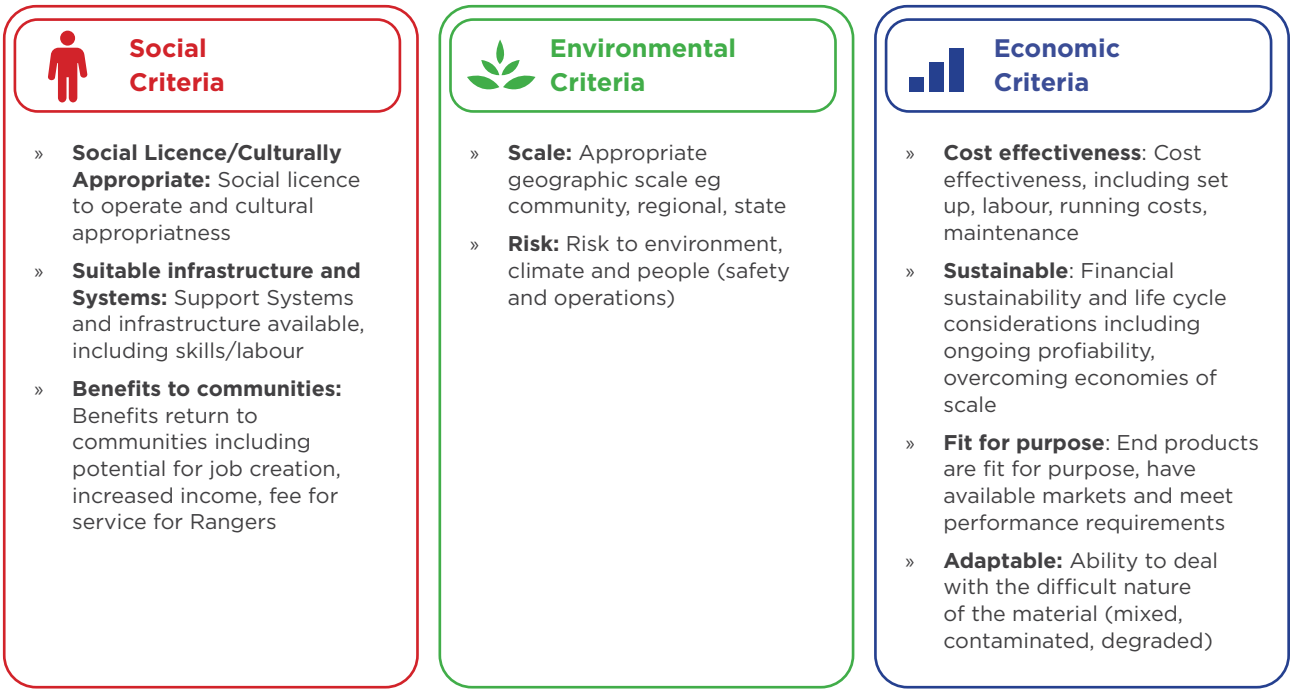


Figure 3: Key criteria for identifying investment options for northern Australia, to assist in making informed decisions

4. Current approaches, gaps and opportunities with respect to ghost nets and marine debris

The remoteness and significant distances of northern Australia, along with the small populations dispersed throughout pose a unique set of challenges, reflecting many remote and regional areas of Australia.

In most cases, there are limited or no domestic waste collection services, sorting and processing facilities or recycling schemes. This is primarily due to the high transport costs and inability to achieve the economies of scale needed to make these types of services and programs economical. Add to this the following factors and it makes for a complex situation requiring highly tailored, integrated, and fit for purpose solutions, for those in the Gulf and more broadly across all northern Australia:

- the significant quantities of marine debris washing up, including ghost nets;
- the difficulties Rangers face in accessing many of the beaches and coastal areas;
- the labour-intensive nature of the work required;
- the limited options for infrastructure and equipment to improve the efficiency and effectiveness of clean-ups; and
- the limited options available currently for what to do with the ghost nets and other marine debris once collected, in terms of disposal.

Each Ranger group in the Gulf faces a unique set of circumstances and challenges. While there is significant benefit from sharing knowledge, experiences and lessons learned between Ranger groups and others in this space, to date, clean-ups and retrievals have been achieved through the innovative and determined spirit of Ranger groups. Their connection to country is the primary driver, working in partnership with others to find ways to do these clean-ups and retrieve ghost nets.

The focus for Rangers has been on those areas where they can cost effectively access to protect and restore their country and reduce impacts on the environment and animals. As the scale of the issue continues to increase across northern Australia, particularly for marine debris, finding potential solutions that can assist in streamlining processes is key. Reducing inefficiencies from multiple handling of the nets and debris for disposal and the need for intensive labour as well as finding economical options for disposal is required.

Most marine debris (including ghost nets) recorded across northern Australia is sea-based waste (up to 90%) from the Arafura and Timor Seas, with a large proportion originating from places such as Indonesia, Papua New Guinea, and other parts of southeast Asia.[20] In areas closer to towns the amount of sea-based waste is lower (usually around 60-70%) with a higher proportion coming from land-based litter.[21] Finding solutions requires consideration of these issues in the context of broader waste management challenges across northern Australia and beyond. Without consideration of the bigger picture, solutions, at least for responsible disposal will be limited.

The Arafura and Timor Seas (ATS) are shared by Indonesia, Timor-Leste, Papua New Guinea (PNG) and Australia. The Arafura Timor Sea Ecosystem Action (ATSEA) program is a vital forum for bringing these countries together to work on transboundary issues such as marine debris and ghost nets. ATSEA, of which Australia is a signatory, has an objective to ensure the integrated, cooperative, sustainable, ecosystem-based management and usage of the living coastal and marine resources. This includes fisheries and biodiversity of the ATS, through formulation, inter-governmental adoption, and initial implementation of a regional Strategic Action Plan.[22]

While not the only forum working on addressing marine debris across southeast Asia, it is highly relevant given its location.

> Given up to 90% of marine debris and ghost nets are foreign in origin, stopping the problem at the source is the only solution to achieve long-term improvement of the issue, working in partnership through the Arafura Timor Sea Ecosystem Action (ATSEA) program between Indonesia, Timor-Leste, Australia and Papua New Guinea. Establishing and implementing a regional marine debris and ghost net action plan and monitoring network is key.

The feedback provided by stakeholders, along with the in-depth desktop review and materials analysis undertaken provides insight into options that can be explored further, along the ghost nets/marine debris impact pathway, towards finding fit for purpose solutions. Each stage (as shown in Figure 4) is discussed below, with further analysis of options found in Annex 1. Included is a benchmarking of each option against key criteria (Refer Figure 3) for identifying investment options for northern Australia, to assist in making informed decisions.

4.1 Interception, tracking and retrieval (in-water)

Locating and removing large ghost nets and other ALDFG such as Fish Aggregating Devices (FADs) directly from the water before they reach the Australian coastline reduces impacts on coastal ecosystems and native species, reduces biosecurity risks and is necessary for reducing navigational hazards for vessels. Multiple government agencies have varied responsibilities when it comes to dealing with ALDFG in Australian waters. This makes the issue complex and best dealt with via a whole of government response to achieve the most efficient and effective outcome in Australia's Exclusive Economic Zone (EEZ). This whole of government response exists to coordinate the detection, tracking, in-water retrieval and disposal of ALDFG. It is led by the Australian Fisheries Management Authority (AFMA), Maritime Border Command (MBC) (a multi-agency task force within the Australian Border Force (ABF)) and Parks Australia.

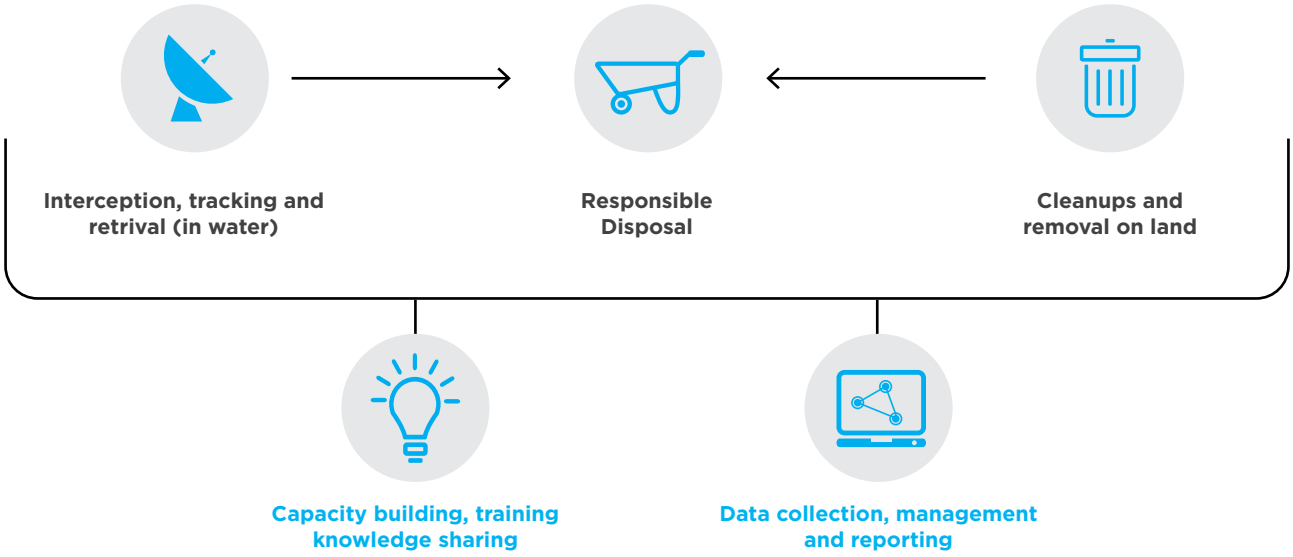


Figure 4 **Stages along the ghost nets/marine debris impact pathway, towards finding pragmatic and practical solutions**

There is a significant amount of foreign ALDFG (ghost nets, FADs and other gear) retrieved within the EEZ, particularly in northern Australian waters. In some instances, the ALDFG are too large for safe retrieval by the responding vessel and are often unable to be relocated by a suitable vessel and/or contracted platform. A trial is underway to test tracking devices across northern Australian waters. In instances where the ALDFG cannot be safely retrieved by the responding vessel, a tracker can be attached to the ALDFG to enable tracking and later re-location and retrieval by a suitable platform. The trial has a focus on preventing ALDFG from entering the Gulf of Carpentaria. While the trial will not be completed until June 2022, several suggestions for strengthening this promising solution are identified.

4.1.1 Available technology solutions for interception and tracking

Remote sensing of marine debris and ghost nets is still in its infancy. The field of research still faces significant technological challenges, particularly with respect to identifying nets that may appear the same colour as the ocean or be floating just below the surface, or for debris that is widely dispersed.[23] Though methods for using satellite data for detecting macroplastic on the surface of the ocean are not widely used, they are developing quickly. For example, Plymouth Marine Laboratory research project has had success in identifying plastic patches in coastal waters using Sentinel-2 optical satellite data, with suspected plastics successfully classified as plastics with an accuracy of 86%.[24] Limitations of the method include the impacts of cloud cover, wave caps, wind and the need for atmospheric correction. Data used has a spatial resolution of 10m, and the researchers developed a Floating Debris Index to identify clumps of debris - individual nets however, need to be visible at the surface over a large area for this method to apply.

While the success of this project gives cause for optimism, implementing remote sensing methods are not yet at the stage of development that could be feasible as an investment option for northern Australia. Justification of cost is made additionally difficult by the sparsity of on-water recovery resources. There may be more extensive costs involved to access imagery that will allow for tracking net movements over time, as opposed to getting a snapshot in time. In this context the use of an active tagging and tracking program is more cost efficient for successful removal of nets. Satellite imagery however, may be more feasible for detecting marine debris densities on beaches. Identifying marine debris on beaches using remote sensing would need to be closely tied to retrieval activities to justify costs and be delivered in partnership with Ranger groups in a way that complements their activities.

Drones are presently being trialled by Rangers to monitor turtle nesting beaches in some areas of western Cape York Peninsula with good success. They are also being used in east Arnhem for asset management, mapping and disaster management, tree condition assessments, wetlands assessment and feral animal monitoring. Although drones come in many different versions, relatively small fixed-wing and/or quadcopter aircraft are the types that are most frequently used to gather video and photographic data and are those most used for sea turtle research. The same technology may be suitable for understanding marine debris accumulation levels and where ghost nets are located. Drone technology is continuing to improve dramatically and is now able to provide mapping more cost effectively than previous photogrammetric techniques that required piloted aircraft. So this technology may also assist in undertaking broad surveys of the Gulf for ghost nets. For example, some unmanned aerial systems (UAS) are very affordable (around AU$230) for a fully functioning remote controlled plane including a nose camera to survey the surface beneath the aircraft as it moves along. They are significantly cheaper and more efficient than other drones due to their polystyrene body construction, which is also very light. A single motor is required to power the plane and it can fly for extended periods of time in comparison to quadcopter drones because it is able to generate lift to move, like an aeroplane.

Drones are now being used with fluid lensing, an experimental algorithm that uses light wavelengths that transmit through water to analyse submarine structures and undertake detailed and highly accurate underwater maps. Such maps could be used to identify where nets are entangled on reefs throughout the Gulf coastal waters and require removal but cannot be seen from the surface. While this technology is too expensive to be used widely, costs continue to reduce as technology advances. Another emerging technology is using drones with artificial intelligence to detect animals or objects in near real time. Using either standard or thermal cameras, this technique could be useful for identifying live animals entangled in nets floating offshore or on remote beaches. It is currently being used to locate koalas impacted after the 2019 bushfires on the east coast of Australia. Likewise, hyperspectral imagery combined with drones is now used to identify and map individual tree species within a forest. For ghost nets and marine debris, hyperspectral imagery might be useful to map the density of marine debris that cannot be mapped effectively using traditional photogrammetry. While drone capability continues to improve in terms of sensor quality and flight times, limitations remain relating to data processing and storage (imagery collected can create large file sizes); licenses for specialised processing software can be expensive; restrictions on the use of drones vary from location to location and include visual line of site obligations, no-fly zones etc; and bad weather can limit their use.

In 2018, the FAO Committee on Fisheries endorsed a set of voluntary guidelines for marking fishing gear in aid of ghost gear source control efforts globally and in illegal, unreported, and unregulated fishing activity.[25] The GGGI addresses potential use of gear marking using technology such as Radio Frequency Identification (RFID) and barcode tagging in the *Best Practice Framework for the Management of Fishing Gear* and has recently undertaken a pilot study in Indonesia with multiple tag types.[26] A study in Spain has shown that they can be successfully used to track and identify ghost nets.[27] RFID tags are physically attached to the net, and with a companion smart phone app, the tags can be read to reveal location. The tags are affordable and accessible on a large scale, with current prices ranging from AU$0.40 per unit upwards. The need for improved source control, combined with the low cost of tags make tagging of nets in overseas fisheries a key potential strategy for preventing the ghost net issue, however, source control is beyond the scope of this study.

Annex 1 provides an analysis of the potential options for investment benchmarked against the criteria in Figure 3 and as discussed above, may strengthen ghost net interception, tracking and retrieval (in-water).

4.1.2 Current approach and associated gaps, challenges and risks

Table 1 provides a summary of the current approach and associated gaps, challenges and risks.

Table 1 Summary of current approach and associated gaps, challenges and risks for detection, interception, and retrieval (in-water)

Current approach	Gaps, challenges, risks
Detection, interception, and retrieval (in-water) » ALDFG are regularly located by fishing boats, MBC vessels on scheduled trips, or via aerial surveillance. » Some Ranger groups in the Gulf of Carpentaria are using drones (eg. for turtle nesting surveys) and have found these to be useful for inspecting nets found floating close to shore. » Ranger groups have a high level of awareness of the expected locations of nets and marine debris. » Key ghost net and marine debris interception points (hotspots) in the Gulf of Carpentaria are known, being the northern Cape York Peninsula of QLD and Northeast Arnhem and south of Gove Peninsula in the NT. » If a MBC vessel is unable to recover a net, AFMA is requested to organise a contracted solution (Parks Australia contributes financially). » Northern Prawn Fishery boats also report and retrieve ghost nets located in-water at their own cost. Between 2015 - 2018 they reported 8 ghost nets, some of which they retrieved. If the net is too big to retrieve or tow, they will notify AFMA of its position. All ALDFG found are logged by NPF fishers in the GGGI Reporter app. Other NT based fisheries[28] also report nets from time to time.	» ALDFG, particularly ghost nets are mobile and can move quickly if caught in currents, or potentially sink, increasing the risk that the ALDFG will not be found again when retrieval is organised. » Potential ghost net and marine debris interception locations, based on known oceanographic currents, ghost net accumulation points are known within the Gulf of Carpentaria. There is less information available across other parts of northern Australia. These locations can be very far away from where port infrastructure exists to offload nets picked up at sea. » There is limited cross over between MBC activity and Ranger group activity. MBC activity is confined mostly to offshore and they have limited capability to pick up nets. » Training, licensing, and technical experience is required for operating drones. Drones have a limited range/battery life and sensitivity to windy conditions. » There is currently no viable technology available to cost effectively locate and remove marine debris prior to it reaching land.
Tracking for eg, via GPS devices and remote sensing (in-water) » A 12 month tracking trial (joint initiative being run by AFMA, MBC and Parks Australia) is underway, using 22 trackers for ghost nets. The trackers send a signal every 6 hours, which is monitored by AFMA. The aim is for quick recovery (within 3 months which is the life of the battery). FADs are included in scope for the trial. The pilot funding has been fully allocated and the project is running well. » GNA ran a trial in 2012 using satellite technology to track the pathway of a net. When it reached Australian mainland, Rangers were able to easily locate it and examine the net for entangled wildlife before removing it.	» Battery life has been identified as a limitation. Solar powered devices that extend the length of time ghost nets can be tracked could be more effective for delayed retreivals. Solar powered units however, are generally larger (and more cumbersome), more costly to transport and more expensive to purchase than battery units. » Using satellite imagery, it can be difficult to see mobile ghost nets and other ALDFG, depending on the size, whether it is mostly submerged, and appears the same colour as the ocean. Identification technologies are developing quickly.

4.1.3 Opportunities for investment

Those options considered most suitable for addressing the situation in the Gulf of Carpentaria with respect to in-water ghost net interception, tracking and retrieval, incorporating the priorities identified by key stakeholders are summarised as follows:

- Any expansion of the tracking trial to other parties, such as Northern Prawn Fishery vessels would best be done after the trial has run its course and the technology has been tested and proven.
- Consider using solar powered tracking devices where it is likely retrieval will be beyond the 3 months life of the current batteries being used in tracking devices during the Australian Government trial.
- Tracking and retrieving multiple nets (or other hazards such as containers) in proximity could increase cost efficiency when tendering for retrieval.
- Satellite imagery via remote sensing technology may be feasible for detecting marine debris densities on beaches. This would need to be closely tied to Ranger retrieval activities to justify costs and be delivered in partnership with Ranger groups in a way that complements their activities. With technology advancing rapidly and some ghost nets being multiple kilometres long, imagery may be able to detect and track them shortly, so it will be important to follow developments with remote sensing capability.
- Drones could be used by Ranger groups to inspect nets close to shore prior to washing up on beaches or for doing a rapid assessment of local beaches to prioritise areas prior to conducting clean ups. With the technology advancing rapidly, drones may also be useful for broader mapping of ghost nets, identifying nets entangled on the seabed and where live animals are entangled and require rescuing. These should be investigated in consultation with Ranger groups.

CASE STUDY

Buoys have been previously used by NASA and other international agencies to track a variety of objects. As part of a ghost net recovery project, the National Oceanic and Atmospheric Administration (NOAA) together with Airborne Technologies Inc. built over 900 buoys. Each of them is the size of a laundry basket, self-sufficient with solar panels embedded. The buoys were provided to the U.S. Coast guard and research vessels to tag and track fishing nets out on open seas.[29]

4.2 Clean-ups and removal (land-based)

Debris loads on beaches and other coastal areas in the Gulf of Carpentaria vary greatly depending on season, location, weather events and changes in debris sources. There is consensus amongst those Ranger groups participating in the study that debris loads are increasing - in some places there has been a reduction in the number of ghost nets washing up, but an increase in marine debris and in other areas there has not been much change with the number of nets being found.

In a recent study, CSIRO compared ghost nets observed from aerial helicopter surveys across the region in the last two decades to understand any changes in numbers and location of nets. Despite management efforts, the study found that the numbers of ghost nets along shorelines in the Gulf of Carpentaria appear to have increased across the region.[30] The study also reported that ghost nets recorded by aerial surveys are an underestimate of the true number of nets present along the coastline, because aerial surveys are less likely to detect smaller fragments of net, nets buried under sand or those that may be obscured by vegetation. As of 2015, CSIRO reported in their study that around 15,000 ghost nets had been removed from the region. Ghost net removal also occurs in the Torres Strait, other parts of the Northern Territory, and the Kimberley in Western Australia. Data collection since 2015 has been inconsistent, due to the limited capacity of GNA and the delivery of heavy workplans by Rangers.

4.2.1 Quantifying the scale of ghost nets for clean-up

Information available to quantify the scale of ghost nets and marine debris still to be cleaned up across the whole of the Gulf of Carpentaria is limited to aerial survey results that generally do not cover all areas. Recent aerial surveys in 2019 and 2020 located significant numbers of ghost nets throughout the survey areas, as reported in the CSIRO study.[31] Figure 5 shows the locations where nets were detected in the 2019 survey. No mapping was undertaken for the 2020 survey but between 1,419 and 1,529 ghost nets were recorded between Peak Point, Punsand Bay on northern Cape York and Aurukun on western Cape York Peninsula. Substantial quantities of marine debris were also identified during both surveys.

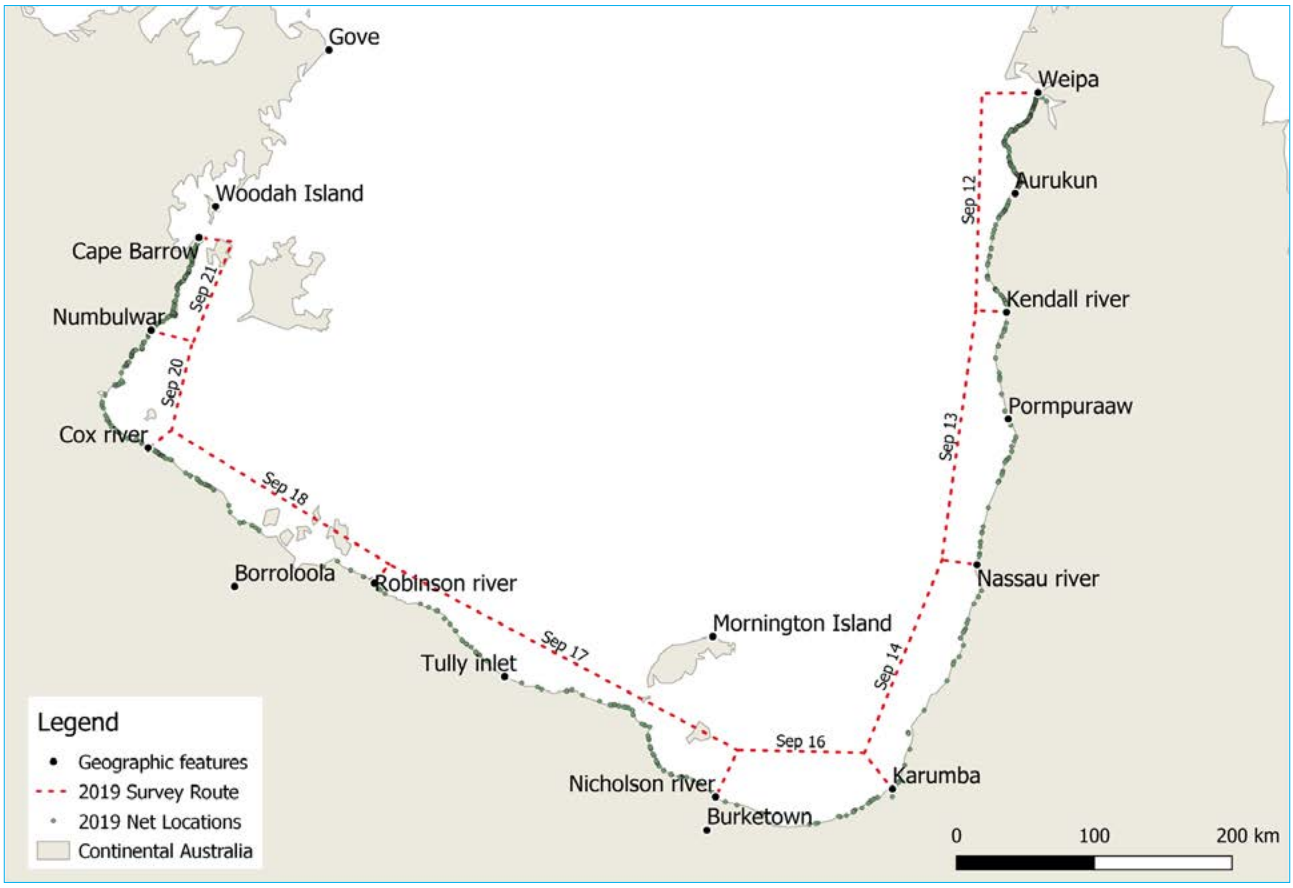


Figure 5 **Location of ghost nets in the 2019 surveys as reported by CSIRO**

The scale of the challenge for Ranger groups to undertake clean-ups and removal of ghost nets and marine debris is significant. For example, Dhimurru Aboriginal Corporation in northeast Arnhem, has 70 kilometres of coastline that attracts marine debris, on the same beaches used by sea turtles for nesting. It is a significant hotspot for marine debris and ghost nets. Working in partnership with Tangaroa Blue, Sea Shepherd and Conservation Volunteers Australia, and previously the NT Government, the Rangers have been conducting annual intensive beach clean-ups for several years. On Djulpan Beach alone, the Rangers, Sea Shepherd and volunteers collected in 2018-2019, 13.1 tonnes of marine debris and 6 tonnes of ghost nets across 12 kilometres of beach over 2 weeks.[32,33] It is a similar situation on Cape York and in the Torres Strait. Tangaroa Blue reported that from 60 clean-ups between 2015-2016, almost 32 tonnes of debris were removed.[34] In Mapoon, a known hotspot on western Cape York Peninsula, 4.6 tonnes were removed from Back Beach, with around 9% being fishing related debris. Australian Marine Debris Initiative (AMDI) data indicates that quantities of marine debris can be as high as 3 tonnes per kilometre in some remote locations but is generally around 65kg per kilometre when averaged across Cape York Peninsula.[35]

4.2.2 Clean-up and removal process options

Undertaking ghost net and marine debris clean-ups requires significant coordinated effort, time commitment, labour and financial resources. Rangers are operating in harsh and difficult conditions because of the remoteness, weather, and the challenging access to get on and off many beaches and the scale of the debris/ghost nets present. Using beach cleaning equipment and infrastructure to make the job much easier, such as those used on urban beaches are generally not suitable, so any solutions need to be fit for purpose and adaptable to each Ranger group situation.

For those Rangers involved in the study, accessing beaches generally involves a combination of 4WDs and all-terrain vehicles (ATVs) with a trailer, and/or boats and in some cases barges (owned or hired). Access is determined by the location, weather and tides and the nature of the beach and its accessibility.

CASE STUDY: FIT FOR PURPOSE COMPACTING AND BALING, INDONESIA

SeaNET Indonesia was a program funded by the Australian Government and led by TierraMar to develop a cost effective and tailored model for fisheries extension services for remote coastal villages in the Coral Triangle region. The aim was to improve conservation outcomes by addressing community priorities related to poverty alleviation and food security. A key focus included a community designed and led ghost net recycling business in Merauke in Papua, Indonesia as a mitigation to reduce the significant quantities of ghost nets found in the area before they were transported in currents to the Gulf of Carpentaria. Based on the ZSL Net-Works model and following strict quality standards provided by Aquafil, the community collected and hand washed nylon monofilament nets, before compacting, baling and shipping to Slovenia for processing by the company Aquafil into the recycled nylon product Econyl. The project commissioned a fit-for-purpose compacting and baling machine designed to suit harsh conditions in a regional remote context.[36]

All Rangers participating in the study indicated that the equipment they use to collect marine debris and ghost nets includes collection and bulk bags, and knives/machetes or in some cases angle grinders for cutting up nets. Rangers identified other equipment that may potentially suit some and improve the efficiency of beach clean-ups.

This included beach cleaning machines, power shifting shovels, motorised sieves, tray loaded winches and heavy payload drones, as well as improving access to beaches where it is by road. It is important to note that generally, beach cleaning machines are designed to collect small post-consumer waste and sift rocks from recreational beaches - price and beach access requirements are key issues. Where debris is sparse, using these machines may end up being slower than a group of people walking and collecting by hand. Not all Rangers indicated these would be useful as the equipment or infrastructure needs to be fit for purpose and suit the situation and conditions each Ranger group is working under. A need for more manpower however, to clean up beaches as well as finding ways to reduce multiple handling of debris or nets were raised as key needs by most participating in the study. In the past, through the GNA program helicopters have been used to assist in collecting nets, however this was an expensive exercise. Regardless, helicopters may prove useful from time to time.

The recent introduction of air boats into Australia is worth investigating. These vessels are widely used in the United States for transport over shallow water, marshland/swamp environments. Australian made vessels have undergone testing for use in remote areas during floods.[37] The available models can be transported on a small trailer and do not need a boat ramp for launch. They can travel over extremely shallow water and over land when the surface is wet. They have a maximum load of 1,100kg and may be useful for Rangers in some situations where ghost nets are in shallow water or for general transport along the beach.

Annex 1 provides further information and an analysis against the criteria in Figure 3, on the potential options for investment identified that are currently being used by some Rangers that may be useful for others. It also identifies new equipment that may assist in improving the efficiency of land-based clean-ups and removal.

4.2.3 Current approach and associated gaps, challenges and risks for land-based clean-ups and removal

Table 2 **Summary of current approach and associated gaps, challenges and risks for land-based clean-ups and removal**

Current approach	Gaps, challenges, risks
Beach access, existing port infrastructure and potential landing areas » Stakeholders reported a wide range of beach access conditions. Some beaches can be accessed by roads and tracks by Ute/4WD Landcruiser and side by side ATVs or quadbikes. Trailers are often used with all these vehicle types. » Some beaches can only be accessed by boat or barge in certain conditions. Some Ranger groups use barges to carry supplies on trips to remote beaches or islands. » Size of the beach, distance from base, road access to the area, getting vehicles and equipment onto the beach, multiple handling of the ghost nets and marine debris and the enormous distances are key considerations. » Path widening and hardening has been conducted by some Rangers to improve access.	» Beach access options are highly variable and site specific for all Ranger groups in the Gulf of Carpentaria. Beach access is also impacted by seasonal road closures and rough sea conditions. » Challenges identified include soft sand, vast distances, steep beaches, rocks and organic debris, presence of turtles nesting/protected species, significant tidal variances and shallow water. » Trips by boat to remote beaches require bringing all supplies to be self-sufficient. Trips can often last from several weeks to months. » A vessel large enough to pull a net from the water can often not get close enough to shore due to the shallow clearance. A 6m vessel struggles to pull a very large net in the water. » Increasing access points to beaches to allow vehicles may be possible in some situations but the risk of environmental impact must be considered. » Impacts on turtle nesting must be avoided eg. crushing turtle nests or creating vehicle tracks that inhibit turtle and hatchling passage. » Vehicle capacity can easily be exceeded if the volume of nets and debris to collect is not known in advance. » Heavy use, salt, unsealed roads etc lead to high wear on all vehicles and equipment. Maintenance is often not undertaken regularly, if at all, depending on budgets available.

Current approach	Gaps, challenges, risks
Clean-ups and ghost net retrieval » All Ranger groups, NGOs and volunteers collect marine debris mostly by hand, sometimes with poles to reduce bending. Several NGOs hold annual campaigns with Rangers and volunteers to clean up easy to access beaches. These events are usually held separately. » Net size is highly variable (up to multiple tonnes and multiple kilometres long) and can be degraded, releasing a powder type substance when moved. » Plastic debris in many cases is highly degraded and crumbles when picked up. » The retrieval method depends on debris type: microplastics must be sifted, marine debris and small nets can be picked up and placed into bags. Large to very large nets are the most challenging and need to be cut up. » Removing nets often requires many people to be involved in dragging or pulling the nets out of the sand (many are embedded), cutting the nets (either by hand using a knife or with angle grinders/handheld concrete saws), then placing it in collection bags and transferring to boats/ barges, ATVs or 4WD utes, before transferring again to small trucks which take the nets and marine debris back to base, before offloading it either in a holding area or landfill. » Tray-mounted winches have been used to assist with lifting in some places, although the harsh conditions lead to high maintenance requirements and most break. » Helicopters have been used in the past to successfully move nets and are regularly used for feral animal control. » Different Ranger groups utilise the Junior Ranger program, NGOs and volunteer teams, general community participation, schools or corporate education programs for annual or regular clean-ups, although these are centred around easy to access beaches. Rangers will do clean ups at other times, as the workplan allows.	» There are significant quantities of debris pieces to pick up manually. A long time is spent over many kilometres walking and bending in hot conditions when scattered across a large area. Beach clean-ups can take significant time and resources, depending on the volume of debris, the length of the beach and the number of people involved. » Bottles/containers retaining seawater/ bodily or unknown fluids are often found posing potential safety risks. » Biosecurity risks must be assessed using established protocols and require nets or debris to be burned when risks detected. » As debris degrades it breaks into smaller pieces and generates microplastics which are not able to be collected without sifting. Many groups do not have the time or equipment to do this effectively. Heavily degraded plastic cannot be raked into a pile for easier collection as this causes the material to disintegrate. » Some beaches, on more remote islands such as the Wessel Group for example have never had clean-up activities due to difficult logistical challenges but have significant quantities of marine debris, reported to be knee-deep in places. » In-water net release from reefs and retrieval poses safety risks to Rangers, where there are crocodiles, sharks and other dangerous marine wildlife. » Helicopters that can carry the weight required are expensive and difficult to organise given their high demand. » There is a clear need for increased labour to support Ranger groups. » Large clean-ups require significant organisation and logistics and are time limited, given the volunteer nature of those participating.
Storage » Some Ranger groups are stockpiling nets for example behind beaches, behind Ranger bases or in shipping containers as landfill sites are full or will not take the nets.	» Highly degraded nets left to dry can create microplastics. Microplastic generation increases once nets are dry. Degradation from UV exposure increases once materials are out of the water. » Uncleaned nets attract rats. They can be smelly and unpleasant.

4.2.4 Opportunities for investment

Those options considered most suitable for addressing the situation in the Gulf of Carpentaria with respect to clean-ups and removal of ghost nets and marine debris, incorporating the priorities identified by key stakeholders are summarised as follows:

- Provide additional resources to support dedicated clean-up teams within Ranger groups as required. These could be supported using a fee for service model.
- Upgrade hand tools for cutting, provide collection equipment like rakes and picks, and modify vehicles to have the necessary infrastructure to increase carrying capacity for transport and storage that are fit for purpose to increase clean-up efficiency. Each Ranger group has specific needs based on the conditions they work in for marine debris/ghost net removal and therefore there is no single solution for all.
- Beach cleaning machines (either sieve or 'picker' mechanisms) may aid in clean-ups in some locations where beaches are easily accessed and flat, where Rangers have highlighted them to be potential options. A trial should be conducted however prior to purchase to ensure they are fit for purpose.
- Stockpiled ghost nets could be stored in shipping containers to reduce degradation and formulation of microplastics and prevent rats once brought back to a Ranger base.
- A landing barge could be used to transport equipment or beach cleaning vehicles to a beach for some Ranger groups that currently do not have barges. The size of the Gulf and water conditions mean that multiple local transport options that suit conditions are preferable compared to one service for the entire region. Boat/barge hire/purchase, fuel, and crew cost must be considered.
- Further investigation is warranted on air boats to establish whether they are fit for purpose and may assist some Ranger groups to improve efficiencies of clean-ups.
- To reduce bulk, fit for purpose mobile compactors/baling machines to use when collecting marine debris and ghost nets or undertaking preliminary sorting, could assist in improving cost efficiencies, reduce bulk and the amount of handling required. This would require some sorting being undertaken by either Rangers or those engaged to undertake baling and compacting process.
- To support the annual clean ups that take place around the Gulf organised by various Ranger groups with their NGO partners, a Gulf wide Clean Up Blitz involving Governments, Ranger groups, NGOs, industry, and communities could take place at identified hotspot areas once or twice a year. This could include use of government infrastructure from Defence and potentially fishing industries in the off-season to provide necessary resources and support to help clean up the more remote hotspot areas as well as remove collected marine debris and ghost nets from collection points to transfer or disposal hubs.

CASE STUDY

Annually, several large scale cleanup efforts over several weeks occur in Papahanaumokuakea Marine National Monument. These are organised by the nonprofit Papahanaumokuakea Marine Debris Project[38], which partners with the state of Hawaii and federal agencies, including the National Oceanic and Atmospheric Administration and the U.S. Fish and Wildlife Service. In the 2021 clean-up, over 43 metric tons of ghost nets and other marine plastic was collected from the Northwestern Hawaiian Islands, on the uninhabited beaches and reefs almost 2,100 kilometres north of Honolulu. Each expedition focuses on a different hotspot area, with the latest focused on the shorelines of the various atolls. A trip later this year will remove nets from the reefs that surround the islands. NOAA estimates that the Northwestern Hawaiian Islands accumulate about 57 tons of debris each year. The clean-up expeditions also provide opportunity for research to strengthen understanding of the problem.

4.3 Responsible disposal

Globally, there are many options emerging for recycling or repurposing of ghost nets and marine debris. Several businesses are now in operation around the world promoting their marine plastic products, such as bracelets, shoes, skateboards, swimming costumes, clothes, carpet tiles and chairs. Generally, the feed stock of ghost nets and marine debris received for these products are coming from places with good infrastructure and cost-effective transport options. Even so, there are many lessons that can be learned from these organisations and businesses who have pioneered the way for others (refer Lessons Learned Box).

The unique situations and challenges that each Ranger group face, will determine the best pathway for responsible disposal in the case of the ghost nets and marine debris found in northern Australia. Each group will require a tailored solution based on a well-informed planning process, that considers not only the amount of materials but also how to get those materials cost effectively from where they are collected to a transfer point where they could be either transported or processed in-situ. There is unlikely to be a single solution for northern Australia, however sub-regional solutions may be possible. It is also likely that any solution will need to be a part of a broader waste management solution for the communities located around the Gulf of Carpentaria to provide economies of scale.

Biosecurity is an important consideration when managing ghost nets and marine debris, especially when it is being stored in open landfills, is being considered for transportation or as feedstock into alternate uses. Given most of this waste is from overseas and potentially contaminated, and that it may have been in ocean currents for many months or years, biosecurity risks can be a real concern. Ranger groups are all trained and engaged in biosecurity protocols with respect to ghost nets and marine debris and regularly inspect and where necessary report any risks. Where risks are detected, nets or debris are removed from the beach to dry out, before being burned. Decontamination of ghost nets may require more attention however, for solutions involving on-processing into products.

4.3.1 Current uses of nets

In some northern Australian Indigenous communities, ghost nets are used as screens on verandas, adorned with shells and glass or plastic floats, or as fencing for chicken pens. Fishing and yam bags are also often made from pieces of net found washed up on beaches. In more recent years, ghost net art has proven to be a powerful vehicle for alerting the public to the damage that ghost nets inflict on the marine environment. Through the Ghost Net Art project, artists in Indigenous communities and elsewhere have created inspired works using weaving, with which they tell stories about the sea and the culture of Indigenous Australian people. These unique art collections have been the subject of exhibitions and installations both in Australia and internationally and are highly valued.[39,40] Some of the art pieces are now part of private and public collections (such as the UBC Museum of Anthropology in Vancouver and the Ethnographic Museum of Geneva).[41]

In addition to retrieving ghost nets, the Northern Prawn Fishery (NPF), Australia's largest and most valuable prawn fishery, fishes in waters across northern Australia. The NPF is certified as sustainable against the Marine Stewardship Council global environmental standard for sustainable and well managed fisheries. It has strict regulations and protocols in place to minimise loss of nets at sea. At the end of each fishing season nets are replaced to maintain fishing efficiency. This means annually, large volumes (>20 tonnes) of end of life nets are taken to landfill at a significant cost to industry, unless other users can be found for them such as crab pot makers, schools (for art projects), aquaculture ponds etc. As a part of its commitment to sustainability, NPF is looking for closed loop solutions.

As a first step, understanding what marine plastic debris and ghost nets are made from (classification), the quantities available and their quality are key to identifying whether suitable options exist for on-processing into commodities and selling into existing markets, or other disposal options will be more suitable.

4.3.2 Understanding what nets are made of

From the materials analysis work conducted as a part of this study on net samples provided from the around the Gulf and on water retrievals, SMaRT@UNSW found that 90% of the samples were made from High-density polyethylene (HDPE). The other 10% consisted of Polyethylene Terephthalate (PET) and Polypropylene (PP) (Refer Annex 2 for results and how the classification process was undertaken).

Currently, the manual labour carried out by the Rangers and volunteers in northern Australia does not extend to classification by polymer and separation of plastics (for example into high quality versus everything else).

4.3.3 Understanding quality and quantity

Polymers are one of the most versatile materials ever created by mankind. Being rigid, soft, and malleable means there are a seemingly unlimited number of applications. It is this very versatility that has led plastic to spread across a multitude of industries around the globe, and as such, enter waste streams within and outside of controllable environments. Exposure to natural environments, however, has effects on polymers in various ways. The effect of salt water, UV radiation and algae and different microbes vary from plastic to plastic as some are more resistant to effects than others. Additionally, salt and sand can damage re-processing equipment, leading to corrosion or scratching of screws and barrels and other parts of machinery that are being used for thermodynamic processes. Finding cost effective options for re-processing that do not require intensive cleaning efforts are key considerations for ghost nets and other marine plastic debris items.

It is crucial to identify to what degree plastic marine debris or ghost nets have degraded, as some polymers might be beyond recovery, or special additives may be necessary to recycle them into a valuable and structurally stable asset for re-use. Depending on how degradation has affected the plastic in its integrity and characteristics, different viable options are available. The weathering of polymers can lead to parts of plastic particles eroding and cracking.[42] Furthermore, as plastics degrade in our oceans, small parts, referred to as microplastics, are separated from the main polymer waste body, not only further contaminating the environment, and impacting on many marine species but also our food sources, making it hard to recover them.[43] It is also important to understand what additives may have been added to the plastic used to make ghost nets and other debris. For example, some plastics contain POPs (persistent organic pollutants) and BDEs (brominated dipenyl ether, flame retardants) which have been banned in many countries for a long time. If hazardous substances or other pollutants are used, these will need to be properly separated first, otherwise they would end up in the recycled plastic and therefore also potentially in the new products. Of paramount importance is toxic-free manufacturing for reuse and recycling to reduce health risks to people.[44,45]

Due to limited data available on the number of ghost nets collected since 2015 and their quality from Ranger groups across the Gulf at this stage it is unclear the quantities available. It is assumed, from the discussion in Section 4.2, that there are significant numbers of nets available to be recovered based on the most recent surveys, subject to the capacity of Rangers to do this. It is also clear from Rangers that the number of nets arriving on beaches will continue.

Learning the lessons

Case Study	Insights/Lessons Learned
Ghost Net Art Project, Australia[46]	» The commercial success of Australian Indigenous woven art pieces shows the high value of products that speak to the issue of ghost nets, to Indigenous culture and connection to country, and to the use of recycled materials. » New end products should attempt to retain this connection and story by balancing the unique characteristics of the material with technical performance needs.
SeaNET Indonesia[47]	» The cost of exporting nets for recycling is prohibitively high from remote locations. The closer the destination the cheaper the cost. » Balers/equipment may need to be custom built to deal with nets and harsh climates. » Relies on high inputs of people power for manual washing and pre-processing, depending on the end purpose.
Fishing for Energy USA[48]	» This successful project relies on ongoing government funding for port-based collection points. » Uses existing large-scale waste to energy facility. » Needs consistent supply, consideration of safety aspects and highly technical capability to operate.
DuraOcean – Ocean Plastic Chair[49] Islander Recycled Kayaks[50]	» Many high-profile products made from fishing nets have supplies from easy to access fishing industries eg. North America, Europe. » Processing is outsourced to large scale 'processing partners'.
Bracenet, Germany[51] Olive Ridley Project, UK Hand woven bracelets, dog leashes etc.[52]	» Small consumer products need a high volume to generate enough revenue to cover costs. » Risk of short life / quickly becoming waste. » Labour availability and cost also important.
Clean Sea Initiative, India Polymers from waste plastic used in roads[53,54]	» Using recycled polymer for bitumen additives required a high level of separation (chemical process). » Concerns about weathering leading to toxic leachates and microplastics into the surrounding environment are supported by research.
Gasification-Sierra Energy, USA Pilot stage project[55] Renewlogy – Pyrolysis, USA Pilot stage project[56]	» Sierra Energy facility requires minimum of 10 tonnes per day. » This and many other processing machines and systems are efficient because they are run constantly. Machines that can run batches must be designed with that in mind, and machines that can cope with differences in feedstock from batch to batch must also be designed specifically. » High technical capability and safety considerations to operate.
Dresden Sunglasses Nets Trial, Australia, Injection moulding for small consumer products[57]	» The injection moulding process and equipment used by the company was not tolerant to the fibrous and contaminated nature of the nets leading to difficulties in processing. » Small products need high and consistent volumes to generate enough revenue to cover costs.

4.3.4 Understanding material flows and product options

Domestic waste management, recycling systems and infrastructure are lacking across northern Australia, limiting options available for cost effective disposal for ghost nets and marine litter, that provide economies of scale. A 2017 regional waste assessment report of Cape York Peninsula identified no coordinated recycling industry presence in the region, and only minimal local recycling taking place for things like batteries, metals and, to a limited extent, cardboard.[58]

As noted previously, it is unclear what the scale of potential material flows are for marine debris and ghost nets across the Gulf of Carpentaria. While there is some information available from beach clean-ups and through the AMDI, quantities are variable and inconsistent each year and not all locations are collecting data. Because of this, and that generally waste volumes are small (relatively speaking compared to municipal waste) and dispersed, the consequences are high costs per tonne collected. This limited and inconsistent supply means that any product produced from it must maximise the potential profit to fuel a sustainable business model. In isolation, the economies of scale are not available for ghost nets and marine debris.

Even when combined with municipal waste from each community across the Gulf, achieving this is unlikely as the volumes are not high enough to out-weigh the high transaction costs without subsidisation. Regardless, an important consideration for ghost nets remains the need to divert them away from landfill and reduce the damage they cause to the environment through impacts on marine wildlife and the continual microplastics generation as they degrade.

Manufacturers in Australia are increasingly looking to use/incorporate recycled materials, driven by public interest in recycling[59]. However, there is concern about resin purity and properties, leading to many importing resin from international suppliers. Changes in Australia's recycling policies mean that soon recycled municipal waste will be exported only after pelletisation[60]. Recycled pellets from the Gulf of Carpentaria, even from municipal waste are unlikely to compete against an influx of recycled pellets from metropolitan sources due to their inability to achieve economies of scale and provide consistent supply. Figure 6 shows the hierarchy of potential end products, considering life cycle aspects (i.e. longer lasting higher end products are prioritised).

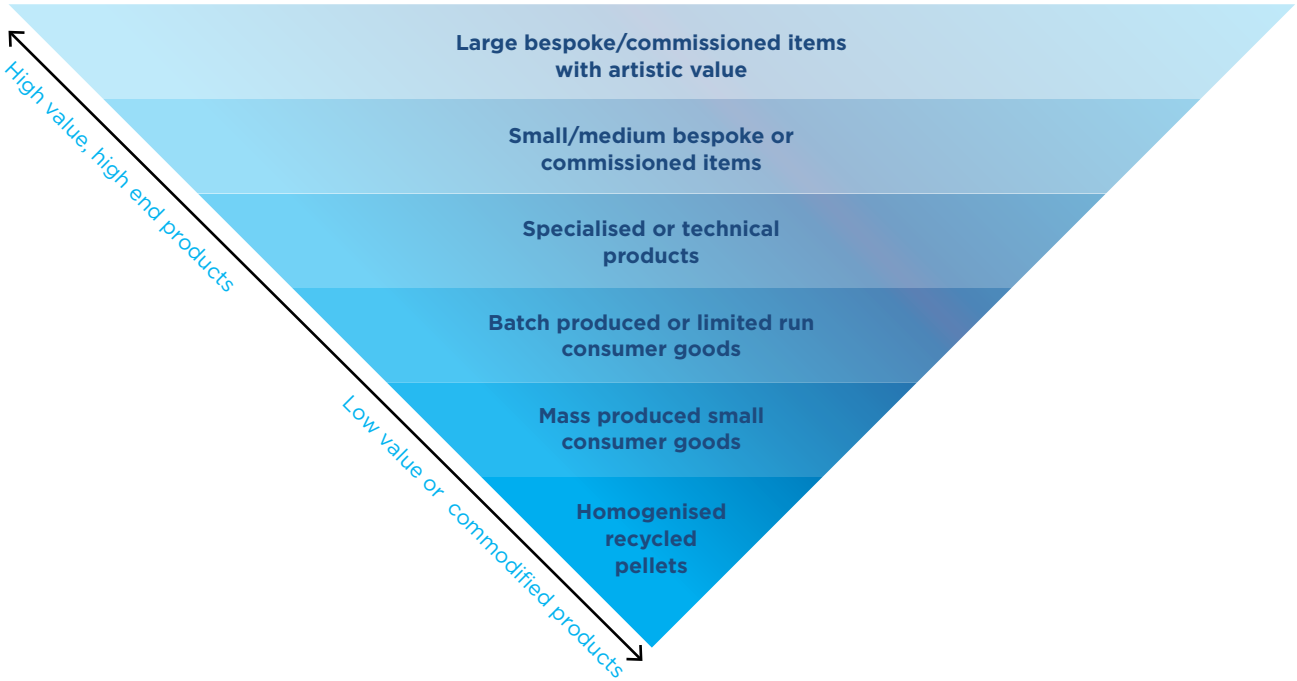


Figure 6 **Hierarchy of end products based on potential profit, with consideration of length of product life.**

Photo by Jane Dermer

For ghost nets and marine debris from northern Australia, overcoming issues around economies of scale, requires an alternate focus on high quality bespoke products that reflect the unique cultural and artistic values and the strong connections to country of Indigenous communities in the region. Such products are more likely to provide opportunity to develop profitable, self-sustaining business models to responsibly dispose of the nets. The process of homogenisation, for example turning marine debris and ghost nets into pellets, is a loss of opportunity to use the unique story and characteristics of the Gulf of Carpentaria and one that will most likely be unsustainable. Opportunities exist and art communities are interested in expanding their capacity in ghost net art weaved pieces as well as into other bespoke products.

For ghost nets and marine debris from northern Australia, to overcome the issues around economies of scale, the focus must be on high quality bespoke products such as homewares, housing products and artistic pieces. Reflecting the unique cultural and artistic values and the strong connection to country of Indigenous communities in the region, will provide opportunity to develop profitable, self-sustaining business models for the region to responsibly dispose of ghost nets.

In recent years there has been a significant improvement in available technologies for recycling and reprocessing including through thermomechanical recycling (extrusion and injection moulding), thermochemical recycling (pyrolysis and waste to energy), re-manufacturing (MICROfactories™) and incineration. Some of these technologies may provide a solution towards responsible disposal for the ghost nets and marine debris washing up across northern Australia if a sustainable business model can be identified. Annex 1 provides an analysis of the technologies benchmarked against the criteria set out in Figure 3 to provide opportunity for responsible disposal of ghost nets. The most feasible technologies were found to be re-manufacturing and in limited cases thermomechanical recycling (extrusion and injection moulding). Section 5 provides a detailed discussion on both preferred methods and how each could provide feasible outcomes for ghost nets, marine debris and end of life fishing nets. All other technologies have significant shortcomings that prevent them from being fit for purpose for the Gulf of Carpentaria.

Re-manufacturing replaces components or re-processes used parts, to recover their value and reinstate it into a like-new condition and quality in a MICROfactorie™. The environmental impact of this technique is reduced by both the reduced waste created and fewer natural resources needed to produce high quality end products such as Green Ceramics™ that can be used in buildings. In addition, the method can handle contamination and mixing of feedstocks and does not need regular supply or quantities to produce end products as products can be bespoke. Section 5 provides more information on the prototyping that would be required to investigate this.

CASE STUDY: GREEN CERAMICS™, AUSTRALIA

The SMaRT Centre has developed a Green Ceramics MICROfactorie™ at UNSW to not only conduct ongoing research and development on its ceramics technology and capability, but to advance its collaboration with industry and the community as part of its continuing work. The UNSW Green Ceramics MICROfactorie™ has developed materials that have been used in numerous industrial and community settings and is now operating at a commercial scale. The ceramics are used as kitchen benches, table tops, floor tiles, furnishings and for other applications. SMaRT uses a variety of waste materials to produce a range of 'green' materials and products for the built environment. The ceramic products are mainly made from types of waste glass and textiles that are traditionally not subject to recycling. This is due to issues such as contamination and material complexity. Other waste streams that can be used to create these ceramics, include waste wood and plastics. Essentially, these green ceramics are a new generation of high performance, non-toxic, engineered composites, for use in buildings, as furniture and for various architectural and decorative applications.[61]

Thermomechanical recycling (Injection moulding and extrusion) is prone to complications and depends strongly on the quality of the feedstock. To control the quality of the extruded or moulded end product, it is important to know what is being fed into the machine. The complexity of the processes and the number of process parameters makes it hard for manufacturers and researchers to meet manufacturing requirements at a low cost. Quality of the extruded parts is the main goal of extrusion, which has a direct effect on expected profits for companies manufacturing plastic products.[62] The need for constant and steady supply of feedstock, together with the chances of contamination from organic materials, cross contamination of different polymers and specialised separation, grinding and cleaning set up needed, lead to both injection moulding and extrusion not being feasible for recycling of ghost nets and marine debris. End of life nets from the NPF and other fisheries around Australia however, that have much less contamination and can be more easily cleaned and are of a higher quality (less degradation), may be a possibility. Section 5 provides more information on the prototyping that would be required to investigate this.

Very small-scale extrusion machines are available commercially, for example Precious Plastic or Plastic Collective Shruder units.[63,64] These small units are suited to batch processing, small volumes (5-50kg per day) for use within and by communities. Although these machines may be well suited to community recycling programs that focus on community outreach or education relating to municipal waste, the key limitation remains the restrictive feedstock requirements (quality and quantity). The machines are not suited to the high levels of contamination and degradedness of most marine debris and the fibrous nature of ghost nets. Given the complexities with working in the Gulf and the need to find economies of scale, it would be difficult to establish a materials pathway that produces enough saleable product/revenue to be sustainable beyond the life of the project using this method. Incorporation of some extrusion may be possible for use in ghost net art or production of 3D printing filament using municipal waste, but in terms of dealing with the ghost net and marine debris issue these machines are not feasible.

CASE STUDY: EXTRUSION & INJECTION MOULDING, AUSTRALIA

An Australian Eyewear manufacturer (Dresden vision) has recycled used shampoo bottles into prescription and sunglass frames. Following sorting, shredding and washing the HDPE-based bottles, they were extruded using a local re-processor in Victoria. After the waste feedstock is turned into pellets, they are fed into an injection moulding machine to create the final product. This approach was only a trial and unfortunately ceased due to the extremely high quantities needed, to ensure economic viability for the re-processing facility.[65]

Thermochemical recycling (pyrolysis and waste to energy) - Pyrolysis is usually designed with a certain feedstock in mind, for example biomass, rubber (e.g. in the form of tyres) or plastic to produce products like diesel. Recent studies have produced oil that could be used in a diesel engine without engine modification using clean waste fishing nets feedstock in a laboratory setting.[66,67] Commonly the setups are installed to process one feedstock alone and are highly specialised for that feedstock. Cross contamination of feedstocks can lead to equipment failure and/or producing unwanted products. The treatment of the exhaust prior to gas ejection, may also not be able to handle unplanned contaminants introduced by different feedstock types. While pyrolysis can be fitted to accept more than one type of feedstock, potentially a combination of biomass, rubber and plastics, in these setups, the intake ratio per feedstock is highly specified and optimised. This makes the machine very sensitive to feedstock quality and change. Every type of feedstock has their own specific temperature at which decomposition occurs and requires individual process durations and pressure.[68] The costs of pyrolysis set-ups in Australia, based on consultations with a local supplier come at a very large initial investment. Even though the technology of pyrolysis shows potential, the large capital needed, together with the specific set up per pyrolysis framework, and the need for consistent and uncontaminated feedstock, make the method unsuitable for processing ghost nets and marine debris. If the quality and quantity challenges can be addressed, it may be suitable however for municipal waste across northern Australia.

Waste to energy is the process of generating energy in the form of heat and/or electricity by the treatment of waste. Through incineration, heat and electricity can be won and then reappropriated into the electricity grid of communities. Waste to energy plants usually operate on a large scale. As mentioned in the case study of Sierra Energy, minimum requirements per day can be 10 tonnes or more (refer Lessons Learned Box). These facilities are designed and made to run continuously without a break. Frameworks that are meant to run in batches must be designed specifically with the application in use in mind. With the high input requirements in terms of volume and sensitivity, this method is not feasible for taking ghost nets and marine debris. If the volume can be achieved, it may be suitable for municipal waste in some instances across northern Australia.

Small scale **incinerators** are affordable and could be used in remote locations, but capacity is limited to small items or would require nets to be cut up for processing. This may be useful for addressing biosecurity risks however on beaches and would replace the open burning that occurs currently. These machines however provide no sophisticated filtration or exhaust systems for their moderate cost. Large scale set-ups are more suited to municipal waste and would need to be developed for special applications and feedstock. These larger systems provide more sophisticated emission filtration by way of pollution control systems that can be attached.

Regardless of the method, **all waste requires a level of pre-processing** to ensure it can be used. Ghost nets and marine debris will need to undergo several steps to make them safe and efficient to use. Depending on the recycling method, shredding, some cleaning and drying may be required. All are proven, efficient and widely available technologies. All processes require training but could be undertaken in-situ by communities within the Gulf. In addition, any lead lines or floats and possibly ropes would also need to be removed as a first step.

Shredding - Some recycling methods, such as thermochemical processing require feedstock to be in a uniform shape and size. The most common one is a pellet shape (round, square or oval), with measurements of around 2-5mm. In thermochemical processing, this size and shape allow for the material to be fed into a feeder throat, after which it is picked up by a screw, to be transported further into a barrel for heating. Without shredding waste materials first, it is usually impossible to feed the material to be reused into any machinery. Given the difficult nature of ghost nets and the high levels of contamination and fibrous nature of nets, shredders may require significant modification and strengthening to be able to efficiently shred nets without damaging the machinery.

Cleaning - Another crucial step is cleaning the waste material properly. When waste is exposed to the elements and the environment, it can absorb a variety of contaminants that can influence the quality of end products, damage the machinery and produce harmful gaseous outputs. Given the high levels of contamination with ghost nets, the preference needs to be on options that will minimise the level of cleaning required, as this will be very difficult. As noted above, end of life fishing nets with less contamination will be much easier to clean.

Drying - Plastics can range from hydrophobic (not water absorbing) to hydrophilic (water absorbing). Both types can be fully re-processed, however the plastic needs to be dried. The hydrophobic polymer has the advantage of usually being less water absorbent, making them easier to dry and in their virgin form, they usually do not need drying at all. However, even hydrophobic polymers can absorb too much moisture when exposed to water for too long, as can occur with ghost nets, rendering them unusable without drying. Hydrophilic polymers on the other hand, must always be dried extensively before they can be used for further processing.

4.3.5 Current approach and associated gaps, challenges and risks for responsible disposal

Table 3 provides a summary of the current approach and associated gaps, challenges and risks.

Table 3 **Summary of current approach and associated gaps, challenges and risks for responsible disposal**

Current approach	Gaps, challenges, risks
Disposal » Most ghost nets and marine debris collected are sent to local unmanaged open landfills throughout the Gulf of Carpentaria. » Nets collected by MBC or AFMA at sea are usually sent to landfill in Weipa or Darwin (or provided to ghost net art communities where requests are made). If they are found on an illegal vessel, it is then incinerated for biosecurity reasons. » The key disposal landfills for NPF end-of-life nets are in Karumba, Darwin, and Cairns. Around 21 tonnes is disposed of each year. » In some cases, ghost nets and marine debris will be burned in-situ where biosecurity risks are identified or there are no other options because landfills are far away, do not accept nets or Rangers do not have the necessary equipment to move the nets.	» Some open landfills in northern Australia are being decommissioned as they are full. Once local landfills are full, waste must be transferred to larger sites. This is currently the case for Mapoon where all waste must now be transported to Weipa. » NPF stakeholders have a high level of interest in reducing plastic waste and closing the loop, and have conducted multiple investigations, with the key barrier being transport cost. » There is no separation or sorting of plastics by polymer or quality by Rangers. This is because it is time-consuming and the priority is to get the marine debris and nets off beaches, rather than understand what it is made of. » Sorting happens by plastic type, but not polymer as part of surveys conducted by NGOs for recording data in the AMDI database. » Burning creates carbon emissions, generation of microplastics and potential toxic leachates and safety risks to Rangers. Open burning of nets and debris on beaches can leave melted residues and must be done after the nets and debris are dry, as far away from the high-water mark as possible. » Marine debris and ghost nets generally are not factored into domestic waste management plans or programs being developed for domestic waste management across northern Australia. It is seen as a separate issue.
Reuse - Ghost net art » Artists require a small quantity of nets to produce high value art pieces through weaving. The nets do not have to be high quality to be used for art. » Unique bespoke products are highly valued in the national and international art markets. Interest in ghost nets art is increasing and it is seen as its own unique art genre. » Small, commissioned pieces can sell for $1-2k. Large, commissioned pieces can sell for $20k and up.	» Limited funding and training in weaving methods is a key barrier to increasing participation in ghost net art programs. » Weaving is a labour intensive process to weave nets into art creations, taking many weeks or months in some cases. » Variety (such as colour) is valued and there is a limit on volumes that can be taken by art centres. Not all nets are wanted. » Transport costs to get nets to art centres are expensive. » Competition between art centres for materials may occur, if net availability decreases.
Transporting nets around the Gulf » Backfilling commercial barges has been used successfully to transport nets to communities with art centres, however even with a subsidised rate this remains expensive. » Supplies and consumer goods are transported to the Gulf from major centres such as Cairns and Darwin by logistics companies; either truck or barge, depending on location and season. These vehicles will take backfills of items back to urban areas for a fee.	» Backfilling with a commercial logistics company is still expensive, even at a discounted rate, for example $2,000 for 2 tonnes of net to be moved from Weipa to the Torres Strait to an art community via barge. » Transporting unprocessed materials such as ghost nets and marine debris is viewed as 'waste' and reported to be highly undesirable, given the contamination levels. It is very expensive given the distances and bulkiness. » Wet season road closures can limit access for transporting goods.

4.3.6 Opportunities for investment

Those options considered most suitable for addressing the situation in the Gulf of Carpentaria with respect to responsible disposal, incorporating the priorities identified by key stakeholders are summarised as follows:

» Work with local and state governments working on municipal waste management and recycling schemes for northern Australia, to explore opportunities for marine debris and ghost nets. Consolidation of different waste streams within regions for more efficient transportation and processing will be important to achieve economies of scale.

» Remanufacturing and to a lesser extent extrusion and injection moulding are considered the most feasible options for disposal. In addition to continuing ghost net art weaving, these options would allow for the expansion of art activities to use Green Ceramics™ and other methods such as 3D printing to maximise opportunities for communities to tell their stories to a broader audience of their connection to country and sell a wider range of products in large urban markets. For example, development of a range of high-quality homeware and building products, reflecting the unique cultures, artistic values and connections to country could be produced from ghost nets and marine debris coming out of northern Australia using cost effective MICROfactorie™ solutions for re-manufacturing (Green Ceramics™) and thermo-mechanical recycling (extrusion and injection moulding for higher quality end of life fishing net only). Prototyping of suitable material pathways to develop products with a ready market should be undertaken however as a key step. A market survey is a pre-requisite to developing the prototypes.

» Undertake a coordinated pilot program to establish a suitable modular recycling pathway for the Gulf of Carpentaria, utilising the prototyped products developed and informed by market opportunities. This could include establishing regional hubs for sorting and aggregation of marine debris and ghost nets and designing and then trialling cost effective logistic options for those Ranger groups and communities keen to participate to transport nets and marine debris from communities to collection points for re-processing. Identifying and working with a suitable supply chain to develop a business model that will provide cost effective and economically viable business and job opportunities for Ranger groups, communities, artists, and industry to share in the benefits will be a first key step.

» Low quality marine debris and nets that are highly degraded should be taken to landfill as a first option unless municipal waste management can provide alternate solutions. Where no other options are viable, provide support to improve the safety and efficiency of burning marine debris and ghost nets by reviewing methods, providing training in safety protocols, and using portable incinerators, rather than open burning.

4.4 Capacity building, training and knowledge sharing

GhostNets Australia provided key roles in coordinating and building the capacity of Ranger groups with respect to ghost nets and their retrieval. The program in its early years, assisted Rangers in finding the best ways to remove nets off beaches, trialling different equipment and providing a fee for service model to assist with the cost of retrieval. Knowledge exchange and learning was a key part in bringing Rangers together to share ideas and experiences and together develop and refine solutions to challenges they were having with the ghost nets. As the capacity of Rangers increased, the program focused more on strengthening capacity in information and data collection and analysis (in partnership with CSIRO), conducting training and providing support to Rangers for the recording of information (size, length, number of animals entangled etc.) as well as through the GNA Net ID Kit, in the identification of where the nets were coming from.

When the program funding ended in 2016, coordination and support to the Rangers ceased, and Rangers were expected to incorporate ghost net activities within workplans and continue with activities. Since then, ghost net retrieval has become scattered and data collection ceased. The fee for service model used by Rangers for ghost nets has meant that much of the work to retrieve nets and marine debris now occurs in amongst the many other priorities built into workplans where Rangers are being funded to do certain activities.

Going forward, should a recycling scheme be established for the Gulf of Carpentaria, the key area for capacity building of Rangers will be in education and training in sorting and separation of high-quality marine debris and nets from the rest. While it should not be expected that Rangers be required to undertake the sorting and separation, given the time pressures they are already under, having this knowledge will be important for them to engage in any new program or business venture that may develop. Upgrading or enhancing information kits such as the Net ID Kit to include practical material science on plastic chemistry and processing requirements, supplemented with new innovative tools such as FTIR and accompanying plastics identification apps will allow Rangers to have improved knowledge with respect to separation without adding significant additional time pressures. There are several handheld devices now available that can instantly provide reliable identification of plastics to assist in sorting of plastic waste streams.[69] In addition, continuing to have opportunity to share knowledge and experiences and learnings will remain important. Likewise, coordination on-ground to connect those Ranger groups that may want to participate in any materials recycling pathway business opportunity that develops will be critical, given the limited capacity of Rangers to take on new tasks. Sharing lessons learned and best practices will lay the groundwork for the cooperative approach needed for a sub-regional or regional pathway for nets to go from waste to valuable re-manufactured products.

Girl at ghost net art workshop in Arukun - photo by Sue Ryan

Building the capacity of communities to support Rangers in the retrieval of marine debris and ghost nets, making it everyone's problem to clean up their country will be important. Providing education and incentives for establishing plastic recycling within those communities wanting to participate will be key. This is particularly where there is opportunity to extend separation of waste to include domestic plastic waste (where container deposit schemes do not exist, which is most of the Gulf of Carpentaria communities). This would not only reduce pressure on landfills but also allow for additional raw materials to become available for inclusion in a materials recycling pathway for the Gulf of Carpentaria to help build economies of scale.

One way to build community capacity may be through using turtles as a flagship to drive community interest and engagement. There may be opportunity to combine the passion and connection most communities hold for turtles, with working together and supporting Rangers to undertake beach clean-ups and reducing the amount of general municipal litter ending up in waterways.

Most Ranger groups are involved in turtle conservation on country and have key priorities in relation to improving nesting success and hatching rates. A recent study has shown that accumulated plastics in beach sediments can cause temperature fluctuations that can have a significant effect on terrestrial ectotherms like crabs and turtles.[70] Several Rangers consulted in this study indicated concern for the impact the high volumes of marine debris may be having on turtles on some nesting beaches, both in terms of females being able to easily access the beach and on hatchling sex ratios.

4.4.1 Current approach and associated gaps, challenges and risks for capacity building, training and knowledge sharing

Table 4 provides a summary of the current approach and associated gaps, challenges and risks.

Table 4 Summary of current approach and associated gaps, challenges and risks for capacity building, training and knowledge sharing

Current approach	Gaps, challenges, risks
Organisational capacity	» Rangers are already extremely busy.
» Capacity to manage ghost nets and marine debris retrieval has increased as Ranger groups have developed, assisted by NGOs and GNA. It is the time pressures and heavy workplans and lack of financial and human resource support that often prevent Rangers from being able to undertake clean-up and retrieval tasks when they would like.	» Risks of loss of institutional knowledge due to staff changes.
» Rangers are not involved in any sorting activities, except when working with NGOs on clean-up events, so knowledge is limited about plastic types.	» Clean-ups generally fit into the gaps between other work programs. For example, turtle and fire management programs are fulltime work and time dependent, but marine debris activities will occur when time allows, or if NGOs provide financial support.
» Some groups are innovating, making their own specialised equipment, such as microplastic sifting trays, raised vehicle tray enclosures, using trawl nets to make debris collection bags etc.	» There has been limited opportunity for Rangers to receive support for innovative ideas, testing of new equipment and sharing of lessons learned.
» Community awareness of the issues can vary, and this is sometimes paired with criticism of Rangers.	» The GNA Net ID Kit was never properly distributed to Ranger groups as it was produced at the end of the funding.
» Rangers do have annual meetings in Darwin and Cairns from time to time as an opportunity to share experiences and learn from each other.	» Some net kits and other resources are out of date and do not include information relating to plastic types.
	» Need for greater cooperation with communities, and incentives/motivators to become active in recycling and clean-ups and make it "everyone's problem" to engage more on the issues and support and work with Rangers.

4.4.2 Opportunities for investment

Those options considered most suitable for addressing the situation in the Gulf of Carpentaria with respect to capacity building, training and knowledge sharing, incorporating the priorities identified by key stakeholders are summarised as follows:

- A knowledge sharing program would allow Ranger groups to learn from the successes of others and build the capacity of Ranger and Junior Ranger programs. Learning exchanges could also be considered (subject to COVID19 restrictions) for art communities/centres who expressed a desire to learn from each other.
- Work with local and state governments working on waste management and recycling schemes for northern Australia, to explore opportunities for sharing resources with respect to education and training on plastic recycling. Undertake education programs for Rangers and communities on establishing plastic recycling programs for those Rangers and in those communities that want to participate. This may provide opportunity to extend any recycling scheme to also include domestic plastic recycling.
- The GhostNets Australia Net ID kit and other information kits produced by NGOs on net identification and how to conduct marine debris clean ups should be reviewed to determine which are the most useful and then updated to reflect latest information as required. This update could include for example, new net examples that have been identified by NGOs such as Sea Shepherd, and practical material science on plastic chemistry and processing requirements. These kits should be supplemented with new innovative tools such as handheld classification units and accompanying plastics identification apps and broader community capacity materials. This will allow Rangers to improve knowledge with respect to separation without adding significant additional time pressures, provide opportunity to engage communities, particularly schools in increasing knowledge on opportunities available from recycling, and increase capacity towards encouraging recycling within communities.
- A joint focus on supporting turtle conservation may be a way to bring stakeholders together, given recent information showing the impact marine debris is potentially having on turtles nesting as well as the sex ratio of hatchlings.

Photo by Jane Dermer

4.5 Data collection, management and reporting

There are currently multiple data collection approaches and databases available for recording information on ghost nets and marine debris across northern Australia. Each employs different methodologies and requires variations to the data being collected. Examples include, the GGGI app, GNA database, AMDI methodology and database, WWF methodology, and databases maintained by federal and state and territory government agencies and universities to track marine debris and biosecurity information and navigational hazards. These reflect the varied end-uses of the data and the lack of coordination to understand what information is really needed, to address what questions or to support what end purpose.

Rangers, over the years have been trained in the various approaches and methodologies, such as the WWF marine debris methodology. Of those participating in the study, most indicated they do not record any data or information given their priority is the clean up the beaches as fast as possible. In some cases, NGOs like Tangaroa Blue have provided training to some Ranger groups in applying the AMDI approach, which is being seen as the preferred method for data collection to suit the objectives of the AMDI. Increased attention is being given to microplastics by some Ranger groups, given the significant quantities being seen on beaches due to the highly degraded state of some debris and ghost nets. Recent training or activities to learn of the extent of the issue are becoming more common in some areas. For example, AusMAP recently conducted training with Dhimmuru Rangers.

Improved data sharing and management were identified as key for the development of a more consistent national approach to managing ghost nets and marine debris. A streamlined national approach is required, where consensus can be reached on what information is needed and for what purpose and a cost-effective way to collect it identified, to reduce pressure on Rangers. The *National Plastics Plan 2021* includes a commitment by the Australian Government to establish a national monitoring protocol and database for plastic pollution, which could potentially include data capture for ghost nets.[71]

The ATSEA program is currently undertaking a major regional marine pollution study in the ATS that will provide a practical framework for decision makers to prioritise pollution reduction strategies and initiatives.[72] It is focused on Timor-Leste and Indonesia. This provides good opportunity for collaboration in this study to increase understanding of marine debris hotspots across all of northern Australia, towards fostering an adaptive co-management approach for ghost nets and other marine debris in the region.

4.5.1 Current approach and associated gaps, challenges and risks for data collection, management and reporting

Table 5 provides a summary of the current approach and associated gaps, challenges and risks.

Table 5 Summary of current approach and associated gaps, challenges and risks for data collection, management and reporting

Current approach	Gaps, challenges, risks
Marine debris and ghost net data collection » Conservation groups are more likely to collect data than Ranger groups. The focus is on citizen science. » Most Ranger groups now use the AMDI methodology. Tangaroa Blue manages the AMDI database. The WWF methodology was used previously. » Ghost nets data is not collected consistently by Rangers. What data has been collected has not been included in the GNA database since the program funding ended in 2016. » Scientific monitoring of marine debris on some beaches has continued with Ranger groups, eg Cape Arnhem managed by Dhimurru, although this finished in 2020. » Both Rangers and NGOs follow government protocols for biosecurity risk identification and reporting. » Handheld technologies are reported to be useful, increasingly using specially developed applications to collect data. This includes for coastal surveillance, marine animal sightings, turtle nesting site monitoring etc. » Photographs are also taken as part of biosecurity reporting.	» Time for data collection by Rangers is limited and must be balanced against the priority of Rangers to clean-up beaches. » Quality control of data varies. Understanding the end-use for the data is a key incentive to improve consistency. » Data from the AMDI, which is currently a public database, as well as other databases are not readily available to those wishing to access it. » Data collected across the various platforms cannot easily be compared. » There is inconsistency in understanding what information is required and for what purpose and how current data collected is used. » Scientific monitoring versus citizen science approaches leads to different data being collected. » Beyond the Gulf of Carpentaria, there is limited information on accumulation points for marine debris and ghost nets in other parts of northern Australia. » There is a need for ongoing consistent training for Rangers when changes to apps, software or methodologies occur. » There is a need to avoid duplicating efforts or 'reinventing the wheel' when it comes to data collection. A lot of work has been undertaken by various groups. Sharing of best practices and training are needed to ensure a more consistent standardised methodology for data collection. » In some situations, an exact measurement is not necessary for data collection and attempting to do this is time consuming. Identification of nets can be based on estimations, with sizes such as 'two fingers', 'palm of hand' etc., with a focus instead on accurate and regular count/weight data to assist with assessments of change over time.
Ghost net identification manuals and marine debris toolkits » Tangaroa Blue Education Kit and Fact Sheets, GGGI app, GNA Net ID kit etc. are all valuable resources available to aid data collection, however they are not used consistently by Ranger groups and others.	» Ghost Net ID Kit resources need to be updated and requires rolling out to Ranger groups. » None of the current education and training materials cover assessment of material quality for separating out valuable materials for any future recycling pathway.

4.4.2 Opportunities for investment

Those options considered most suitable for addressing the situation in the Gulf of Carpentaria with respect to improving data collection, management and reporting, incorporating the priorities identified by key stakeholders are summarised as follows:

- Update and roll out ghost net and marine debris identification resources, with associated training and on-ground capacity building.
- Expand knowledge and understanding of the scale of microplastics in the Gulf of Carpentaria and northern Australia.
- Expand knowledge and understanding of marine debris accumulation points across northern Australia outside of well documented areas such as the Gulf of Carpentaria. An appropriate sampling regime would be required as a pre-requisite.
- A data management strategy is required for developing a consistent approach to data collection and management for Australia. Identifying the key questions needing answers to strengthen decision making should drive what data requires collection, how it could most cost effectively be collected, by who and how often. For example, the location of the net, type, and information to identify source are the priorities for consideration of source identification. Weight of material collected, and the clean-up time contribute to understanding of clean-up effort and efficiency. Debris type and density from a representative sample of beaches are needed to track changes in debris load at a location over time.
- The Australian Government commitment to establish a national monitoring protocol and database for plastic pollution could potentially include data capture for ghost nets and marine debris. It should provide a centralised open access database that consolidates all other databases and provides on-water net tracking locations and a monitoring and reporting function that communicates with government agencies.
- Streamline data collection for Ranger groups to improve the ease of collection, and data collection quality and regularity. Should a recycling pathway be established, data collection could be undertaken by others down the supply chain, rather than by Rangers, for example those at transfer and sorting stations.
- Through ATSEA, establish and implement a regional marine debris and ghost net action plan and monitoring network in partnership with Indonesia, Timor-Leste and Papua New Guinea.

5. Piloting potential regional recycling pathway approaches

The analysis to identify feasible options for responsible disposal of ghost nets and marine debris undertaken in Section 4.3 and Annex 1 identified re-manufacturing and in some circumstances, thermomechanical recycling (extrusion and injection moulding) as having the greatest potential.

Before any investment in such technologies however, it is important that prototyping and piloting exercises are undertaken to ensure the technology is fit for purpose and that a sustainable business model is possible.

5.1 Distributed modular pathways

Finding sustainable and pragmatic solutions to the ghost nets and marine debris challenges in northern Australia, beyond stopping the situation at its source, is centred around overcoming the vast distances, both for retrieval, transport and disposal/processing. Ranger groups have limited resources and infrastructure available to them. The harshness of conditions and the remoteness and unpredictability of where nets and other marine debris wash up on beaches makes a challenging combination of problems to overcome. Undertaking a coordinated pilot project to establish a suitable modular recycling pathway for the Gulf of Carpentaria, utilising the prototyped products developed and informed by market opportunities, will provide opportunity to learn and refine and determine how best to structure it.

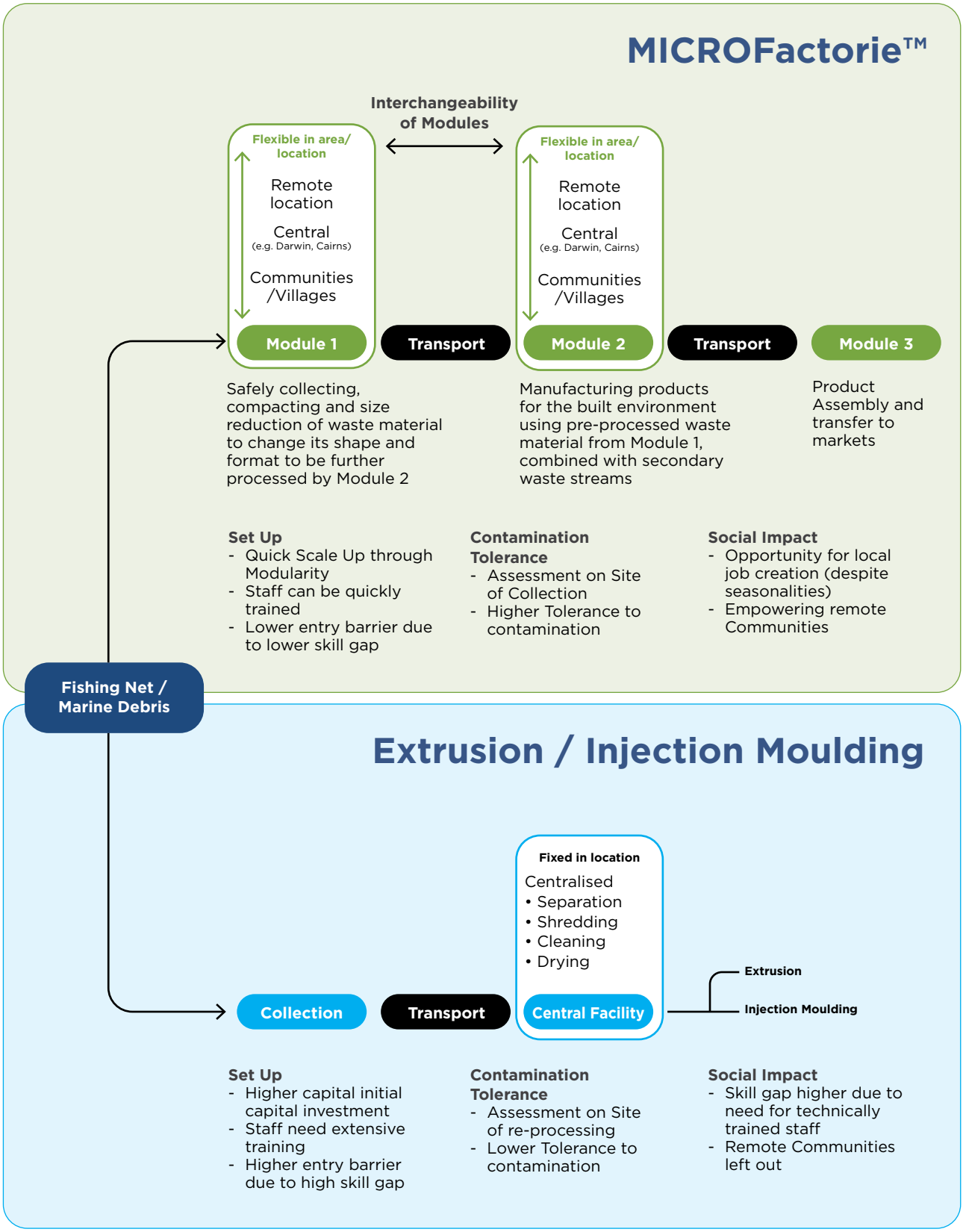
A regional approach may be possible if economies of scale and inefficiencies can be addressed through a sound business model that shares benefits and can be self-sustaining beyond the life of the *Ghost Nets Initiative* investment. As a part of a pilot, any approach would need to be framed within the broader municipal waste management and recycling strategies and plans for regional and remote areas being developed by state, territory and federal governments to build economies of scale.

The development of a business case and further exploration of the supply chains and potential job creation opportunities for such an approach (beyond the scope of this study), would need to be included in any pilot. Engaging Ranger groups, Traditional Custodians, communities, ghost net artists, government, and non-government stakeholders in the process is paramount.

As a part of a pilot, regional hubs could be established for sorting and aggregating marine debris and ghost nets. Trialling cost effective logistic options for those Ranger groups and communities keen to participate to transport nets and marine debris from communities to collection points for re-processing would be important. Working with the supply chain to develop a business model that will provide a cost effective, equitable and economically viable business and job opportunities for Ranger groups, communities, artists, and industry to share in the benefits would be key.

While many options are possible for re-processing, as indicated in Section 4.3 and Annex 1, the most effective approach worthy of exploration is the establishment of regional modular pathways that provide cost-effective options for re-manufacturing (Green Ceramics™), complemented with some limited thermomechanical recycling (extrusion and injection moulding). Figure 7 provides an example of what a distributed modular pathway for Queensland and another for Northern Territory for ghost nets and marine debris, using the MICROfactorie™ and extrusion and injection moulding options may look like. The example is framed in broader waste management and recycling across the region with early steps completed in communities or towns around the Gulf of Carpentaria/Torres Strait and final steps in the larger centres of Darwin and Cairns.

Figure 7 **Example of distributed modular pathway for Queensland and the Northern Territory for ghost nets and marine debris**



5.1.1 About MICROfactories™

Through optimisation and consolidation of existing systems and manufacturing frameworks, MICROfactories™ can give industries and researchers brand new perspectives. Re-manufacturing, for example to produce Green Ceramics™ is a manufacturing framework that is well suited to MICROfactories™. It replaces components or reprocesses used parts, to recover their value and reinstate it into a like-new condition and quality. The environmental impact of this technique is reduced through less waste created and natural resources needed, preserved landfill space, and reduced air pollution from products that would have otherwise been reprocessed or incinerated, because they are being kept out of the waste stream altogether.[73] In fact, MICROfactories™ improve manufacturing procedures and are a driver of innovative new techniques, equipment and systems. Advantages brought by MICROfactories™ include among others, the following:

General Environmental Aspects

» Resources and energy-saving
» Simplified waste and pollution control
» Less noise and vibrations for staff and neighbours

Economic Aspects

» Less capital investments necessary
» Reduced maintenance and operational costs
» More efficient space utilisation
» Better portability and reconfigurability

Technical and Engineering Aspects

» Increased productivity due to parallel allocation of machinery
» Improved yield by a piece-by-piece process, reducing statistical likelihood of faults
» Reduced ramp-up times for new mass production

Human-Related Aspects

» Quicker staff recruitment due to less mentally and physically stressful operations (smaller machine sizes)
» Gateway for new users, door openers to education and hobbyists.

Certain parts of the modules, cost and functionalities could be subject to change, depending on where they are set up and what materials and product specifications the modules are dealing with. Key considerations in a modular approach are outlined in Figure 8.

MODULE 1: MATERIALS HANDLING AND PRE-PROCESSING

Setup locations: Onsite at primary ghost net accumulation area, can be moved to where need is.

Capable of: Initially pre-processing waste material.

Setup: Truck/ute or barge with a material handling assistance tool, such as winch or crane, to assist with collecting heavy or hard to reach ghost nets.

Energy Source: Diesel.

Cost estimate: AUD $200k - 300k.

Processing Description: Safely collecting, compacting and size reduction of waste material to change its shape and format to be further processed by Module 2.

MODULE 2: BLENDING AND MOULDING MODULE

Setup in: Towns or cities, leveraging existing supply chains.

Capable of: Manufacturing products for the built environment using pre-processed waste material from Module 1, combined with secondary waste streams.

Setup: Shed or MICROfactorie™ with required equipment such as mixing and compression moulding equipment.

Energy Source: Power Grid.

Cost estimate: AUD ~$500k.

Processing Description: Pre-processed waste material will be mixed with secondary materials (e.g. timber, glass, nylon etc.) and fillers depending on the final product application and usage. e.g. Furniture.

Requirements: Formulation of material mix according to physical and structural demands.

Output: Products for the built environment.

MODULE 3: PRODUCT ASSEMBLY AND TRANSFER TO MARKETS

Transfer of products into pre-existing joinery facilities. For joinery, gluing, sanding, assembly.

Transfer to urban markets.

Figure 8 Key considerations in a modular approach

5.1.2 About extrusion and injection moulding

Extrusion

Extrusion is a large-scale manufacturing technique, using a continuous process, to melt and enrich polymers with desired additives. The raw material (in this case polymer) is fed into a hopper above an extrusion machine. Gravity then feeds granulated pieces of plastic down into a feeder throat, which connects to a rotating screw. The screw size and design are heavily dependent on the material being used and on the requirements of the product. The screw forces plastic forward through a barrel, heated by screw-shear and electric heating elements. After the polymer has melted completely in the barrel it is ejected through a nozzle than continuously extrudes multiple strands of plastic that are directly transported into a water bath to cool down. After exiting the water bath, the strings or hardened plastic reach a rotating blade cutter that cuts the newly extruded plastic into a certain pellet size.[74]

To control the quality of the extruded product, it is important to know what is being fed into the machine. Only high-quality clean nets and marine debris would be suitable, so this option is likely to complement re-manufacturing where contamination is not of concern.

The complexity of the extrusion process and the number of process parameters makes it hard for manufacturers and researchers to meet manufacturing requirements at a low cost. Quality of the extruded parts is the main goal of extrusion, which has a direct effect on expected profits for companies manufacturing plastic products.[75]

Injection Moulding

Injection moulding works similarly to extrusion. The raw material is fed into a hopper, which in turn feeds it via gravity into a feeder throat. A screw transports the feedstock into a heated barrel, melting the raw materials. After the polymer is molten it is injected into a steel mould, while maintaining pressure for a certain time span, depending on the product size and design. The plastic will then cool down within the mould for a set time before it is opened and the finished product can be de-moulded, via manual labour or mechanical ejection.[76]

Figure 9 outlines the key considerations for this module.

CENTRAL FACILITY: MATERIAL HANDLING AND PROCESSING

Setup locations: Centralised site, preferably in a city, or industrial location.

Capable of: Firstly separating, shredding, cleaning and drying materials. In the second step reprocessing it via extrusion and/or injection moulding.

Setup: Warehouse-type set up, providing a permanent space for large machinery including dryers, shredders, injection moulding machines, extrusion lines. Separate space for manual separation of fishing nets and marine debris might be required.

Energy Source: Power Grid.

Description Processing: After nets and marine debris have been delivered to the central facility, they need to be evaluated and assessed. Starting with separation according to material types, followed by shredding, cleaning, drying before they are ready to be extruded and/or injection moulded.

Figure 9 **Key considerations using extrusion and injection moulding**

6 Conclusion

Finding sustainable and pragmatic solutions to the ghost nets and marine debris challenges in northern Australia, beyond stopping the situation at its source, is centred around overcoming the vast distances, both for retrieval, transport and disposal/processing.

Ranger groups have limited resources and infrastructure available to them. The harshness of conditions and the remoteness and unpredictability of where nets and other marine debris wash up on beaches makes a challenging combination of problems to overcome. In most cases, there are limited or no domestic waste collection services, sorting and processing facilities or recycling schemes. This is primarily due to the high transport costs and inability to achieve the economies of scale needed to make these types of services and programs economical. It makes for a complex situation requiring highly tailored, integrated, and fit for purpose solutions.

As the scale of the issue continues to increase across northern Australia, finding potential solutions that can assist in streamlining processes, reducing inefficiencies from multiple handling of the nets and debris and the need for intensive labour as well as finding economical options for responsible disposal are key.

This study has identified opportunities for directing investment to options considered practical and pragmatic that may assist in addressing the challenges raised by stakeholder groups. While some are quite straight forward and easy to implement or trial and require minimal investment, options for responsible disposal will require greater investigation. Undertaking a coordinated pilot project to establish a suitable modular recycling pathway for the Gulf of Carpentaria, and prototyping potential remanufactured products would be required.

A regional or sub-regional approach may be possible if economies of scale and inefficiencies can be addressed through a sound business model that shares benefits and can be self-sustaining beyond the life of the *Ghost Nets Initiative* investment. As a part of a pilot, any approach would need to be framed within the broader municipal waste management and recycling strategies and plans for regional and remote areas being developed by state, territory and federal governments to build economies of scale. The development of a business case and further exploration of market opportunities, supply chains and potential job creation opportunities for such an approach, would need to be included in any pilot.

Engaging Ranger groups, Traditional Custodians, communities, ghost net artists, government, and non-government stakeholders in the process is paramount.

Annex 1 Assessment of Options

The following tables provide summaries of the analysis undertaken to benchmark options against the criteria set out in Figure 3. It identifies new technologies, infrastructure and tools that may aid Rangers and others in addressing interception and tracking, clean-ups and retrieval and responsible disposal of ghost net and marine debris issues across northern Australia.

Table 6 **Ghost Net Interception, tracking and retrieval (in-water)**

Stage - Interception, tracking, retrieval					
Name	**Remote Sensing**	**Satellite Tracking**	**ATI UAS (Drones)**	**Quadcopter Drones**	**RFID Gear Tagging**
Option/technology Details					
DESCRIPTION: What is it?	High resolution detailed satellite imagery	Tagging of ghost nets with satellite buoys	Unmanned system (drones)	Unmanned system (drones)	Radio frequency identification for gear tagging
UNIT COST: How much is it?	100 sqkm capture = AUD $5,000 - Changes significantly depending on how often we capture	N/A	New from AUD $230 including camera	New AUD $2,800-$3,800 including camera	New USD $0.40 cents = AUD $0.52
STAGE: Pilot or Commercial? Is it market ready, proven on commercial scale?	Commercial, but not proven for marine debris or ghost nets	Specialised/ made to order. Proven for tracking ghost nets and pilot underway in Australia	Commercial and proven for uses such as mapping habitat and aerial counts however cannot hover	Commercial and proven for uses such as turtle monitoring in remote areas. Can hover	Commercial and trialled for active fishing gear
Social Criteria					
RISK: People (Safety and Operations)	Safe, requires specialist knowledge and training	Safe, minimal training required; no PPE needed	Safe, no PPE needed, training required (<7kg Licence /training AUD $1,350)	Safe, no PPE needed, training required (<7kg Licence / training AUD $1,350)	Safe, limited training required; no PPE needed
BENEFITS TO COMMUNITIES: Benefits return to communities. What benefit is there? What kind?	Indirect benefit - may allow interception at sea to reduce ghost nets reaching coast	Indirect benefit - Allows for interception at sea to reduce ghost nets reaching coast	Increased cleanup efficiency, prioritisation of effort	Increased cleanup efficiency, prioritisation of effort	Indirect - improved data collection to identify where nets come from
SOCIAL LICENCE/ CULTURALLY APPROPRIATE: Social licence to operate and cultural appropriateness. What is the level of concern?	Low potential for community concern	Low potential for community concern	Low potential for community concern where not used within urban areas	Low potential for community concern where not used within urban areas	Low potential for community concern

Stage - Interception, tracking, retrieval					
Name	**Remote Sensing**	**Satellite Tracking**	**ATI UAS (Drones)**	**Quadcopter Drones**	**RFID Gear Tagging**
SUITABLE INFRASTRUCTURE AND SYSTEMS: Support systems and infrastructure available, including skills/ labour	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate, but requires partnership with industry/source countries
Environmental Criteria					
RISK: Environmental and climate	Low risk for people and environment	Low risk for people and environment	Low risk for people and environment	Low risk for people and environment	Low risk for people and environment
SCALE: Appropriate geographic scale eg community, regional, state. Will it work in remote areas?	Can work in remote areas and is scalable to region and state level	Can work in remote areas and is scalable to region and state level	Can work in remote areas and is scalable to region and state level	Can work in remote areas and is scalable to region and state level	Can work in remote areas and is scalable to within several kilometres
Economic Criteria					
ADAPTABLE: Ability to deal with the difficult nature of the material (mixed, contaminated, degraded)	N/A	N/A	Weather dependent	Weather dependent	Is not affected by contamination
COST EFFECTIVENESS: Cost effectiveness, including set up, labour, running costs, maintenance.	Expensive but targeted use may be cost effective	May be cost effective if units can be consistently retrieved	Cost effective for specific mapping	Cost effective for some mapping and monitoring activities	Cost effective as a source control measure
SUSTAINABLE/ FIT FOR PURPOSE: Does it generate a saleable end product, would it contribute to a financially sustainable business? Does it have available markets and meet performance requirements?	Technology developing. Unlikely to identify nets at sea Might locate marine debris on beaches	Trials underway in Australia are promising	Fit for purpose for continuous mapping over long distances	Fit for purpose for monitoring activities and accessing impacts	Not fit for purpose for ghost nets. Fit for purpose for active fishing gear tracking. Reader must be within a few kilometres of the net

Stage - Interception, tracking, retrieval					
Name	**Remote Sensing**	**Satellite Tracking**	**ATI UAS (Drones)**	**Quadcopter Drones**	**RFID Gear Tagging**
LINK:	www.esa.int/Enabling_Support/Preparing_for_the_Future/Discovery_and_Preparation/The_Discovery_Campaign_on_Remote_Sensing_of_Plastic_Marine_Litter	https://spinoff.nasa.gov/Spinoff2009/er_5.html	www.atiak.com/products/resolution-3-airframe/ www.zohd.net/zohd-drift	https://justdrones.com.au/store/swellpro-splash-drone-4/ www.droneit.com.au/7kg-remote-pilot-licence#Pricing	www.alibaba.com/product-detail/Waterproof-Washable-Fabric-Label-RFID-UHF_1600225418307.html?spm= a2700.gallery offerlist.normal_ offer.d_title.23ee50b9AR2urX&s=p
OVERALL FEASIBILITY POTENTIAL:	High, requires testing for locating marine debris on beaches and ghost nets at sea	High, Australian Government trial underway	High, requires testing to determine suitability for surveying nets and marine debris on remote beaches or just offshore	High, requires testing to determine suitability for surveying nets and marine debris on remote beaches or just offshore	Low, Is for active gear tracking

Photo by Jane Dermer.

Table 7 **Clean-ups and removal (ghost nets and marine debris) (land-based) (part 1 of 2)**

Stage - Cleanups and Removal on Land					
Name	**4WD, UTE**	**ATV Side by Side**	**Beach Cleaning Machine**	**Angle Grinder**	**Powered sifting shovel**
Option/technology Details					
DESCRIPTION: What is it?	Road vehicles that can drive on sand and in harsh terrain	Small vehicles that can drive on sand	Bobcat machine with attached powered front mounted sieve	Powered hand tool that can cut ghost nets	Hand tool and battery powered hand tool
UNIT COST: How much is it?	Used AUD $60,000 + running and maintenance costs	New Honda SXS 1000-3 AUD $26,000 plus running and maintenance costs	New KUBOTA SVL75-2C CAB TRACK LOADER AUD $85,000 plus running and maintenance costs	New AUD $329 plus running costs	USD $57 = AUD $76 plus running costs
STAGE: Pilot or Commercial? Is it market ready, proven on commercial scale?	Currently used by Rangers	Currently used by Rangers	Commercial and generally used in urban settings	Commercial, widely available. Currently used by some Rangers	Commercial, manufactured in USA
Social Criteria					
RISK: People (Safety and Operations)	Moderate safety, no PPE needed, training required	Moderate safety, PPE needed, training required	Moderate safety, PPE needed, training required	Low-moderate safety, PPE needed, training required	Safe, PPE needed, training required
BENEFITS TO COMMUNITIES: Benefits return to communities. What benefit is there? What kind?	Increased cleanup efficiency and access. Business opportunities for maintenance	Increased cleanup efficiency. Business opportunities for maintenance	Increased cleanup efficiency. Business opportunities for maintenance	Increased cleanup efficiency	Increased cleanup efficiency
SOCIAL LICENCE/ CULTURALLY APPROPRIATE: Social licence to operate and cultural appropriateness. What is the level of concern?	Low potential for community concern. Management to ensure no impact on turtle nesting	Low potential for community concern. Management to ensure no impact on turtle nesting	Low potential for community concern. Management to ensure no impact on turtle nesting	Low potential for community concern	Low potential for community concern
SUITABLE INFRASTRUCTURE AND SYSTEMS: Support systems and infrastructure available, including skills/ labour	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate

Stage - Cleanups and Removal on Land					
Name	**4WD, UTE**	**ATV Side by Side**	**Beach Cleaning Machine**	**Angle Grinder**	**Powered sifting shovel**
Environmental Criteria					
RISK: Environmental and climate	Medium risk for people and environment	Medium risk for people and environment	Medium risk for people and environment	Medium risk for people and low risk for environment	Low risk for people and environment
SCALE: Appropriate geographic scale eg community, regional, state. Will it work in remote areas?	Is already being used in remote areas	Is already being used in remote areas	Is already being used in remote areas	Is already being used in remote areas	Can work in remote locations - diesel or battery operation required
Economic Criteria					
ADAPTABLE: Ability to deal with the difficult nature of the material (mixed, contaminated, degraded)	Requires tray with caged sides to carry waste. Handles rough terrain	Used in conjunction with trailer to carry waste. Handles rough terrain	Would require testing. Only suitable in some easily accessible locations	Is not affected by contamination. Already being used to cut through ghost nets	Is not affected by contamination. Could be used in beach setting.
COST EFFECTIVENESS: Cost effectiveness, including set up, labour, running costs, maintenance.	Cost effective, if maintenance costs managed	Cost effective, if maintenance costs managed	May be cost effective, if maintenance costs managed	Cost effective (low cost)	May be cost effective (low cost)
SUSTAINABLE/ FIT FOR PURPOSE: Does is generate a saleable end product, would it contribute to a financially sustainable business? Does it have available markets and meet performance requirements?	Fit for purpose for accessing beaches	Fit for purpose for beach operations	Requires testing in remote locations. Limited use as dependent on beach terrain and access	Fit or purpose for cutting up ghost nets	Requires testing but most likely fit for purpose for marine debris removal
LINK:	www.toyota.com.au/landcruiser-70	www.hondashop.com.au/product-category/motorcycles/new-motorcycles/atv/side_by_side_atv/	https://kubota.com.au/product/svl75-2/ www.constructionweekonline.com/products-services/article-37894-bobcat-delivers-sand-cleaner-for-tracked-loaders	www.bunnings.com.au/ryobi-18v-one-9-0ah-brushless-angle-grinder-kit_p0125296	www.tarballfork.com/Equi-Tee_%20Mfg._White_Paper.pdf
OVERALL FEASIBILITY POTENTIAL:	High	High	High, in some locations	High	High, requires testing

Table 8 **Clean-ups and removal (ghost nets and marine debris) (land-based) (part 2 of 2)**

Stage - Cleanups and Removal on Land					
Name	**Small debris motorised sieve**	**Drone (heavy payload)/ Valkyrie Heavy Pro**	**Helicopter**	**Boat/Barge**	**Air Boat**
Option/technology Details					
DESCRIPTION: What is it?	Lightweight motorised cordless sifting machine for small marine debris	Quad copter drone to remotely lift and carry items up to 30kg payload	Helicopter to remotely lift and carry items up to multi tonne payload	Purchase, hired service or backfilling of scheduled commercial service	Shallow hull air boat, can travel over some land surfaces
UNIT COST: How much is it?	USD $1,350 = AUD $1,789 plus running costs	New USD $3,500 = AUD $4,500 plus running costs	AUD $640-$1,400/hour	AUD $1,000/ tonne $35-50k for second hand 6m barge $20-$60k for 10m vessel $350k for 22m landing barge plus running and maintenance costs	Price not available, estimate ~ AUD $50,000 and up
STAGE: Pilot or Commercial? Is it market ready, proven on commercial scale?	Commercial, could be custom built. Currently in use in urban settings	Commercial would require testing	Commercial, used in the region for other activities like aerial culling	Owned/ Used by some Ranger groups. Commercial transport available	Commercial, Australian Manufacturer. Would require some testing
Social Criteria					
RISK: People (Safety and Operations)	Safe, PPE needed, training required	Safe, PPE needed, training and license to operate required	Outsourced/ Qualified operator only. Some Rangers have qualifications	Outsourced if large vessel, if small vessel training needed. PPE required	Safe, PPE needed, training and license to operate required
BENEFITS TO COMMUNITIES: Benefits return to communities. What benefit is there? What kind?	Increased cleanup efficiency	Opportunities for local business	Increased cleanup efficiency and access. Opportunities for local business	Increased cleanup efficiency and access. Opportunities for local business	Increased efficiency and access. Opportunities for local business
SOCIAL LICENCE/ CULTURALLY APPROPRIATE: Social licence to operate and cultural appropriateness. What is the level of concern?	Low potential for community concern	Low potential for community concern	Low potential for community concern	Low potential for community concern	Low potential for community concern
SUITABLE INFRASTRUCTURE AND SYSTEMS: Support systems and infrastructure available, including skills/labour	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate

Stage - Cleanups and Removal on Land					
Name	**Small debris motorised sieve**	**Drone (heavy payload)/ Valkyrie Heavy Pro**	**Helicopter**	**Boat/Barge**	**Air Boat**
Environmental Criteria					
RISK: Environmental and climate	Low risk for people and environment	Low risk for people and environment	Medium risk for people and low risk for environment	Medium risk for people and low risk for environment	Low - Medium risk for people and environment. May be some noise pollution
SCALE: Appropriate geographic scale eg community, regional, state. Will it work in remote areas?	Can work in remote locations - diesel or battery operation required	Requires testing in remote areas	Is already being used in remote areas	Is already being used in remote areas	Can work in remote areas, can be transported on trailer
Economic Criteria					
ADAPTABLE: Ability to deal with the difficult nature of the material (mixed, contaminated, degraded)	Can be used in beach setting, can be adapted with different sieve sizes	Requires testing for use in remote locations and rough terrain	Is not affected by contamination. Already operating in remote and rough terrain	Already operating in remote areas. May require small boat to support in shallow water	Able to operate in shallow water, no parts underwater and reduced risk of entanglement
COST EFFECTIVENESS: Cost effectiveness, including set up, labour, running costs, maintenance.	May be cost effective (low cost)	May be cost effective, requires trial	Not cost effective for purchase, may be cost effective for hire with targeted use	May be cost effective, depending on level of use, hiring reduces maintenance costs	May be cost effective, requires trial
SUSTAINABLE/FIT FOR PURPOSE: Does is generate a saleable end product, would it contribute to a financially sustainable business? Does it have available markets and meet performance requirements?	Requires testing but most likely fit for purpose for marine debris removal	Requires testing but most likely fit for purpose in some instances	Requires testing but most likely fit for purpose for carrying large ghost nets off remote beaches	Fit for purpose for transporting ghost nets and marine debris off beaches	Requires testing but most likely fit for purpose in some instances
LINK:	https://theshaker-usa.com/pricing	www.valkyrie.pro	www.outbackhe-licopters.com.au/index.htm www.helipad.com.au/index.php/charter/rough-costs-guide	www.carpentaria-contracting.com/activities/ma-rine-services/ www.seaswift.com.au	www.airboatsin-ternational.com
OVERALL FEASIBILITY POTENTIAL:	High, requires testing	Medium, requires testing	High, in some locations	High, in some locations	Medium, requires testing

Table 9 **Responsible disposal (part 1 of 4)**

Stage - Responsible Disposal or Re-processing					
Name	**Classification (FTIR Analysis) Lab grade unit**	**Classification (FTIR Analysis) Small unit**	**Classification (FTIR Analysis) Field/mobile unit**	**Pre-processing (Auxiliary Equipment) Dryer**	**Pre-processing (Auxiliary Equipment) Cleaning**
Option/technology Details					
DESCRIPTION: What is it?	FTIR analysis measures the range of wavelengths in the infrared region that are absorbed by a material	Near Infrared Spectroscopy: FTIR analysis. Can be plugged in and used in factory setting	Near Infrared Spectroscopy: FTIR analysis. Can be used in the field with phone app and device	Equipment necessary to pre-process the material, e.g. cleaning, drying, cutting/shredding	Equipment necessary to pre-process the material, e.g. cleaning, drying, cutting/shredding
UNIT COST: How much is it?	New USD $45,000 = AUD $58,000	Plastell unit GBP £2,500 = AUD $4,570	TrinamiX unit - Price not available	Used - New AUD $1,000 - $20,000	New from USD $1,800 = AUD $2,300
STAGE: Pilot or Commercial). Is it market ready, proven on commercial scale?	Commercial Market Ready	Commercial Market Ready	Early stage commercial, new product	Commercial Market Ready	Commercial Market Ready
Social Criteria					
RISK: People (Safety and Operations)	Safe, no PPE needed, training required. Requires specialist knowledge	Safe, no PPE needed, training required. Requires some specialist knowledge	Safe, no PPE needed, training required. Requires some specialist knowledge	Moderate safety, PPE and training required	Moderate safety, PPE and training required
BENEFITS TO COMMUNITIES: Benefits return to communities. What benefit is there? What kind?	Potential skilled role in materials pathway	Potential skilled role in materials pathway	Potential skilled role in materials pathway	Potential skilled role in materials pathway	Potential skilled role in materials pathway
SOCIAL LICENCE/ CULTURALLY APPROPRIATE: Social licence to operate and cultural appropriateness. What is the level of concern?	Low potential for community concern	Low potential for community concern	Low potential for community concern	Low potential for community concern	Low potential for community concern
SUITABLE INFRASTRUCTURE AND SYSTEMS: Support systems and infrastructure available, including skills/labour	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Technology and support infrastructure are adequate	Support infrastructure could be sufficient at a regional town	Support infrastructure could be sufficient at a regional town

Stage - Responsible Disposal or Re-processing					
Name	**Classification (FTIR Analysis) Lab grade unit**	**Classification (FTIR Analysis) Small unit**	**Classification (FTIR Analysis) Field/mobile unit**	**Pre-processing (Auxiliary Equipment) Dryer**	**Pre-processing (Auxiliary Equipment) Cleaning**
Environmental Criteria					
RISK: Environmental and climate	Low risk for people and environment	Low risk for people and environment	Low risk for people and environment	Low risk for people and environment	Low risk for people and environment
SCALE: Appropriate geographic scale eg community, regional, state. Will it work in remote areas?	Unit suited to lab setting	Can work in remote areas in factory setting	Can work in remote areas and has been trialled in the Gulf of Carpentaria	Can work in local community subject to space availability. Potential for scaling	Can work in local community subject to space availability. Potential for scaling
Economic Criteria					
ADAPTABLE: Ability to deal with the difficult nature of the material (mixed, contaminated, degraded)	Results may be affected, requires technical knowledge to interpret	Results may be affected, requires technical knowledge to interpret	Results may be affected, requires technical knowledge to interpret	Unlikely to be affected by contamination	May be affected by contamination and require modification for nets
COST EFFECTIVENESS: Cost effectiveness, including set up, labour, running costs, maintenance.	May be cost effective depending on materials pathway design. Could be outsourced	May be cost effective depending on materials pathway design. Could be outsourced	May be cost effective depending on materials pathway design	May be cost effective depending on materials pathway design	May be cost effective depending on materials pathway design
SUSTAINABLE/ FIT FOR PURPOSE: Does is generate a saleable end product, would it contribute to a financially sustainable business? Does it have available markets and meet performance requirements?	Fit for purpose proven technology for classification of waste	Fit for purpose proven technology for classification of waste	Fit for purpose proven technology for classification of waste however training for Rangers required	Fit for purpose proven technology for drying	Fit for purpose, proven technology for cleaning
LINK:	www.agilent.com/en/product/molecular-spectroscopy/ftir-spectroscopy/ftir-compact-portable-systems/4300-handheld-ftir	https://matoha.com/plastics-identification	https://trinamixsensing.com/plastics	www.machines4u.com.au/view/advert/2006-HOPPER -DRYER-HDT-100/447526/	www.alibaba.com/product-detail/Washing-Machine-50kg-Washing-Machine-50kg_1600118016643.html?spm=a2700.7724857.normal_offer.d_ image.bf5e49e98mCyHV&s=p
OVERALL FEASIBILITY POTENTIAL:	High	High	High, requires testing with Rangers	High, requires testing for ghost nets	High, requires testing for ghost nets

Table 10 **Responsible disposal (part 2 of 4)**

Stage - Responsible Disposal or Re-processing					
Name	**Pre-processing (Auxiliary Equipment)** **Shredder**	**Baling**	**Extrusion, large**	**Extrusion, small**	**Injection**
Option/technology Details					
DESCRIPTION: What is it?	Equipment necessary to pre-process the material, e.g. cleaning, drying, cutting/shredding	Compressing waste, reducing its cubic volume for storage or transport	Material extruded into pellet or filament	Small extruder or combined shredder/extruder creates pellet or filament	Material injection moulded into a new plastic product for sale/ re-purposing
UNIT COST: How much is it?	Used from AUD $35,000 New AUD $50,000 and up depending on size	Used AUD $7,000-$19,700 New AUD $20,000 and up	Used ~ AUD $10,000 (plus engineering costs) New pelletising line ~ AUD $100,000	New ~ AUD $10,000-$25,000	Used - New AUD $5,000 - $100,000
STAGE: Pilot or Commercial. 'Is it market ready, proven on commercial scale?'	Commercial Market Ready	Commercial, may need custom build to cope with heavy use. Is being used to compact ghost nets in Indonesia	Commercial Market Ready	Commercial Market Ready e.g. Plastic Collective, or Precious Plastic	Commercial Market Ready
Social Criteria					
RISK: People (Safety and Operations)	Moderate safety, PPE and training needed	PPE and training needed	Moderate safety, PPE and training needed	Moderate safety, PPE and training needed	Moderate safety, PPE and training needed
BENEFITS TO COMMUNITIES: Benefits return to communities. What benefit is there? What kind?	Potential skilled role in materials pathway	Potential skilled role in materials pathway	Potential skilled role in materials pathway	Potential skilled role in materials pathway	Potential skilled role in materials pathway
SOCIAL LICENCE/ CULTURALLY APPROPRIATE: Social licence to operate and cultural appropriateness. What is the level of concern?	Low potential for community concern	Low potential for community concern	Low potential for community concern	Low potential for community concern	Low potential for community concern

Stage - Responsible Disposal or Re-processing					
Name	**Pre-processing (Auxiliary Equipment)** **Shredder**	**Baling**	**Extrusion, large**	**Extrusion, small**	**Injection**
SUITABLE IN-FRASTRUCTURE AND SYSTEMS: Support systems and infrastructure available, including skills/ labour	Support infrastructure could be sufficient at a regional town	Support infrastructure could be sufficient at a regional town	Support infrastructure could be sufficient at a regional centre	Small unit has low infrastructure needs	Support infrastructure could be sufficient at a regional town
Environmental Criteria					
RISK: Environmental and climate	Low risk for people and environment	Low risk for people and environment	Medium risk for people and environment	Medium risk for people and environment	Medium risk for people and environment
SCALE: Appropriate geographic scale eg community, regional, state. Will it work in remote areas?	Can work in local community subject to space availability. Potential for scaling	Can be used in remote locations (on back of ute), or regional town depending on size	Feasible for larger regional centres and scalable	Feasible for remote location	Feasible for larger regional centre and scalable
Economic Criteria					
ADAPTABLE: Ability to deal with the difficult nature of the material (mixed, contaminated, degraded)	Is affected by contamination, very low tolerance. Requires significant modifications and sorting of waste	Is not affected by contamination	Is affected by contamination, very low to no tolerance	Is affected by contamination, very low to no tolerance	Is affected by contamination, very low to no tolerance
COST EFFECTIVENESS: Cost effectiveness, including set up, labour, running costs, maintenance.	May be cost effective depending on materials pathway design	May be cost effective depending on materials pathway design	May be cost effective depending on materials pathway design	Unlikely to be cost effective unless for community education focus as low volumes produced	May be cost effective depending on materials pathway design
SUSTAINABLE/ FIT FOR PURPOSE: Does is generate a saleable end product, would it contribute to a financially sustainable business? Does it have available markets and meet performance requirements?	Significant modifications required for ghost nets and will require testing. Processed material could be sold as pellet feedstock or used in remanufacturing	Fit for purpose proven technology for bailing ghost nets	Fit for purpose proven technology for clean end of life nets. Homogenised pellets have a low chance of profitability	Small machine -production capacity is restricted	Fit for purpose proven technology for clean end of life nets. May be sustainable depending on what product is made

Stage - Responsible Disposal or Re-processing					
Name	**Pre-processing (Auxiliary Equipment)** **Shredder**	**Baling**	**Extrusion, large**	**Extrusion, small**	**Injection**
LINK:	www.machines4u.com.au/view/advert/Industrial-Single-Shaft-Recycler-Shredder-15kW/626132/	www.machines4u.com.au/view/advert/Bramidan-B4-Vertical-Baler-Great-for-Cardboard-Plastic-Quiet-and-compact-in-size/654044/ www.machines4u.com.au/view/advert/SAM-400-Vertical-Baler-52-Tonne-Pressing-Force-Touch-screen-Semiautomatic-Slide-Door/673196/	www.machines4u.com.au/view/advert/Erema-Extrusion-Pelletiser-Line-with-Zergomat-Die-Face-Cutter/659275/	www.plasticcollective.co/resource-recovery/ http://preciousplastic.com/solutions/machines/pro.html	www.machines4u.com.au/view/advert/Injection-Moulding-Machine/697395/
OVERALL FEASIBILITY POTENTIAL:	High, requires modifications and testing for ghost nets	High, requires testing if off shelf	High for clean end of life nets (feedstock restriction)	Low (feedstock restriction) unless education focus	High for clean end of life nets (feedstock restriction)

Table 11 **Responsible disposal (part 3 of 4)**

Stage - Responsible Disposal or Re-processing					
Name	**Re-Manufacturing**	**Incineration** **Small - Can be trolleyed by hand / 1 person**	**Incineration** **Medium/Trailer -Mounted on trailer, can be towed by 4WD.**	**Incineration** **Medium/ Container Unit**	**Pollution Control System**
Option/technology Details					
DESCRIPTION: What is it?	MICROFactorie™ solution (Green Ceramics™ e.g.)	Material will be incinerated to degrade quickly. Left over material can be compacted together	Material will be incinerated to degrade quickly. Left over material can be compacted together	Material will be incinerated to degrade quickly. Left over material can be compacted together Needs Truck and Crane to load and unload / or helicopter	Separate unit to capture fumes and emissions from larger incinerators
UNIT COST: How much is it?	Module-dependent: AUD ~$200k - $1M	AUD $4,700	New trailer USD $29,000 = AUD $37,500 Incinerator USD $15k - $365k = AUD $20k - $400k	New container USD $33,800= AUD $43,700 Incinerator USD USD $15k - $365k = AUD $20k-$400k	Price not available
STAGE: Pilot or Commercial? Is it market ready, proven on commercial scale?	Commercial, Market Ready but requires protyping with ghost nets	Commercial Market Ready	Commercial Market Ready	Commercial Market Ready	Commercial Market Ready
Social Criteria					
RISK: People (Safety and Operations)	Moderate safety, PPE and training needed	Moderate safety, PPE and training needed	Moderate safety, PPE and training needed	Moderate safety, PPE and training needed	Moderate safety, PPE and training needed
BENEFITS TO COMMUNITIES: Benefits return to communities. What benefit is there? What kind?	Potential skilled role in materials pathway	Commercial/ indirect - reduced plastic loads in environment and landfill	Commercial/ indirect - reduced plastic loads in environment and landfill	Commercial/ indirect - reduced plastic loads in environment and landfill	Commercial/ indirect - reduced emissions and exposure to toxic fumes
SOCIAL LICENCE/ CULTURALLY APPROPRIATE: Social licence to operate and cultural appropriateness. What is the level of concern?	Low potential for community concern	Moderate potential for community concern	Moderate potential for community concern	Moderate potential for community concern	Moderate potential for community concern

Stage - Responsible Disposal or Re-processing					
Name	**Re-Manufacturing**	**Incineration Small - Can be trolleyed by hand / 1 person**	**Incineration Medium/Trailer -Mounted on trailer, can be towed by 4WD.**	**Incineration Medium/ Container Unit**	**Pollution Control System**
SUITABLE INFRASTRUCTURE AND SYSTEMS: Support systems and infrastructure available, including skills/labour	Support infrastructure could be sufficient at a regional town	Small unit has low infrastructure needs	Small unit has low infrastructure needs	Scale of technology and support infrastructure may not be adequate	Scale of technology and support infrastructure may not be adequate
Environmental Criteria					
RISK: Environmental and climate	Low risk for people and environment	Medium - High risk for people and environment	Medium - High risk for people and environment	Medium - High risk for people and environment	Medium - Will reduce risks of air pollution when used
SCALE: Appropriate geographic scale eg community, regional, state. Will it work in remote areas?	May be feasible for mobile/ remote centre subject to space availability. Scalable	May be feasible for mobile/ remote location. Not scalable	May be feasible for mobile/ remote location. Scalable	May be feasible for regional centre. Scalable	For use with larger incinerators
Economic Criteria					
ADAPTABLE: Ability to deal with the difficult nature of the material (mixed, contaminated, degraded)	Has medium to high tolerance of contamination	Is not affected by contamination	Is not affected by contamination	Is not affected by contamination	Is not affected by contamination
COST EFFECTIVENESS: Cost effectiveness, including set up, labour, running costs, maintenance.	May be cost effective depending on materials pathway design	May be cost effective depending on materials pathway design	May be cost effective depending on materials pathway design	Unlikely to be cost effective without municipal waste streams	May be cost effective when used with larger incinerators
SUSTAINABLE/ FIT FOR PURPOSE: Does is generate a saleable end product, would it contribute to a financially sustainable business? Does it have available markets and meet performance requirements?	Fit for purpose for mixed feedstocks. May be sustainable depending on what product is made	Fit for purpose to address biosecurity concerns on beaches for smaller items	Fit for purpose to address biosecurity concerns on beaches for larger items	Fit for purpose to remove waste for landfill	Fit for purpose when use with larger incinerators

Stage - Responsible Disposal or Re-processing					
Name	**Re-Manufacturing**	**Incineration** **Small - Can be trolleyed by hand / 1 person**	**Incineration** **Medium/Trailer -Mounted on trailer, can be towed by 4WD.**	**Incineration** **Medium/ Container Unit**	**Pollution Control System**
LINK:	www.smart.unsw.edu.au/technologies-products/microfactorie-technologies/green-ceramics	www.inciner8.com/the-sirocco.php https://spillpro.com.au/incinerators/portable-non-hazardous-waste-incinerators	https://www.inciner8.com/trailer-mounted-incinerators.php	www.inciner8.com/containerised-incinerators.php	www.inciner8.com/small-pollution-control-systems.php
OVERALL FEASIBILITY POTENTIAL:	High, requires testing	High, requires testing	High, requires testing	Low, more suited to municipal waste	Low, more suited to municipal waste

Photo by Jane Dermer

Table 12 **Responsible disposal (part 4 of 4)**

Stage - Responsible Disposal or Re-processing			
Name	**Pyrolysis Small Scale**	**Pyrolysis Large Scale**	**Integrated Waste to Energy**
Option/technology Details			
DESCRIPTION: What it is?	Produce diesel from waste material. Thermal decomposition of materials at elevated temperatures in an inert atmosphere	Decomposition of materials at elevated temperatures in an inert atmosphere. Continuous production	Thermal decomposition of materials combined with energy generation eg. Sierra Energy gasification lessons learned case study
UNIT COST: How much is it?	Mobile unit: AUD $1.7M	Price not available - Custom-built facility	Sierra Energy example: USD $3M set up cost
STAGE: Pilot or Commercial. Is it market ready, proven on commercial scale?	Commercial, units available for purchase in Australia. Has been trialled using clean end of life nets in laboratory setting	Custom built facility Has been trialled using clean end of life nets in laboratory setting	Custom built facility
Social Criteria			
RISK: People (Safety and Operations)	PPE and training needed	PPE and training needed	PPE and training needed
BENEFITS TO COMMUNITIES: Benefits return to communities. What benefit is there? What kind?	Potential skilled role in materials pathway	Potential skilled role in materials pathway	Potential skilled role in materials pathway
SOCIAL LICENCE/ CULTURALLY APPROPRIATE: Social licence to operate and cultural appropriateness. What is the level of concern?	Moderate potential for community concern	Moderate potential for community concern	Moderate potential for community concern
SUITABLE INFRASTRUCTURE AND SYSTEMS: Support systems and infrastructure available, including skills/labour	Technology and support infrastructure may be adequate	Would require large and consistent quantity of input (municipal)	Would require large and consistent quantity of input (municipal)
Environmental Criteria			
RISK: Environmental and climate	Medium risk for people and environment due to production of petrochemicals	Medium risk for people and environment due to production of petrochemicals	Medium risk for people and environment due to production of petrochemicals

Stage - Responsible Disposal or Re-processing			
Name	**Pyrolysis Small Scale**	**Pyrolysis Large Scale**	**Integrated Waste to Energy**
SCALE: Appropriate geographic scale eg community, regional, state. Will it work in remote areas?	Possibly feasible for remote centres. Scalable	Feasible for regional centres. Scalable	Feasible for regional centres. Scalable
Economic Criteria			
ADAPTABLE: Ability to deal with the difficult nature of the material (mixed, contaminated, degraded)	Highly likely to be affected by contamination	Highly likely to be affected by contamination	Is not affected by contamination
COST EFFECTIVENESS: Cost effectiveness, including set up, labour, running costs, maintenance.	Unlikely to be cost effective as will not have volumes required of feedstock of ghost nets	Unlikely to be cost effective - high minimum daily input requirements for feedstock	Unlikely to be cost effective - high minimum daily input requirements for feedstock
SUSTAINABLE/FIT FOR PURPOSE: Does is generate a saleable end product, would it contribute to a financially sustainable business? Does it have available markets and meet performance requirements?	May produce saleable fuel, quality unknown, may be variable	May produce saleable fuel, quality unknown, may be variable	Produces energy
LINK:	https://pyrotechenergy.com/pyroflash-plants/	Example: Plastic Energy https://plasticenergy.com/technology/	Example: Sierra Energy https://sierraenergy.com
OVERALL FEASIBILITY POTENTIAL:	Low-Medium, requires testing	Low, more suited to municipal waste	Low, more suited to municipal waste

Notes: Explanation is provided about some methods for responsible disposal.

Extrusion - a large-scale manufacturing technique, using a continuous process to melt and enrich polymers with desired additives. The raw material (in this case polymer) is fed into a hopper above the extrusion machine. Gravity then feeds granulated pieces of plastic down into a feeder throat, which connects to a rotating screw. The screw size and design are heavily dependent on the material being used and on the requirements of the end product. The screw forces plastic forward through a barrel, heated by screw-shear and electric heating elements. After the polymer has melted completely in the barrel it is ejected through a nozzle than continuously extrudes multiple strains of plastic that directly are being transported into a water bath to cool down. After exiting the water bath, the strings or hardened plastic reach a rotating blade cutter that cuts the newly extruded plastic into a certain pellet size.[77]

Injection Moulding - works similarly to extrusion. The raw material is fed into a hopper, which in turn feeds it via gravity into a feeder throat. A screw transports the feedstock into a heated barrel, melting the raw materials. After the polymer is molten it is injected into a steel mould, while maintaining pressure for a certain time span, depending on the product size and design. The plastic will then cool down within the mould for a set time before it open and the finished product can be de-moulded, via manual labour or mechanical ejection.[78]

Pyrolysis - Biomass and organic materials are heated in the absence of oxygen. Without the oxygen, materials do not combust and burn, but rather break down into the chemical compounds that make up the feedstock. The result is the decomposition of feedstock into charcoal and combustible gases. Each pyrolysis setup is usually designed with a certain feedstock in mind, such as rubber (e.g. in the form of tyres) or plastic or organic matter. Commonly the setups are installed to purely process one feedstock alone and is highly specialised for it, meaning that it cannot process other feedstocks. Doing so may cause equipment failure and/or produce unwanted products when feeding feedstock into a pyrolysis setup that it was not made for. The treatment of the exhaust prior to gas ejection, may also not be able to handle unplanned contaminants introduced by different feedstock types. However, pyrolysis can be fitted to accept more than one type of feed stock. It could be a combination of multiples of biomass, rubber and plastics. In these setups, the intake ratio per feedstock is highly specified and optimised, leaving them very sensitive to feedstock quality and change. Every type of feedstock has their own specific temperature at which decomposition occurs and requires individual process durations and pressure. A small-scale unit functions the same way, with the added feature of being flexible in its set up, due to being mounted on a trailer or in a 20ft container. This allows for it to travel without having to be disassembled.

Waste incineration combusts waste materials like plastics and other organic materials. The waste stock is reduced to 2-3% of its original volume. The leftover is partly ash and slack, depending on the waste composition. This method reduces the waste material, while also recovering some of its energy in the form of electricity. Usually, the heat and steam created in large incinerators are strong enough to power turbines, to create electricity that can be fed into the local power grid. As the plastic is consumed, excessive amounts of greenhouse gases are emitted as by-product unless fitted with a pollution control system. The plastic as a material cannot be used again in a circular economy framework.

Annex 2 Materials Analysis

Recycling oceanic waste polymers is a tricky undertaking. Marine debris and ghost nets arrive in varying degrees of deterioration, further complicating any recycling or repurposing procedures of the discarded materials.

Thirty-eight samples of varied types of ghost nets found across the Gulf of Carpentaria, through in-water retrievals as well as beach clean-ups were provided for the study from AFMA, Parks Australia, Northern Prawn Fishery and the Ghost Net Art Project for analysis. All were in varying states of degradedness.

Classification

The classification of plastic is a necessary first step to successfully reintroduce them into any economy. Different plastics are used for different applications. It is relatively easy to classify these materials using laboratory instruments or handheld devices for use in the field.

Application in use

Structurally more rigid and stable polymers are necessary for products and services that require them to withstand certain amounts of physical pressure, like building materials. Others are allowed to deform easier like food containers. To not compromise the material's integrity and characteristics, it is important that plastics are separated accordingly.

Bond

There are a variety of different polymer families with different chain lengths and elemental makeups. Some plastics will not properly bond with each other, again leading to unstable compounds and products, but furthermore to physical delamination. These delaminations are usually visible to the naked eye, making it impossible for some plastic blends to be reused for consumer products that have cosmetic requirements and standards.

Ghost net materials analysis results

When analysing the different ghost net and end of life fishing net samples provided, 90% of the samples were found to be made from high-density polyethylene (Figure 10). The other 10% consist of polyethylene terephthalate (PET) and polypropylene (PP) (Figures 11 and 12). They were analysed at the University of NSW (UNSW) using Fourier-transform infrared spectroscopy (FTIR), which is a technique that measures the reflectance of an object on an infrared spectrum of absorption or emission. Once a sample was scanned, the local database provided the closest match to identify the spectral reading. As shown in figures below, the readings (red) were significant enough to identify each sample as either HDPE, PET or PP, however they deviated from the indexed match (blue). This may be due to degradation and contamination of the plastic, such as organic materials (like seaweed), salt and sand particles. In each figure, in addition to a picture of the sample net, a magnified image of the waste plastics surface using scanning electron microscopy (SEM) is provided, revealing small fragmentations in the threads, cracks and some contamination like sand and salt.

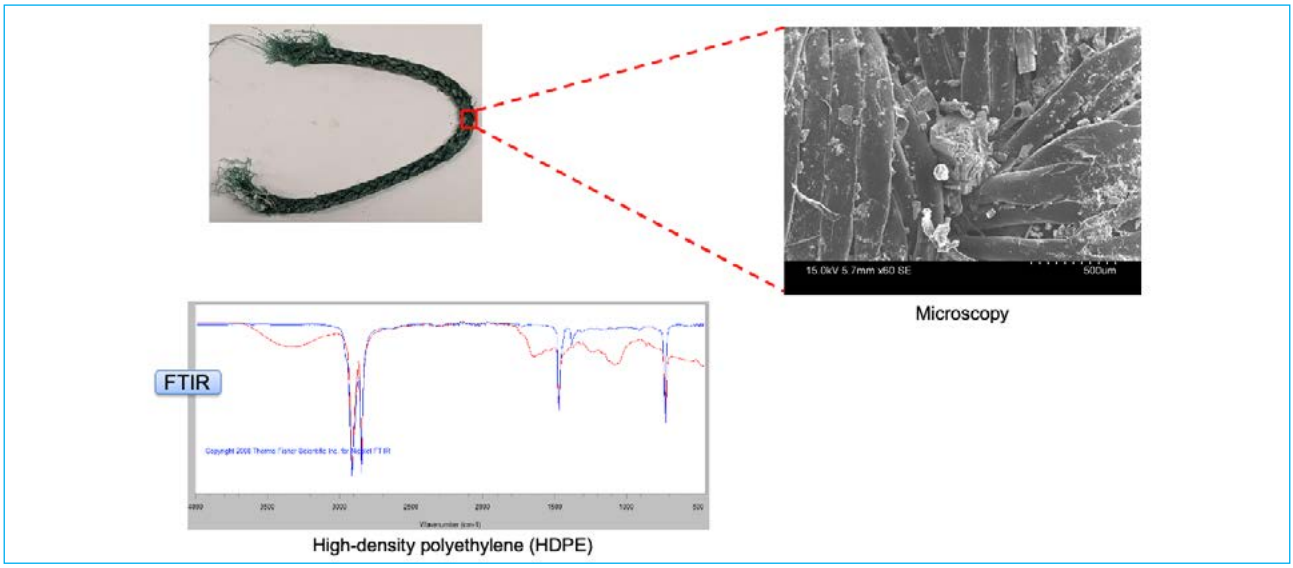


Figure 10 Test Results Net 2 - HDPE

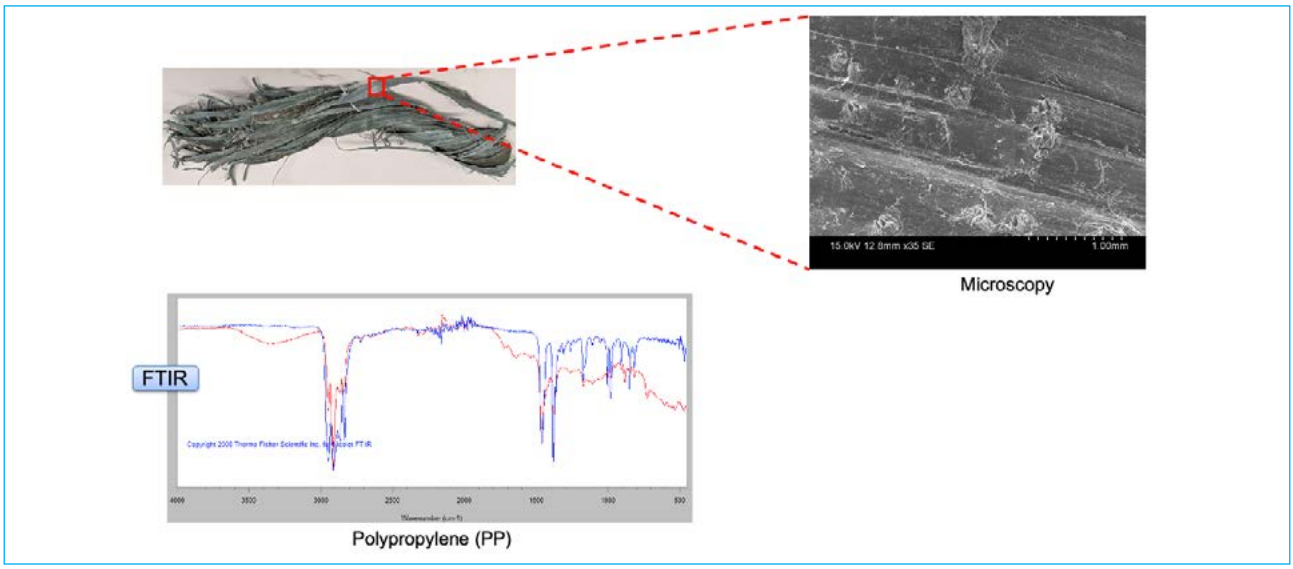


Figure 11 Test Results Net 1 - PP

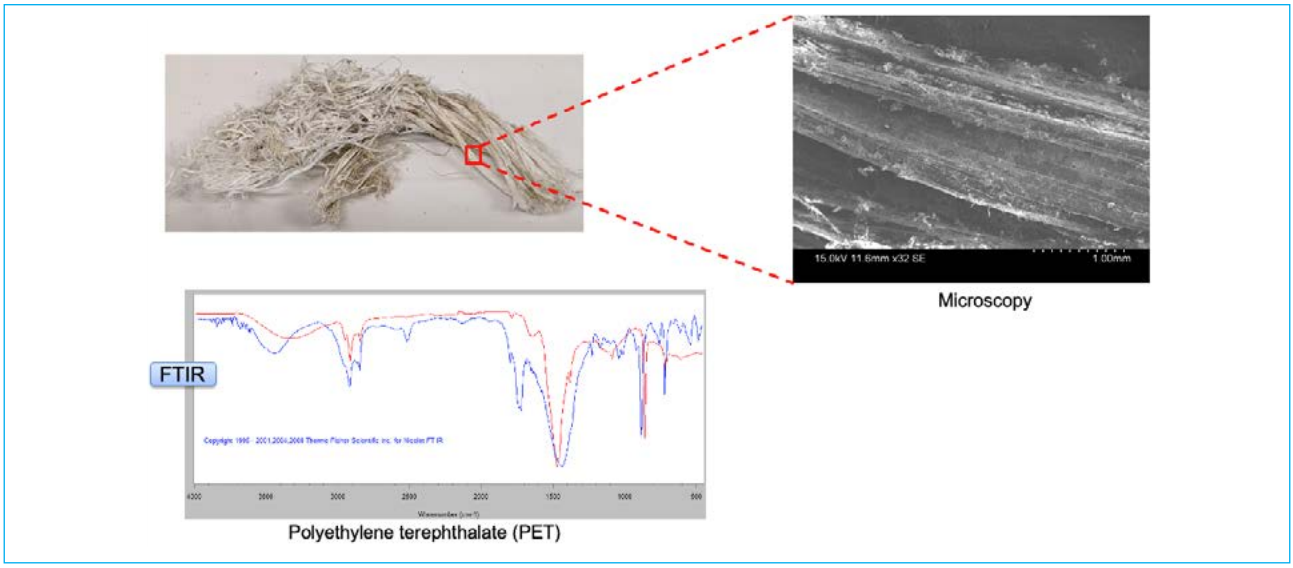


Figure 12 Test Results Net 3 - PET

Annex 3 Stakeholder participation

The following stakeholders participated in the study, either through participation in workshops and/or through individual interviews.

Organisation
Anindilyakwa Land and Sea Rangers (Groote Eylandt)
Dhimurru Rangers / Dhimurru Aboriginal Corporation
Gumurr Marthakal Rangers (Galiwinku)
Ii-Anthawirriyarra Sea Rangers
Mapoon Land and Sea Rangers
Pormpuraaw Land and Sea Rangers
Torres Strait Regional Authority / Rangers
Yirralka Rangers / Laynhapuy Indigenous Protected Area
Northern Australia Indigenous Land and Sea Management Alliance (NAILSMA)
Northern Land Council, Northern Territory
QLD Department of Environment, QLD Indigenous Ranger Program
NT Department of Environment, Parks and Water Security, NT Aboriginal Ranger Program
Department of Agriculture, Water and the Environment and Parks Australia
Australian Fisheries Management Authority
Maritime Border Command
Commonwealth Science and Industrial Research Organisation (CSIRO)
Charles Darwin University
Global Ghost Gear Initiative
World Animal Protection
Sea Shepherd
Tangaroa Blue
Earthwatch Australia
Minderoo – Flourishing Oceans
GhostNets Australia
Ghost Net Art Project
Austral Fisheries
Northern Territory Seafood Council
Northern Prawn Fishery Industry Pty Ltd
Western Cape Turtle Threat Abatement Alliance/Cape York Natural Resource Management (NRM)
Northern Gulf NRM
Southern Gulf NRM

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