Final

Material flows in the Australian fisheries and aquaculture sectors

FRDC Circular Economy Project 2021-133: Initiative 1.

Bega Regional Circularity Co-operative

July 2024

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Material flows in the Australian Fisheries and aquaculture sectors
Project 2021-133

2024

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Foreword

This report forms part of the project report for the Circular Economy (CE) program with FRDC as **Project 2021-133**: *Circular economy Program 2022-2025*. There are five project initiatives within the CE program designed specifically for the Fishing and Aquaculture industry sectors:

1. National material flow assessment for circularity opportunity (This report)
2. Industry Circularity capacity and capability building – Circular Advantage
3. Circularity measurement and performance monitoring – case studies
4. Innovation capacity building – Circular Accelerate
5. CE methodology and performance monitoring and measurement - Community of Practice

Initiative 1 was executed by KPMG and utilized data collated by FRDC and ABARES in data collected in 2020-21 (Agricultural Australian Bureau of Agricultural and Resource Economics and Sciences).

Material Flows in the Australian Fisheries and Aquaculture Sector

Uncovering opportunities to enhance circularity and drive positive socio-economic and environmental impact in the fisheries and aquaculture sector through a nationwide material flow analysis.

19 July 2024

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Executive Summary

Fishing and aquaculture are important parts of the Australian economy and Australian identity, contributing over five billion dollars to the national economy and employing around 40,000 people in 2017/18 (1). Fishing is an integral part of the Australian way of life, as a single nation on a single continent, 87% of Australia's population lives within 50 kilometres of the coast (2). One in five Australians identify as active fishers, and over three quarters are seafood consumers (3) (4). Seafood is 9% of the countries' animal protein intake, making it a form of sustenance, a source of income and livelihood (5).

Whilst the fisheries and aquaculture sector has long been mindful of wastage both in terms of catch and consumption of materials, to date the primary focus has centred around preventing overfishing. With global pressure on fish populations, preventing overfishing is essential to sustaining a healthy marine ecosystem and the viability of the Australian fishing and aquaculture sector. Sustainable fish stocks are also fundamental to a circular economy, which favours renewable resources over 'non-renewable' resources. In the circular economy, a product is deemed circular if it is derived from renewable inputs, e.g. a well-managed healthy fish stock as opposed to a non-renewable resource (e.g. an overfished stock). Circularity is also determined by whether a product can be reused, recovered, or recycled at end of life. Considerable work has been done to understand and manage the sustainability of fish stocks in Australia outside of this analysis. This report seeks to take a broader focus on the circularity of the entire fisheries and aquaculture sector by identifying the different types of materials being used and analysing the waste generated through a Material Flow Analysis (MFA).

This report seeks to apply a circular lens to the Australian fisheries and aquaculture sector to understand the materials used (inputs) and the end fates of these materials (e.g. how materials are disposed) in order to understand areas of high material usage or high waste generation and identify opportunities to address these and improve circularity across the industry to enhance positive socio-economic outcomes and reduce environmental impact.

I. Uncovering opportunities to enhance circularity in the fisheries and aquaculture sector

To grow and catch fish a significant volume of materials, energy, and fuel is required. For instance, this could include the energy required to maintain a hatchery in land-based aquaculture, to the fuel required to power fishing vessels and at refrigeration, and the nets, lines and gear required to catch fish.

Not only are significant volumes of materials required to grow and catch fish, but once caught or harvested, seafood and fish products then require more energy and materials in processing, to maintain freshness and preserve their shelf life through refrigeration and packaging.

While the energy and materials required to grow, harvest, catch, process and preserve seafood is paramount to ensuring food safety, what is the impact on materials usage? What are the opportunities to improve efficiencies and capitalise on lost value?

To identify the different materials and ends fates of materials within the supply chain stages of the fisheries and aquaculture sector, an MFA was conducted. The MFA is a useful tool to understand the materials usage within a system, by visualising the quantity of materials inputted and the quantities of end fates or "waste products". By understanding when, where and approximately how much material is being used, stakeholders can then prioritise the least circular areas most likely to benefit from intervention.

In a world of finite resources and continued population growth, the importance of properly managing the earth's resources cannot be understated. The circular economy offers a paradigm for a more sustainable future. In the ideal circular world there is no waste, resources are kept in use at their highest value whilst regenerating nature. Circular systems prioritise 'non-virgin' and 'renewable' materials, and their recovery potential, i.e. how well products are designed for recovery and whether or not they can feasibly be recovered within the locale they are generated.

The circular economy is increasingly seen as a major focus for government, industry and investors alike. This interest is not just from an environmental and 'goodwill' perspective, but also due to the economic opportunity, the efficiency of circular systems in which materials re-circulate at a higher value for longer periods, maximising utility until end of life at which the product can be either returned to the environment or broken down and reused or recycled. Value is derived from maximising the embedded value within products and materials, rather than increasing consumption. There is a considerable positive socio-economic and financial opportunity for the fisheries and aquaculture sector to transition to a circular economy and lead the way for other industries to follow.

II. Summary of the methodology and scope

For the MFA, a system boundary was developed (see 2.2.2). The system boundary was developed based on initial work conducted by the FRDC and UTS and expanded upon through stakeholder and industry workshops, interviews and site visits held July to September 2023. The boundary for wild catch is from catch to market and aquaculture is from hatchery to market. The supply chain stages within the scope of this assessment include production, processing, retail, and wholesale. In addition to these stages, the production stage has been broken into aquaculture and wild catch (commercial and recreational), and Indigenous fisheries (commercial) given the diversity of production methods (e.g. how fish are caught or grown/harvested). For each production method, key products, materials, and energy inputs were quantified and categorised and a useful life was assigned to determine the method's contribution of waste.

Waste was then distributed across various end fates (e.g. emissions, landfill, organics recycling, loss to environment). Given the multitude of materials across production methods, materials were aggregated. Classifications were then used to generate material flows for wild catch and aquaculture respectively.

The functional unit of this assessment is 1 tonne of 'in-scope species' ready for customer purchase (i.e. final fish consumed or t_{fish}). The analysis period for this study is calendar year 2021. Materials and energy consumption intensities (tonnes of material consumed per tonne of final fish consumed or $\frac{t_{material}}{t_{fish}}$) was derived for each stage across the supply chain.

III. Key findings of the fisheries and aquaculture material flow analysis

This is the first time in Australia that material usage has been attempted to be quantified across the entire fisheries and aquaculture sector. As such, the primary objective is to establish an initial understanding of the approximate scale and proportion of different materials used across the supply chain, and how the materials are disposed of once reaching the end of their useful lives. *By understanding the material usage and disposal, interventions can then be developed to target circular action.* Given the pioneering nature of this report, data availability was often limited. A summary of assumptions can be found in Summary of key assumptions, exclusions and limitations 2.2.6 with further detail provided in Appendix 1 - Detailed MFA Methodology 8. The key findings of the MFA are summarised below.

Key findings - Material inputs

- The total material consumption for the Australian fisheries and aquaculture sector was approximately 390,000 tonnes.
    - This resulted in the generation of 1,621,115 tonnes of carbon dioxide equivalent (tCO2e) emissions and the disposal of 54,900 tonnes of organic waste to landfill.
    - The next most significant material inputs after emissions and organic waste include plastics, followed by metals.
- Aquaculture accounted for over half of the sector's material consumption in absolute terms (67%). When considering material intensity (excluding water, chemicals and electricity):
    - Aquaculture used 3.7 tonnes of material per tonne of final fish consumed.
    - Wild catch (commercial) used 3.1 tonnes of input material per tonne of final fish consumed.
    - Wild catch (recreational) used 1.7 tonnes of input material per tonne of final fish consumed.
- The two most significant material inputs in absolute terms were:
    - Bait and fish feed 192,726 tonnes (47%)
    - Fuel for vessels and generators 116,968 tonnes (29%)
- Within the remaining 24% the most significant physical material inputs were:
    - Plastics (55%)
    - Metals (16%)
    - Paper and cardboard (12%)
- Within the plastics category, the large majority was fishing gear and equipment (69%) with the remainder being packaging (31%).

Key Findings – Material outputs (end fates)

- The overwhelming majority of total material outputs (end fates) was emissions (81%) with final fish consumed constituting 6.1% (end fates).
- Of the organic waste generated:
    - 32% Effluent from aquaculture (sea cages)
    - 17% Offal from wild catch (commercial)
    - 22% Bycatch from wild catch (commercial)
    - 17% Offal from aquaculture
- Within total offal, 77% is from offal waste produced during the processing supply chain stage.
    - 41% from aquaculture processing
    - 36% from wild catch processing
- The remaining 23% is generated during the wholesale/retail supply chain stage:
    - 15% from aquaculture wholesale/retail
    - 8% from wild catch wholesale/retail

IV. Recommendations

Based on the findings of the MFA six potential circular interventions and eight supporting enablers were developed to help target the areas with high material usage and low circularity.

Potential circular interventions

The following potential interventions were developed to address six key areas: bait and fish feed, emissions, effluent, offal, fishing gear and equipment, and packaging. For each intervention, the relevant circular strategies being employed are highlighted. Further details on the potential circular strategies can be found in Chapter 4 and detailed potential circular interventions in Chapter 5.

Table 1: *Summary of potential circular interventions.*

POTENTIAL CIRCULAR INTERVENTION AREA AND TITLE		*CIRCULAR INTERVENTION DESCRIPTION*	CIRCULAR STRATEGIES								
			Redesign & procurement	Eliminating pollution	Regenerating nature	Extending lifespan	Product as a service	Sharing & trading	Product stewardship	Value from waste	Recycling & composting
Bait and Fish feed	**Alternative sources**	Investigate alternative baits or protein sources from sustainable sources. Conduct a detailed study into bait and fish feed sourcing, local solutions and research and development to provide higher value nutrients while using less and/or identify current waste streams as potential sources for bait and fish feed.	✓	✓	✓						
Bait and Fish feed	**Storage and shelf life**	Guidance and greater awareness on best practice handling of bait to ensure storage and extended shelf life. Continued improvements in best practices including storage and transport technologies.		✓		✓					
Emissions	**Reduce bait and fish feed carbon footprint**	Review the key suppliers and current bait and fish feed emissions profile. Identify strategies to reduce energy requirements, e.g. decentralised local production to reduce transport emissions and reliance on imports.	✓	✓	✓						
Emissions	**Electrification and alternative fuels**	Investigate, particularly for inshore and close to shore vessels, how feasibility of electric vessels can be expanded or encouraged. Investigate feasibility and conduct horizon scan of alternative fuels.		✓							
Emissions	**Energy rebates**	Funding to support renewable energy adoption by entities and further work to understand the regulatory implications of entities becoming 'energy producers' and removal of any related barriers.		✓							
Effluent	**Circular effluent options**	Investigate opportunities to utilise effluent in polyculture activities (where two or more species are produced in the same place). Further understand the costs and benefits of commercialising these opportunities.		✓	✓					✓	
Offal	**Aggregate and process organic waste**	Provide funding for local partnerships (e.g. markets, regional areas) to aggregate volumes and develop composting or co-digestion solutions. Support navigation of regulatory barriers and licensing for small-scale solutions. Facilitate trading between offal producers and local organic waste feedstock providers.						✓		✓	✓
Offal	**Foster organic waste innovation**	Support piloting and commercialisation of conversion of seafood processing waste into commercial products such as fish bait, animal feed, textiles or as a raw material for instance to produce cholesterol, lipids and proteins.								✓	
Fishing gear and equipment	**Standardisation and circular design**	Research and development to standardise materials in gear and equipment and reduce use of mixed materials. This should prioritise design for durability and repairability. Identify ways to increase the use of recycled and biobased materials in procurement.	✓	✓		✓				✓	
Fishing gear and equipment	**Product stewardship**	Establish and scale up product stewardship schemes (for example, the Rig Recycle Program) and work with industry, government and consumers to develop long-term scheme solutions. Partner with the recycling sector to identify material recovery gaps and consider localised solutions.						✓	✓		✓
Fishing gear and equipment	**Expand gear rental services**	Consider opportunities to expand rentals (product as a service model) and facilitate sharing of gear. Fishing gear rentals are an existing service around Australia that enables infrequent fishers to rent gear as opposed to buying new gear. Sharing could also be explored through the creation of a gear sharing platform.					✓	✓			
Packaging	**Australian Packaging Covenant Organisation (APCO) alignment**	Align with APCO's targets and commit to 100% reusable, recyclable, or compostable packaging (6). Identify and redesign problematic packaging across the supply chain following APCO's guidelines (7) and prioritise reusable models.	✓			✓		✓			✓

Potential enablers

To accelerate progress to a more circular fisheries and aquaculture sector, eight enablers have been proposed based on the findings of the MFA. These enablers are summarised in Table 2 below, and further details can be found in Chapter 6.

Table 2: *Summary of potential circular enablers*

CIRCULAR ENABLER	PRIORITY	TIMEFRAME	STAKEHOLDERS
Centralised Coordinating Bodies	Medium to High	Short term	System-wide representation
Policy Levers and Government Engagement	High	Short to medium term	Government at federal and state levels, cross departmental, peak bodies, and fisheries and aquaculture sector.
Utilise Existing Channels / Certifications	Medium	Short to medium term	Industry associations, certification bodies, sustainability initiatives
Knowledge Sharing and Capacity Building	Medium	Short to medium term	Industry associations, Research institutions, Knowledge-sharing platforms
Circular Supply Chain Innovation	High	Medium to long term	Industry associations, research institutions, technology start-ups, businesses across the sector
Funding Accessibility	High	Short to long term	Government, industry associations, research institutions, private sector
Material Traceability and Recovery Pathways	Medium	Short to long term	Industry associations, government agencies, research institutions, technology providers
Sector Decarbonisation	High	Short to long term	All stakeholders

The opportunity

The Australian fisheries and aquaculture sector is facing an increasing number of pressures from environmental challenges, resource constraints, economic pressures, to cross-border sustainability related regulations and export tariffs, as well as growing consumer demands for sustainability. By implementing these potential enablers and interventions, the sector has the opportunity to recover value from its most significant material losses, helping facilitate a transition towards a circular economy for positive socio-economic and environmental impact.

1. Introduction

The Fisheries Research and Development Corporation (FRDC) has a long history driving research and development to support efficiency and growth for enduring prosperity. In recognition of the importance of circularity to the sector, in 2020 the FRDC funded the first systems-wide circular economy project for the Australian fisheries and aquaculture sector (8). The project aimed to understand current circular economy activities, opportunities and barriers in the fisheries and aquaculture sector in Australia through stakeholder engagement. This report seeks to build on the initial opportunities and barriers identified and quantify material usage across the sector through a nationwide Material Flow Analysis (MFA). The aim is to understand where there is lost value and prioritise efforts to increase circular economy outcomes in the fisheries and aquaculture sector to enhance positive socio-economic and environmental impact.

1.1. What is a circular economy?

Our economy is predominately linear. Materials such as minerals, fossil fuels and biomass are extracted, turned into products that are designed to be consumed for a finite period, before ultimately being discarded. Sustaining our current lifestyles and consumption patterns requires natural resources that overstep the limits of our planetary boundaries. At current rates of consumption, by 2050 we would require the equivalent of almost three planets worth of natural resources (9). In 2023, globally only 7.2%of the 100 billion tonnes of resources extracted was reintroduced into our economy, the remaining 93% was discarded – representing a significant loss of value (10). Australia's circularity rate is below the global average, with 5.4% of extracted resources being reintroduced to the Australian economy (11).

The circular economy presents an alternative. An economic system where value is derived from maximising the embedded value within products and materials, rather than increasing consumption. In a circular economy, waste and pollution are designed out, resources are kept in use and nature is regenerated.

The circular economy is also touted for the role it can play in supporting carbon emissions reduction ambitions. Capital markets are increasingly seeking opportunities to invest in carbon abatement activities and there is growing demand from the financial sector to invest and finance decarbonisation of the economy (12). Decarbonisation strategies to date have largely focused on transitioning to renewable energy, however, energy related to emissions only account for 55% of global greenhouse gas (GHG) emissions (10). The remaining 45% of total global emissions are embodied emissions in products and food (13). This means that changes in the way products and food are made and utilised has the potential to help eliminate almost half of the remaining emissions – 9.3 billion tonnes of carbon dioxide equivalent ($CO2_e$) in 2050 (13).

End to end food systems have an important role to play in reducing global emissions. Regenerative production practices can be used to design out waste along the supply chain, agricultural practices to sequester carbon, and avoided emissions related to uneaten food and unused by-products (13). The food system makes up one-third of GHG emissions. Globally, food waste alone is responsible for 24% of total freshwater resources and 23% of global fertiliser use (10).

Beyond the environmental benefits, there is significant economic value to be gained from embracing a circular economy. Material cost savings from transitioning to a circular economy are estimated to at AUD $26 billion by 2025 and AUD $210 billion in GDP by 2047-48, with the most significant opportunities in the food industry (14). Globally, a circular economy could represent up to USD $4.5 trillion opportunity over the next decade (15). This demonstrates the significant financial opportunity that a transition to a circular economy represents and reflects the growing interest in sustainability and circularity from the capital markets.

The Ellen MacArthur Foundation developed the 'the butterfly diagram', a globally common framework to illustrate the circular economy at a system level. The butterfly diagram shows the continuous flow of materials in our economy via two key cycles: the biological cycle and the technical cycle. Figure 1: Circularity for seafood (16) shows the applicability of the butterfly diagram for the fisheries and aquaculture sector.

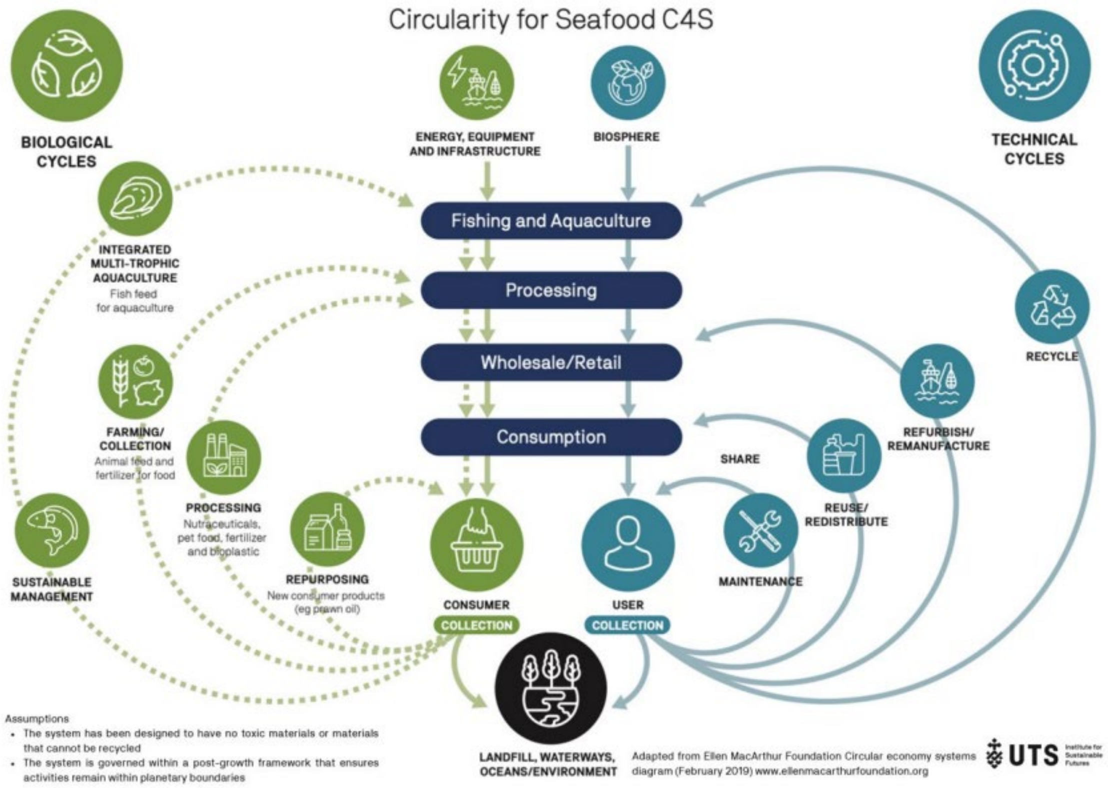

***Figure 1:** Circularity for seafood.*
Source: Adapted from UTS report (16).

In the biological cycle, nutrients from biodegradable materials are returned to the Earth to regenerate nature, such as food. In the technical cycle, products are kept in circulation through processes such as reuse, repair, remanufacture and recycling.

The outer loops of the butterfly diagram break products down to their parts or materials, incurring added costs and environmental impact associated with reprocessing, transport, and remanufacturing and is where much of the embedded energy is lost (16). For this reason, the outer loops are the least profitable and least environmentally effective.

To drive circularity in practice there are multiple strategies beyond waste reduction and recycling. The circular strategies below have been developed specifically for this project, drawing on insights from stakeholder workshops, engagement, and global leading practice. The circular strategies outlined in Table 3 can be utilised by businesses to transform operations and products. While some strategies may be more suited to biological cycles than technical cycles, fundamentally, these strategies enable businesses to embrace varying degrees of circularity for positive socio-economic and environmental impact.

Table 3: *Summary of circular strategies*

Strategy	Description
Redesign & procurement	Redesign or procure products that use less resources and are made from renewable (biobased or recycled) resources, to last longer, have multiple useful lives and eliminate waste relative to standard industry practices.
Eliminating pollution	Reduce emissions and other pollutants (such as litter or loss) across key areas of business operations.
Regenerating nature	Ensure business activity does not threaten biodiversity and instead supports nature to thrive (e.g. ensuring fish-stocks are not threatened by activities).
Extending lifespan	Extend the lifespan of products and keep the product in circulation via reuse, repair, refurbishment, and remanufacture.
Product as a service	Embrace product-as a service model where manufacturers retain ownership (through leasing or subscription) of products and sell the services they provide. Thus, enabling products, parts and materials to be cared for, repaired, reused and recycled.
Sharing & trading	Share and trade existing resources to reduce the need for new materials by providing online platforms and access to second-hand markets, as well as co-operative models.
Product stewardship	Provide a service to collect old or used products and recover the value through reuse or recycling.
Value from waste	Taking waste by-products and transforming them into new products offerings.
Recycling & composting	Recycle or compost waste materials into reusable materials.

Throughout the report, case studies are provided to illustrate how the circular strategies outlined above can be implemented and operationalised.

1.2. The Australian policy landscape

Australia is still in the early stages of embracing the circular economy and the current regulatory and policy landscape reflects this. Currently, the majority of circular economy policies and regulations focus on downstream waste processes such as recycling. This can lead to a lack of incentives for entities to innovate their offerings to embrace higher circular value processes and outcomes, such as reuse, redesign, product as a service and remanufacture.

The existing regulatory framework creates barriers to advancing circularity. This manifests at various levels, from federal to state and council jurisdictions.

However, within the Australian Government there is new momentum. In November 2022, the Federal Government announced a Ministerial Advisory Group (MAG) on the Circular Economy to guide Australia as it transitions to a circular economy by 2030 (17). The MAG is tasked with reviewing how products are designed, manufactured and used across all sectors of the economy. The recent government ambitions for a circular economy signals the increasing likelihood of government further developing regulatory interventions and incentives to support the transition.

Globally, there is a shift towards circular economy, with countries such as Japan, Netherlands, China and Chile announcing bold circular ambitions as more focussed efforts to develop roadmaps for circular cities. This is important for the Australian export market to consider, as international markets will increasingly demand sustainable and circular products. All Australian states have circular economy policies, and while the focus of these policies varies, there is a general trend towards improving the application and recovery of materials, product design and minimising waste generation. With the announcement by the Federal Government to transition Australia to circular economy by 2030, this signals the likelihood of future regulatory interventions (18).

1.3. Overview of fisheries and aquaculture in Australia

Fisheries and aquaculture production is an important source of accessible, nutritious food and employment. Additionally, fishing activities are a critical part of the national fabric, with approximately one in five Australians identifying as active fishers, and over 80% of Australians identifying as seafood consumers (3) (4). Australia's fisheries and aquaculture sector has changed over the last 20 years. Figure 2 shows the expected commercial value (gross value product) of the two main production methods aquaculture and wild catch, from 2002-03 to 2027-28, has shifted from a predominately wild catch-based sector to a maturing aquaculture sector.

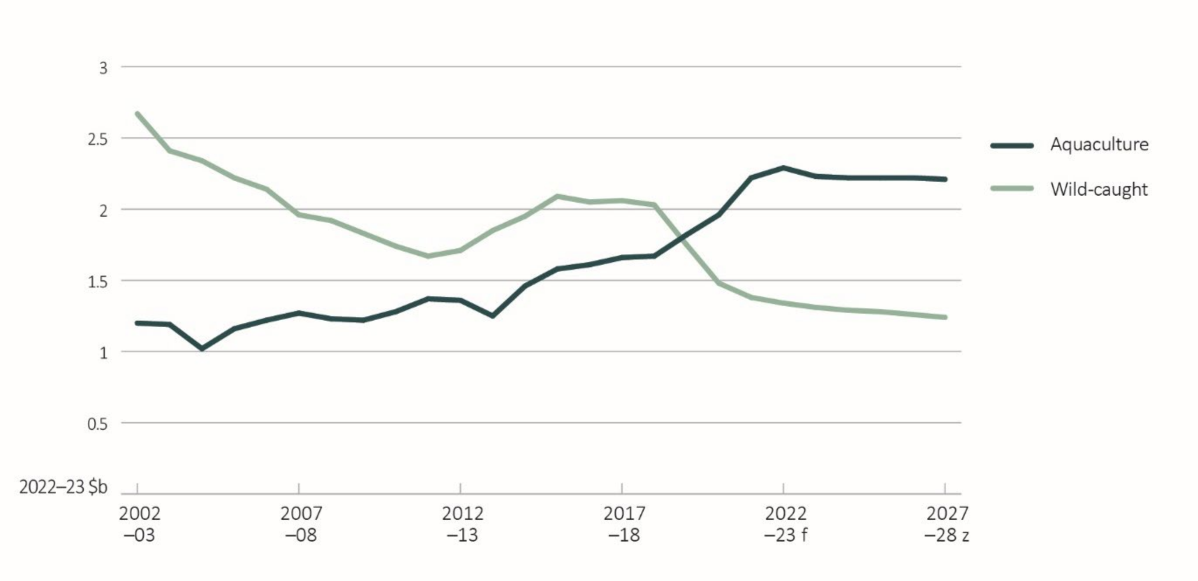

Figure 2: *Gross Value Product (GVP) of production methods 2002-3 to 2027-28.*
Source: ABARES (19)

In 2021, the sector contributed $3.09 billion directly in production value to the Australian economy and was responsible for employing 17,000 people (10,000 in wild catch and 7,000 in aquaculture) (20). In 2021, 356,000 tonnes of seafood were consumed in Australia, of which, 62% of seafood was imported (21).

Despite the Australian commercial fisheries and aquaculture sector producing a diverse range of products, a relatively small number of species comprise the majority of the Gross Value Product (GVP). Concentration in production means that just three species groups (salmon, rock lobster and prawns) account for around 65% of the GVP in 2022-23 (20).

Seafood plays an important role in the human diet in Australia and represents between 5-6% of total protein consumption, and 9% of total animal protein consumption (5). In 2021, the average Australian seafood consumption was 13.9 kg per person (from domestic and international sources), an increase from 12.8 kg per person the prior year (20). Forecasted demand for seafood is likely to be boosted by rising health consciousness and the growing preference for environmentally friendly alternatives to red meat.

Australians are also avid recreational fishers. One in five Australian adults participate in recreational fishing every year. Recreational fishing is estimated to contribute over 100,000 jobs and over $11 billion per year indirectly and directly to the Australian economy (22).

To date, Australia's seafood sector has predominately focused its policy efforts on preventing overfishing as the primary approach to sustainability. Ongoing sustainable harvest from fish stocks is important to optimise resource allocation, minimise adverse impacts of fishing on the marine ecosystem, and ensure positive commercial outcomes and longevity of the sector, however, this approach is limited. The circular economy offers a more holistic and far-reaching vision of sustainability for the fisheries and aquaculture sector than the conventional focus on preventing overfishing and avoiding pollution (8).

To drive a circular economy for the sector, an understanding of the materials and energy consumption across the supply chain at a particular point in time is required. The MFA helps us understand what materials are used in what quantities, how they are used, and where the materials go – at each stage in the supply chain – to identify where there is lost value in the sector. This analysis can then help guide stakeholders and decision makers to bring greatest benefit to the sector. The following section outlines the methodology undertaken for the Australian fisheries and aquaculture MFA.

2. MFA methodology

This section provides an overview of the approach taken to develop the MFA for the sector. Further detail is provided in Appendix 1 – Detailed MFA Methodology.

2.1 MFA explained

An MFA is a point in time assessment that quantifies the physical flow of matter and energy in an isolated system boundary. MFAs can be used to evaluate efficiencies for managing environmental impact and resources (23). Through quantification of the total material usage and end-of-life practices, the existing material consumption activities, areas where there is lost value, or high consumption can be identified. Additionally, MFAs provide useful information on the relationship between material flows (including energy) and activities that occur at different stages of a process. Results are illustrated through a ‘Sankey diagram’, which visualises the movement and magnitude of material through the system boundary.

2.2 MFA methodology

The initial system boundary assessment involved the identification of the in-scope subspecies and the most common methods (termed production methods) of capture or cultivation. For each production method, key products, materials and energy inputs (collectively referred to as materials or inputs) and end fate’s (outputs) are categorised as illustrated in Figure 7.

Within each production method, useful life is assigned to each element to determine yearly contribution of waste. Waste is then assigned across various end fates to gain an understanding of their eventual destination. The eventual destination is the final destination of a material (i.e. how and where the material is disposed of, recycled, consumed or repurposed).

Given the multitude of materials across methods, materials were aggregated into general classifications. The classifications were then used when generating the flows for wild catch and aquaculture respectively. We then identified how and where the materials flowed from production to processing to wholesale/retail.

This MFA is primarily based on calendar year 2021 Australian Bureau of Agricultural and Resource Economics and Sciences (ABARES) fisheries and aquaculture statistics, recreational fishing surveys, commonwealth fishing logbooks, catch disposal records and catch effort data (20). This data represents the most holistic public summary of fisheries and aquaculture production available at the time of analysis. We recognise that there may be anomalies within the dataset due to potential disruptions due to the COVID-19 pandemic. Recent research from the FRDC on the impacts of COVID-19 on the fisheries and aquaculture sector found that there was a large variance in the impacts across the sector. There were both positive and negative impacts, such as increases in domestic retail and takeaway seafood demand and decreases in exports of seafood and dine-in food service, across the sector, effecting how organisations operate (24).

Given that 2021 provided the most holistic data availability across multiple data sets, it was established as the period of analysis.

In order to follow a consistent volume of materials and energy through the system, a function unit was established. The functional unit of this study is ‘1 tonne of in-scope subspecies ready for customer purchase’ (final fish consumed or t_{fish}). Results that are normalised by the functional unit do not have a time frame associated with the unit. Results presented in absolute terms are calculated for the calendar year 2021. Materials and energy consumption intensities (tonnes of material consumed per tonne of final fish consumed or $\frac{t_{material}}{t_{fish}}$) are derived for each production, processing method and wholesale/retail method. The derived material and energy consumption intensities methods were used to estimate total material and energy consumption for the in-scope subspecies. Results were scaled for actual production based on the available production datasets to provide a sectoral view.

2.2.1 Key terminology

For the purposes of this report, the sector refers to all fisheries and aquaculture activities and within this are three sub-sectors; aquaculture, wild catch (commercial) and wild catch (recreational). The supply chain stages are categorised into three high-level stages; production, processing, and wholesale / retail. The in-scope species are defined into three categories, crustaceans, finfish and molluscs with underlying subspecies. These terms are visualised below in Figure 3.

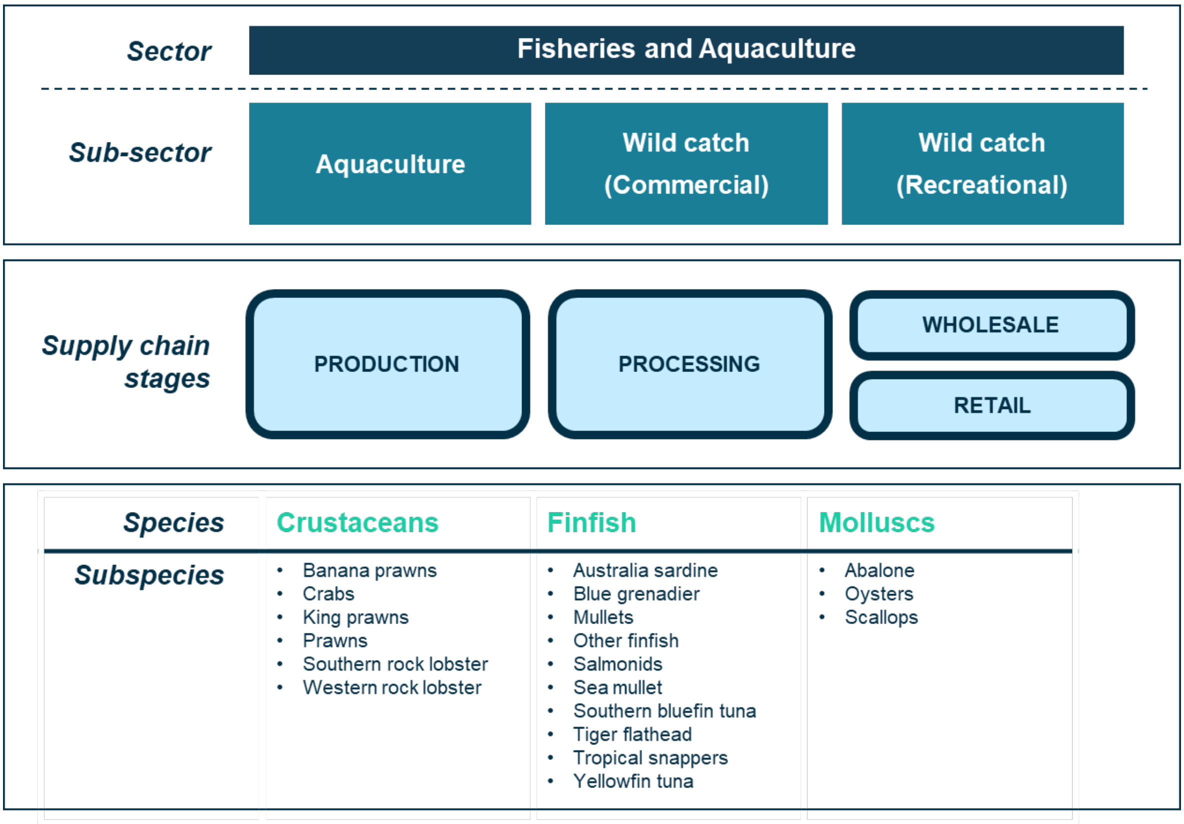

***Figure 3:** Key terms relating to sector, supply chain stages and species*

2.2.2 System boundary

The system boundary is shown in Figure 4, which illustrates the geographical boundary of this assessment and the supply chain stages including production for both wild catch and aquaculture. Within this sector, there are three sub-sectors that will be covered:

- Wild catch (commercial)
- Wild catch (recreational)
- Aquaculture

The full list of production methods covered within the three sub-sectors within the scope of this MFA can be found in Table 13.

The captured or cultivated species then undergo processing and are then transported to market (wholesale / retail or export). A detailed system boundary methodology is outlined in Appendix 1 – Detailed MFA Methodology 8.

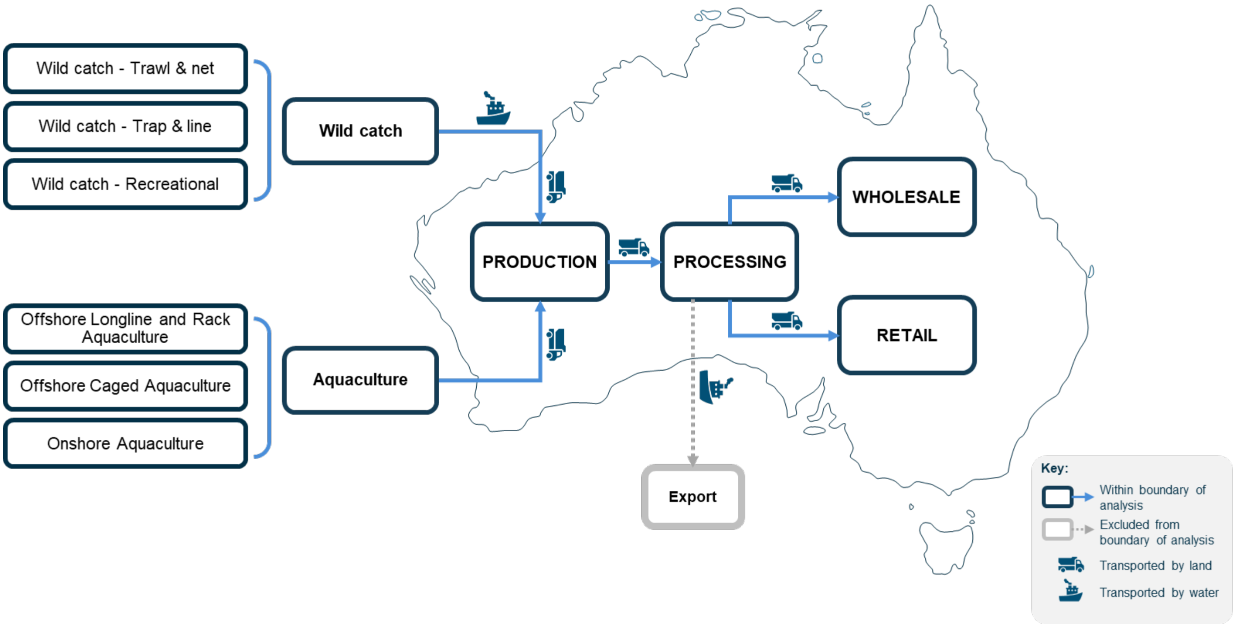

Figure 4: *Fisheries and aquaculture system boundary*

2.2.3 In-scope subspecies

To quantify material use, materials and energy are assigned to each subspecies in order to understand a materials intensity metric for each subspecies.

The total quantity of fish production in Australia was determined from the 2021 ABARES Australian Fisheries and Aquaculture data (20). Fish production in Australia can broadly be divided into four key categories:

- Imports
- Domestic commercial production (wild catch (commercial) and aquaculture)
- Domestic recreational fisheries production (wild catch (recreational))
- Exports (assumed to be contained within domestic commercial production)

In 2021, 63% of Australia's seafood consumed was imported. The remaining 37% consisted of domestic production (commercial and recreational), with 21% of domestic production exported (20).

For the purposes of the MFA, imports have been excluded to allow recommendations to focus on driving impacts within Australia. Therefore, the MFA has focused on 304,235 tonnes of Australia's wild catch and aquaculture and additional 8,029 tonnes of recreational fishing production. The tonnage breakdown of Australian seafood industry production, imports, exports and recreational is outlined in Figure 5. Exports are considered to be within production and have been separated in the figure below to illustrate their relative magnitude.

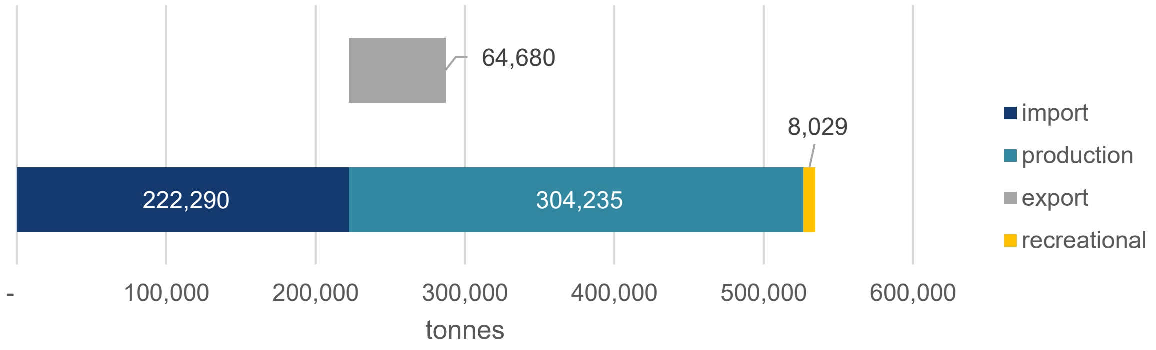

Figure 5: *Sector-wide production, imports and exports (2021) (20).*
Source: ABARES 2021 and Recreational fishing surveys.

Of the 304,235 tonnes of aquaculture and wild catch (excluding recreational fishing) in-scope fishing production, the three major species groups of crustaceans, finfish and molluscs form 90% of the main fishing production methods of aquaculture and wild catch. Of each of these categories, the top 80% of production tonnes by subspecies group for aquaculture and wild catch were identified. Similarly, for recreational fishing the top 80% of production tonnes were included in the scope of this assessment. This cap was to ensure a maximised impact focus.

The species and subspecies of fish production form the basis of analysis for the MFA, as shown in Figure 6. This process was reviewed and validated with the industry through an MFA methodology workshop feedback session.

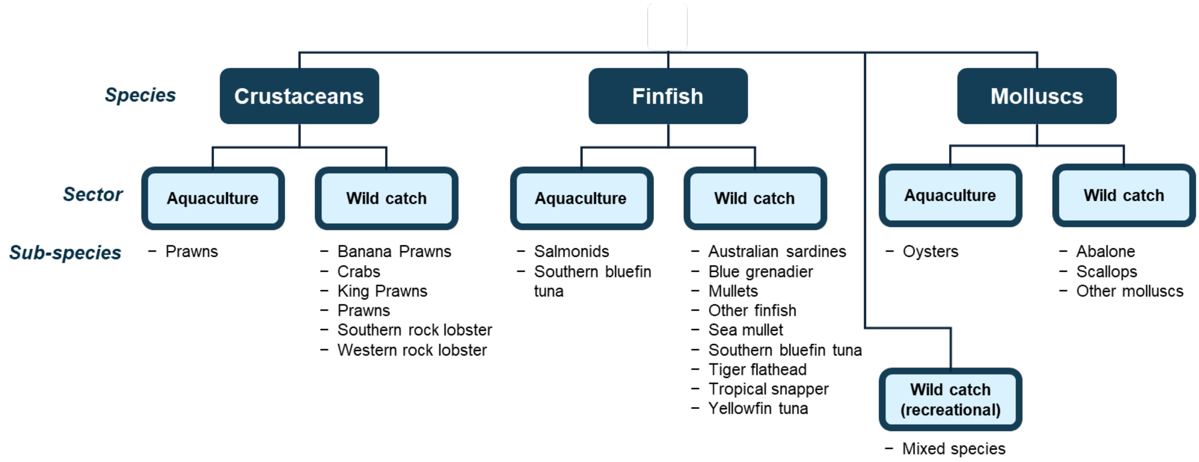

Figure 6: *Fish production by species and sub-species.*

Southern Bluefin Tuna (SBT) in aquaculture has been included as in-scope subspecies in Figure 6 as a significant proportion of Australian Sardine is utilised as the feedstock into SBT production.

Overall, this study represents approximately 75% of the total production tonnes in 2021 ABARES Australian Fisheries and Aquaculture data (20) and recreational fishing surveys.

2.2.4 Inputs and end fates (outputs)

The aggregated material and energy inputs and end fates that the MFA considers are outlined below in Figure 7. Material inputs have been classified into groups. For example, "Metals" would include (but not limited to) steel, aluminium and lead. Further details on the definition of each input or end fates (outputs) and the specific materials included for each input and end fate category are outlined in 8. Appendix 1 – Detailed MFA Methodology.

Various materials and waste products are generated as outputs throughout the supply chain, such as offal as a by-product of the processing stage. This waste is assigned an end fate group as it is generated, depending on how the waste flows through the supply chain.

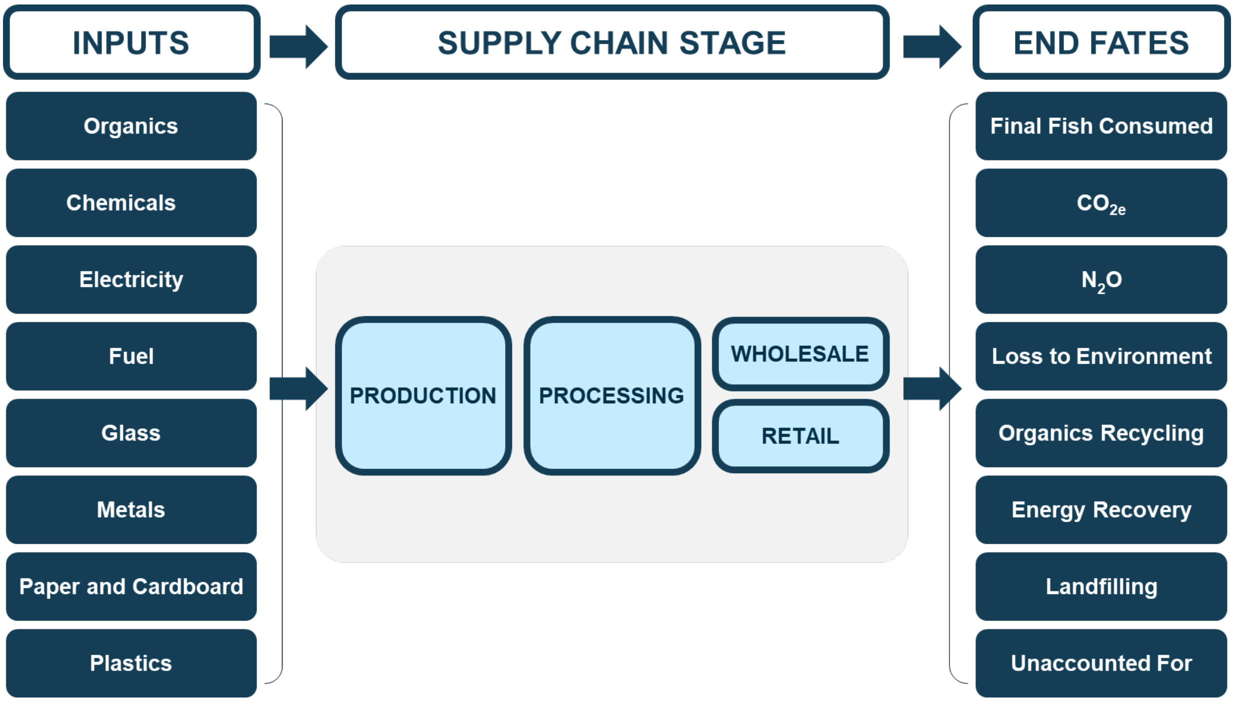

Figure 7: *MFA aggregated material input categories and output (end fate) categories*

2.2.5 Approach to data uncertainties and collection

The approach to data collection and collation for this MFA included a combination of primary data sources and desktop research:

- **Primary data sources**: Key data inputs, either considered sensitive or critical to the reliability of the MFA were prioritised for discussion in one-on-one industry stakeholder interviews and sector-specific workshops with stakeholders. These inputs were prioritised over any desktop information, where obtained, as they were considered more accurate.

- **Desktop research:** A combination of assessing FRDC's research database and desktop research was undertaken. A list of key data sources used are provided in 8. Appendix 1 – Detailed MFA Methodology. Datasets were prioritised for use if they were local (Australia), 2021 datasets or within a reasonable timeframe from the base year (<20 years) and peer-reviewed or reputable sources. International sources that were greater than 20 years old or considered unreliable, were only considered for use in the absence of any other data.

2.2.6 Summary of key assumptions, exclusions and limitations

In quantifying key material flows for an entire sector at a nationwide scale, a number of assumptions, exclusions and limitations exist. A summary of these are included below, with additional detail provided in 8. Appendix 1 – Detailed MFA Methodology.

- Data for the MFA is from calendar year 2021 production quantities, given this was the most complete set of data available at the time of analysis. Current fishing production quantities are likely to vary. Results of the MFA aim to provide a proportionate view of material use in the sector, rather than specific granular results.
- Given the scale of the sector and the limitations on data availability, an approach of identifying what is material to the sector based on quantities to define what is 'in-scope'. This included a review of the relative magnitude of the modelled results and assessment of data validity. This MFA does not seek to quantify 100% of all materials utilised in the sector but illustrates the approximate volume flows of the most material inputs.
- Materials inputs and end fates of the top 80% of subspecies from the top three species groups (crustaceans, finfish, and molluscs), by volumes are quantified in this MFA. All other fish species are excluded from this MFA.
- This MFA is a first of its kind for the sector. Full datasets were not available for all species and methods. In the absence of data and where sector wide modelling was required, proxies from one or more sample representative items (using industry data and site visits to fish markets) were used for modelling flows.
- Overall, the proportion of key material inputs (glass, metals, organics, paper and cardboard and plastics) destined for different end fates such as energy recovery, landfill, organics recycling or recycling were based on the 2022 Australian National Waste Report (25) data, unless more specific data or information was provided by industry.
- Imports are excluded from the MFA given their catch / growth is outside of Australian jurisdiction.
- Packaging, ice and fuel for transport on exported fish are included and are assumed to be part of the 'production' tonnes provided.
- Stockpiling is excluded from the MFA and does not appear as an end fate category. While it is understood that stockpiling occurs, particularly in smaller facilities and fisheries, due to a lack of data it was not able to be quantified.
- The magnitudes of flows (in tonnes) for wild catch are not comparable with aquaculture due to non-comparable system boundaries. The boundary for wild catch is from catch to market and aquaculture is from hatchery or nursey to market.
- Water volumes in this MFA primarily relate to ice in the wholesale supply chain stage. Water and ice are used in other stages of the supply chain, however due to data limitations, this was excluded.
- Material inputs and end fate for vessels and their construction were excluded.
- Upstream packaging for gear and equipment (packaging that the gear arrives in when purchased) are excluded.
- A process of data interrogation was undertaken to corroborate results calculated by the MFA. This included comparison to other data sources (specific data sources outlined in 8. Appendix A – Detailed MFA Methodology) or to other results of the MFA to assess consistency. Corroboration was not possible in all cases, but significant effort was made to corroborate data where possible.

3 Overview of MFA results

There are a range of complex interactions and flows between materials in the fisheries and aquaculture sector. This section outlines the overall findings of the MFA. Results are presented at the sector level, followed by material specific insights and results for materials with the greatest opportunity for circular intervention. Recreational and Indigenous fishing are later analysed qualitatively.

Results are based on available data and should be viewed as directional estimations as opposed to exact figures. The objective is to identify where there are opportunities for circular interventions as opposed providing a baseline for annual re-assessment.

The proportion of total material used by supply chain stage and sub-sector is outlined in Figure 8. This illustrates the breakdown of total material use by sub-sector (aquaculture, wild catch (commercial) and wild catch (recreational) and supply chain stage (production, processing and wholesale/retail). The aquaculture production sub-sector is responsible for the largest amount of total material inputs annually, followed by wild catch (commercial) production.

Two metrics are utilised throughout: absolute values and material intensity. Absolute total values only illustrate a partial picture and indicate where the majority of resources are used in the sector. Material intensity metrics are useful for comparisons. Values presented as intensities provide an indication of supply efficiency at a particular point in the supply chain or across the sector. The units associated with intensity values will be presented as $\frac{t}{t_{fish}}$ throughout this report (this unit is tonnes of material input or end-fate per tonne of final fish consumed).

A sub-sector may have a high material intensity, indicating that the use of materials is relatively inefficient compared to other parts of the sector. However, if the absolute value is small, then the overall impact on the sector is likely to be minimal, regardless of the intensity.

Total Material Inputs

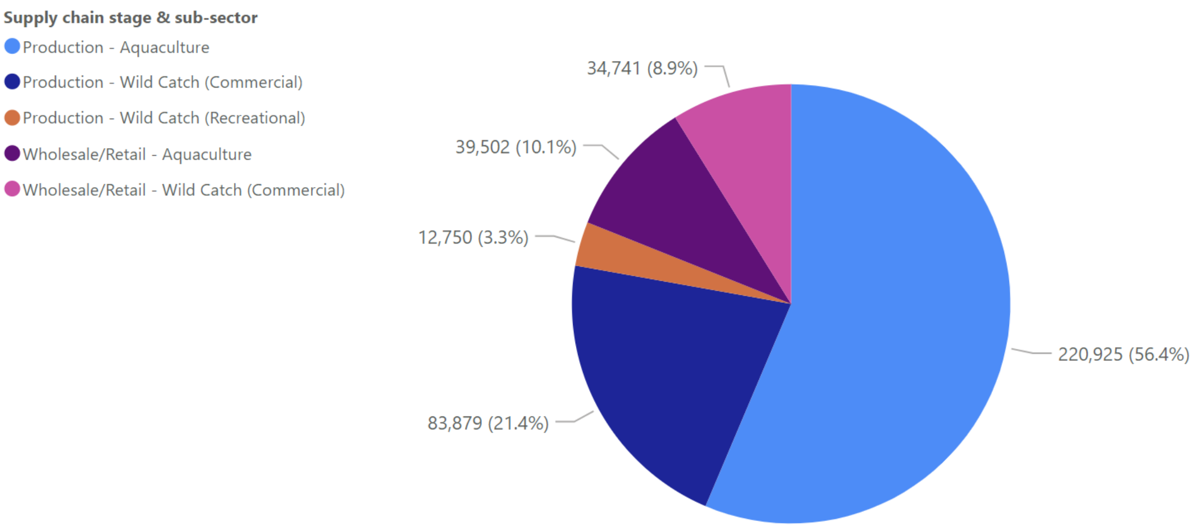

Figure 8: *Sector total material inputs by supply chain stage and sub-sector (excluding chemicals, electricity, and water). Source: FRDC and RCC Analysis*

Figure 9 shows the total material intensity by supply chain stage and sub-sector, against each sub-sector and supply chain stage's absolute material input. These material intensity values indicate that despite aquaculture production being the greatest absolute consumer of materials, aquaculture's material intensity is on par with the material intensity of wild catch (recreational) production.

When comparing absolute values the aquaculture subsector consumes the most materials, with 67% of the total material inputs (excluding chemicals, electricity and water), and material input intensity of 3.7 $\frac{t}{t_{fish}}$. As shown in Figure 9 the material intensity of aquaculture was large across the three subsectors with the material intensity of wild catch (commercial) and wild catch (recreational) being 3.1 and 1.7 $\frac{t}{t_{fish}}$ respectively. This indicates that there is a higher amount of material used in production of fish via aquaculture.

The absolute quantity of material inputs for wild catch (recreational) and wild catch (commercial) are 12,750 and 118,620 tonnes respectively. This reveals that wild catch (recreational) is a small percentage of the total material inputs for the sector. The material used in the wild catch (recreational) sub-sector is discussed throughout, but a separate qualitative discussion is also provided in 3.4 Recreational Fishing.

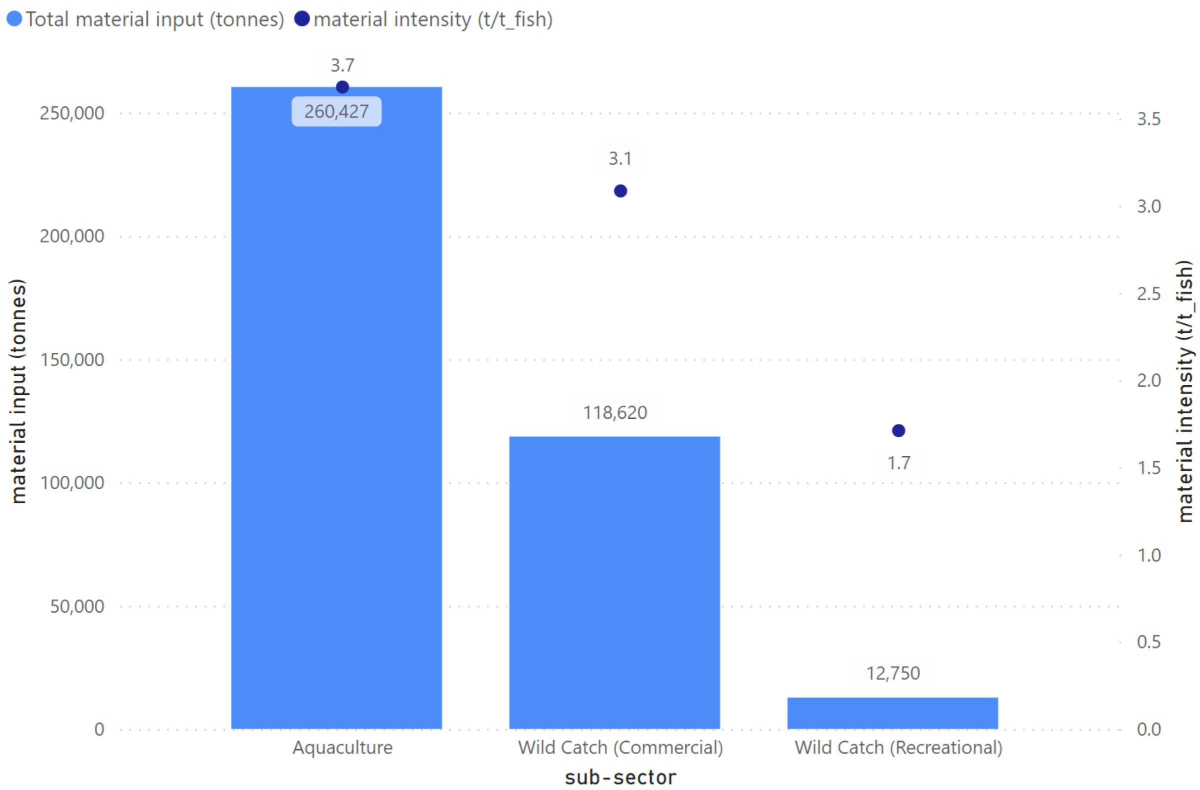

Figure 9: *Total material inputs (tonnes) and intensity ($\frac{t}{t_{fish}}$) by sub-sector (excluding chemicals, electricity, and water).*

Source: FRDC and RCC Analysis

Table 4 below details the total material intensity, physical supply intensity and electricity intensity on a per species basis. The table shows that the molluscs species group (abalone, oysters and scallops) are the most material intensive species within the MFA.

Table 4: *Total physical supply of materials and intensity per final fish consumed.*
Source: FRDC and RCC Analysis

Subspecies	Production Tonnes	Final fish consumed (Tonnes)	Physical Supply (analysis period is the calendar year of 2021)							
			Materials input (excl Chemicals, Water and Electricity)		Chemicals And Water			Electricity		
			Inputs	Total materials intensity	Chemicals	Water	Total Physical Supply Intensity (excl electricity)	Electricity	Electricity Intensity
Units	t_{prod}	t_{fish}	t	$\frac{t}{t_{fish}}$	t	t	$\frac{t}{t_{fish}}$	kWh	$\frac{kWh}{t_{fish}}$fc
Abalone	2,272	185	3,562	19.25	-	47,637	277	2,673,094	14,449
Australian Sardine	40,014	2,277	6,859	3.01	-	586,771	261	17,653,258	7,753
Banana Prawns	3,063	1,037	4,988	4.81	-	106,172	107	3,603,194	3,475
Blue Grenadier	11,940	8,628	11,389	1.32	-	2,223,564	259	140,46,681	1,628
Crabs	3,487	1,097	8,451	7.70	-	250,250	236	3,795,827	3,460
Crustaceans - Recreational	645	645	1,244	1.93	-	-	2	758,871	1,177
Finfish - Recreational	6,807	6,807	11,506	1.69	-	-	2	56,057,063	8,235
King Prawns	3,299	1,118	5,373	4.81	-	113,155	106	3,881,516	3,472
Mullets	2,000	1,480	1,903	1.29	-	381,321	259	2,353,309	1,590
Other Finfish	10,324	6,957	10,697	1.54	-	1,680,512	243	12,146,188	1,746
Other Molluscs	1,246	103	1,956	18.99	-	23,518	247	1,465,914	14,232
Oysters	11,234	933	19,814	21.24	-	207,337	243	13,215,882	14,165
Prawns (Aq)	8,727	3,136	22,589	7.20	-	25,201	15	82,133,647	26,191
Prawns (Wc)	4,416	1,387	7,185	5.18	-	320,847	237	51,92,155	3,743
Salmon	84,045	61,048	177,324	2.90	14651	14,423,257	239	74,157,618	1,215
Scallops	5,226	461	8,320	18.05	-	111,812	261	6,148,538	13,337
Sea Mullet	2,484	1,837	2,371	1.29	-	473,454	259	2,921,859	1,591
Southern Bluefin Tuna (Aq)	7,600	5,622	39,771	7.07	-	1,448,803	265	17,882,353	3,181
Southern Bluefin Tuna (Wc)	5,661	4,187	2,374	0.57	-	1,079,149	258	2,497,435	596
Southern Rock Lobster	2,966	918	10,875	11.85	-	236,517	269	3,490,113	3,802
Tiger Flathead	2,227	1,530	2,131	1.39	-	372,324	245	2,619,929	1,712
Tropical Snappers	2,558	1,837	3,395	1.85	-	416,410	229	3,009,589	1,638
Western Rock Lobster	6,630	2,051	22,621	11.03	-	528,623	269	7,800,487	3,803
Yellowfin Tuna	1,923	1,354	3,827	2.83	-	329,956	247	2,261,908	1,671
Grand Total:	**230,794**	**116,635**	**390,525**	**3.35**	**14,651**	**25,386,590**	**221**	**341,766,428**	**2,930**

3.1 Sectoral wide materials flows

The overall flows of all materials in the nationwide fisheries and aquaculture sector are illustrated in Figure 10. The diagram shows the flow of materials through wild catch and aquaculture production, processing, wholesale/retail, and the different end fates.

The Sankey diagram (Figure 10) outlines the material inputs on the left-hand side. The materials are an aggregate of their intermediate processes as they flow through production, processing, wholesale/retail stages, and the ultimate end fates (such as landfilling or recycling). Species move between each supply chain stage (production, processing, wholesale/retail) where waste is generated (e.g. losses) before passing on to the next stage. The Sankey diagram shows how the flows interact with each other. The inputs and end fates are categorised based on Figure 7. The functional unit of this study is '1 tonne of in-scope subspecies ready for customer purchase' (final fish consumed or t_{fish}). In a retail context, this would be purchased in a supermarket, and in a wholesale context, this would be bought from the wholesaler by a restaurant, fishmonger, etc.

Figure 10 shows one circular flow in the bottom left-hand corner, from finfish to aquaculture production stage. This circular flow relates to the aquaculture production of southern bluefin tuna. Southern bluefin tuna have organic inputs of both live wild caught Southern bluefin tuna and Australian sardine as fish feed. The most significant end fate for the sector overall is GHG emissions. GHG emissions constitute 77% of total tonnes of total material end fate which includes but is not limited to emissions associated with fuel for vessels, refrigeration, transportation and electricity. Comparatively, final fish consumed or t_{fish} is 7.7% of total material end fate.

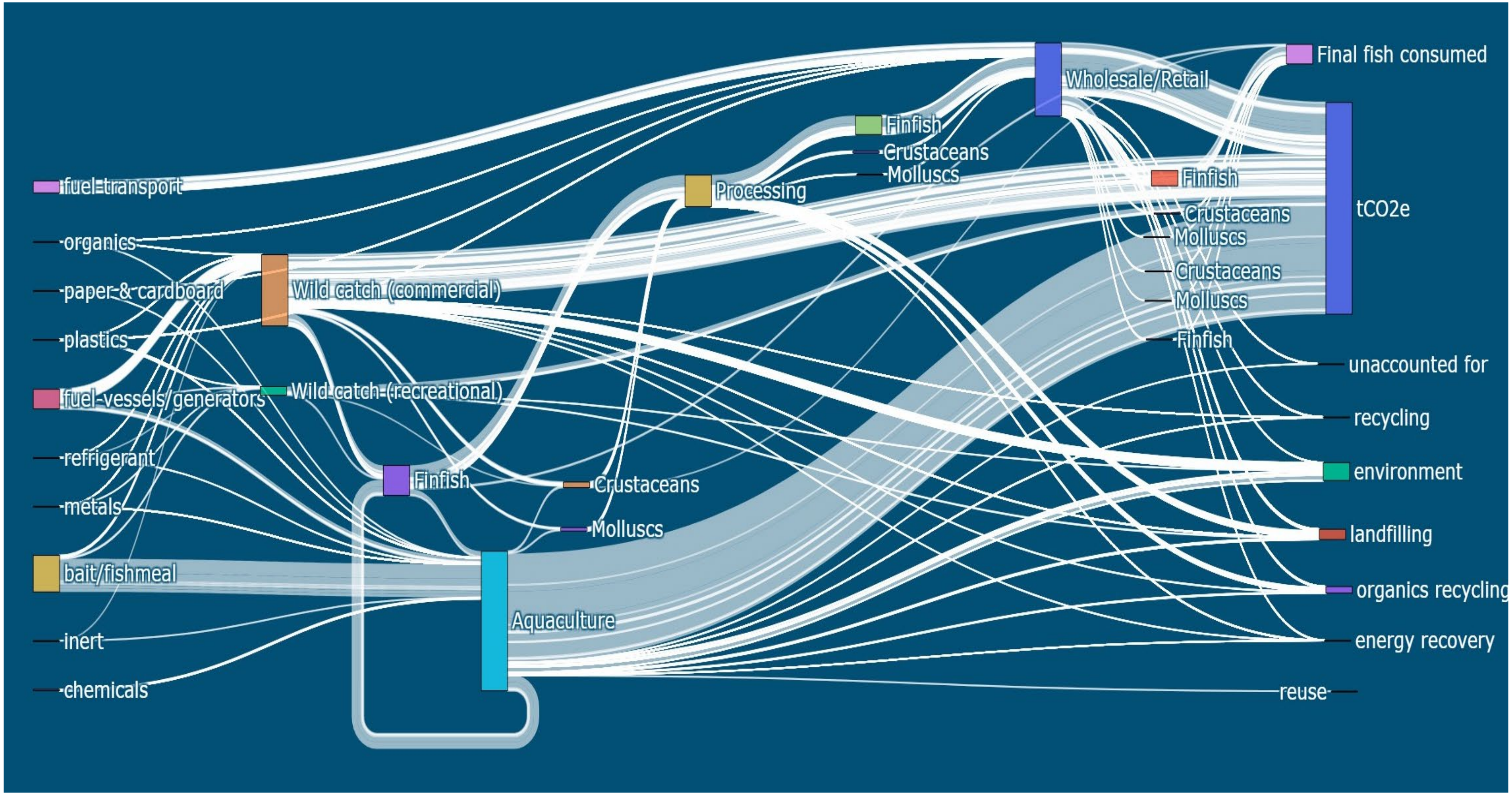

Figure 10: *Overall flows – wild catch and aquaculture materials inputs (excluding electricity, and water) to end fates*
Note: Units in tonnes, and analysis period is calendar year 2021
Source: FRDC and RCC Analysis

Figure 11 and Figure 12 below split the Sankey diagram into the two key sub-sectors: wild catch (commercial and recreational) and aquaculture. A separate wild catch (recreational) Sankey diagram is provided in 3.4 Recreational Fishing.

The magnitudes of flows (in tonnes) for wild catch are not comparable with aquaculture due to non-comparable system boundaries. The boundary for wild catch is from catch to market and aquaculture is from hatchery or nursey to market.

For the purposes of illustrative analysis, fuel, electricity, water and chemical inputs and end fates are excluded from the diagrams below, because they dwarfed all other inputs. Fuel, electricity, water and chemical inputs are discussed in 3.3 Material Specific Discussion.

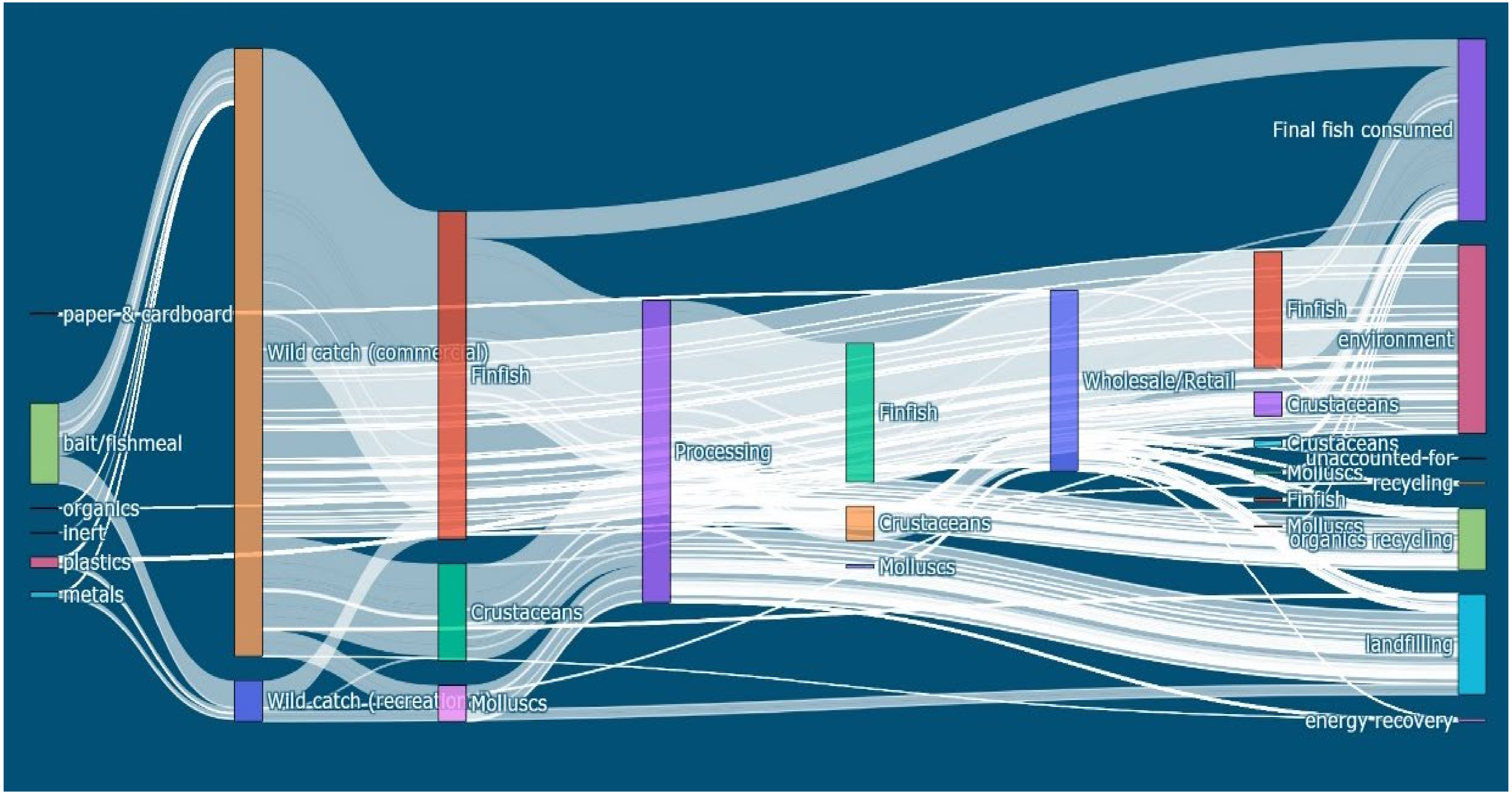

Figure 11: *Wild catch material inputs (excluding chemicals, electricity, GHG emissions, and water) to end fates*
Note: Units in tonnes, and analysis period is calendar year 2021
Source: FRDC and RCC Analysis

On the left-hand side of Figure 11, inputs have been aggregated under broad material input categories: paper and cardboard, bait and fish feed, organics, inert (non-organic materials such as ballast, concrete, or stone), plastics and metals. Bait and fish feed represent the largest quantified input for the wild catch sub-sector (in tonnes). This is followed in magnitude by plastics and metals, respectively.

Figure 11 illustrates which supply chain stage (production, processing, wholesale/retail) utilises each respective material input category. The outputs of each production method include but are not limited to waste and unprocessed fish (a list of production methods can be found in Table 13). Unprocessed fish are then categorised under the broad species groups of Crustaceans, Finfish, and Molluscs, which flow between each sub-sector. Waste is generated due to the processing and packaging of the respective fish products, ending at the point of sale. All waste generated has been allocated to an end fate category which are detailed in Figure 7.

The end fate for the majority of waste generated (excluding final fish consumed or t_{fish}), is bycatch (loss to environment), followed by landfill or organics recycling.

Figure 11 specifically illustrates wild catch flows. On the left-hand side of the Sankey diagram, for Finfish (between wild catch (commercial) and processing), there is a reduction in the flow to processing. This is due to a large quantity of Australian sardine being used as feed for southern bluefin tuna (which is not reflected in this diagram).

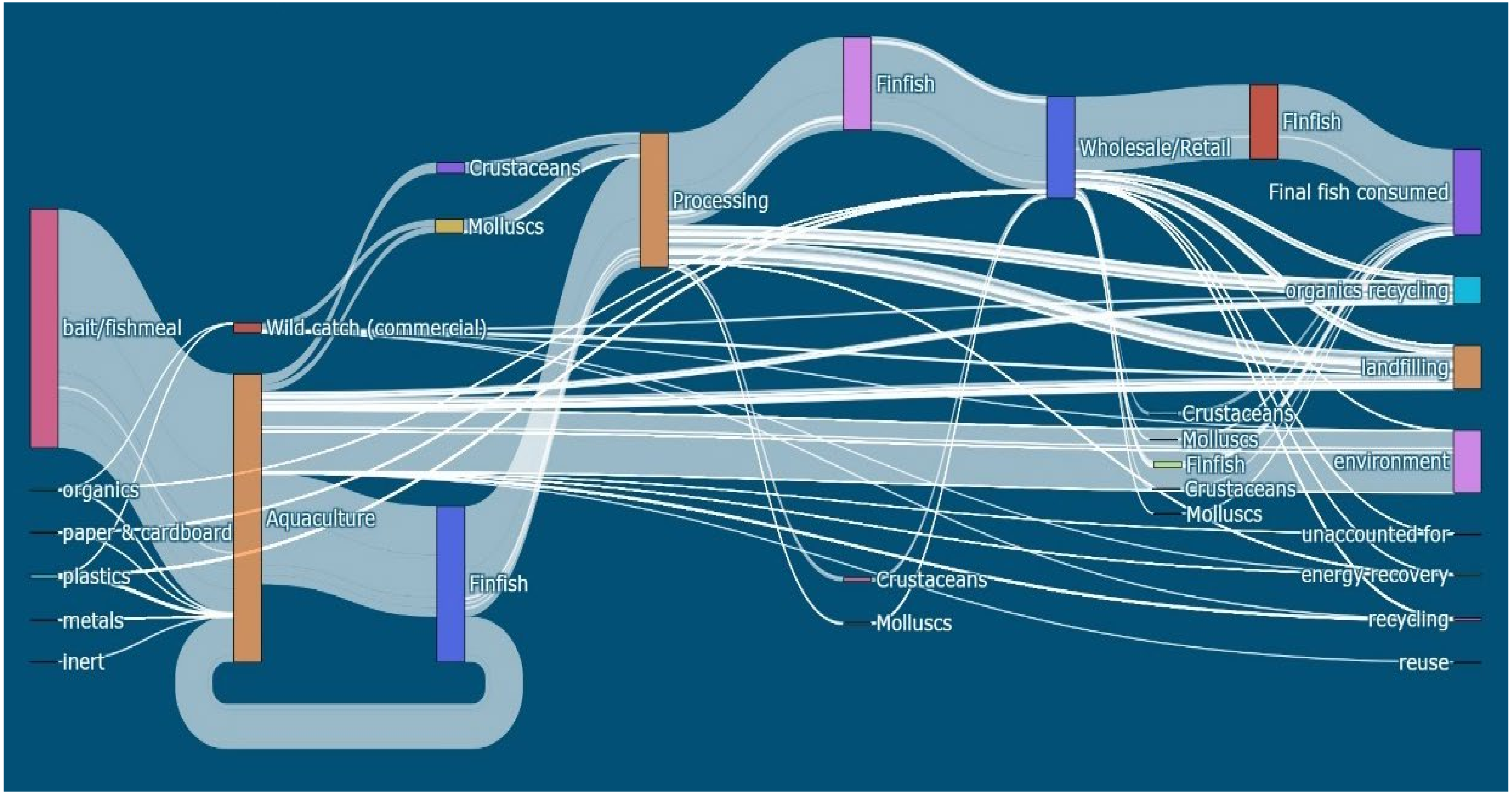

Figure 12: *Aquaculture material inputs (excluding chemicals, electricity, GHG emissions, and water) to end fates*
Note: Units in tonnes, and analysis period is calendar year 2021
Source: FRDC and RCC Analysis

On the left-hand side of the aquaculture Sankey diagram (Figure 12 inputs have been aggregated under broad material input categories: paper and cardboard, bait and fish feed, organics, inert, and plastics and metals. For the aquaculture sub-sector, the sheer magnitude of bait and fish feed substantially outweighs the proportion of other material inputs. This is due to the bait and fish feed required to grow fish from hatcheries to harvest-ready fish. Figure 12 illustrates which supply chain stage (production, processing, wholesale/retail) utilises each respective material input category. The outputs of these production methods include but are not limited to waste and unprocessed fish. Unprocessed fish have then been categorised under the broad species groups of Crustaceans, Finfish, and Molluscs, which then flow between each sub-sector. Finfish represents the largest produced species group. All waste generated has been allocated to an end fate category which are detailed in Figure 7. When looking at waste generation (excluding t_{fish}), the losses to the environment are significant for aquaculture. This is predominately due to effluent (liquid waste from fish and feed, including microalgae and suspended solids produced and discharged by aquaculture production), categorised as organic loss to the environment.

Key Takeaways

A detailed account of the findings by material and end fate is provided in the sections below. In summary the Figure 10, Figure 11 and Figure 12 key focus areas are:

- **Bait and fish feed** are the most significant material inputs, and form 99% of the organic input into the sector. Investigating organic waste streams as potential bait and fish feed alternatives and opportunities to improve the efficiency of use, will be important in maximising utility of this key input.
- **Emissions** are the most significant output (end fate) generated by the sector. Emissions constitute 77% of total tonnes of total material end fate, with majority from fuel for vessels and generators. There is a significant amount of emissions related to production and transportation of bait and fish feed. Emissions related to bait and fish feed, present a significant opportunity to investigate the use of electric and hybrid, close to shore vessels, alongside mechanisms to encourage renewables adoption.
- Of all **organic waste** produced by the sector, the three largest sources include: offal generated in processing and the wholesale market forms 34%, effluent from sea cages at 32%, and bycatch at 22% of total organics waste generated. There are significant opportunities to work through regulatory barriers, develop partnerships and to consolidate offal generated by different entities to provide scale, support and commercialisation of processing technologies to convert offal into commercial products.
- **Plastics forms** 5,993 tonnes representing 1.5% of the total material input into the sector. The majority of this is from fishing gear and equipment, while the remainder is packaging. There are several collaborative opportunities to reduce consumption and improve recovery outcomes, including design (standardising gear), scaling up product stewardship schemes, and align with APCO's targets and commit to 100% reusable, recyclable, or compostable packaging (6).

3.2 Breakdown – inputs and end fates

Of the total material inputs into the sector in absolute terms (406,448 tonnes), the most significant are bait and fish feed (192,726 tonnes), followed by fuel for vessels and generators (116,968 tonnes), which form 47% and 29% of material inputs respectively. Figure 13 below shows the breakdown of material inputs into the sector. The pie chart presents the breakdown of materials inputs. This is an alternative visualisation of the left-hand side inputs in Figure 10.

When bait and fish feed, chemicals and fuel are excluded, the most significant material inputs are plastics (55%), metals (16%), and paper and cardboard (12%) (see Figure 14). These exclusions allow for a closer view of other material inputs in the sector. The importance of bait and fish feed, and emissions should not be understated and are discussed specifically in 3.3.1 Organics.

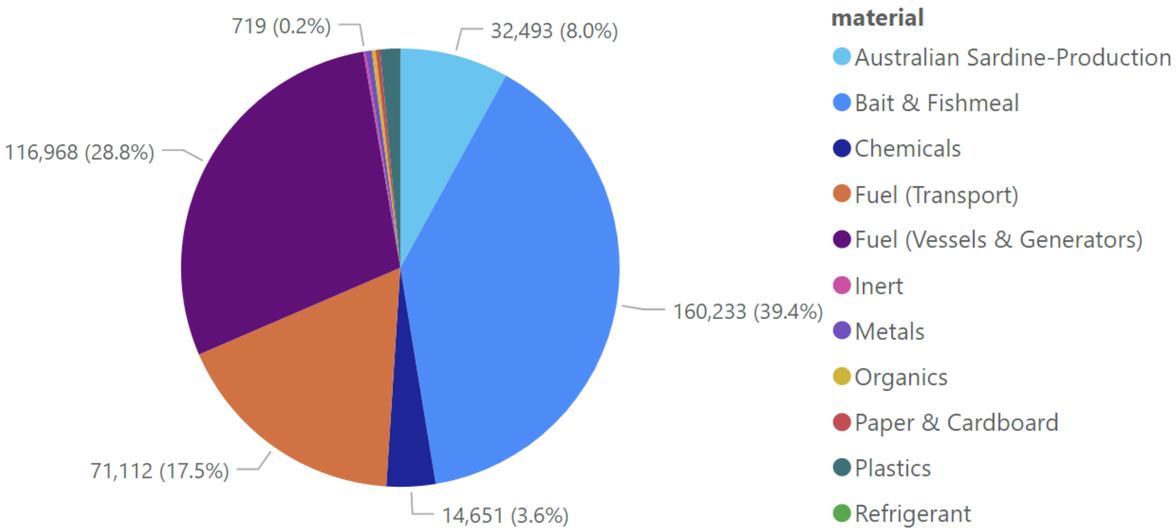

Figure 13: *Sector total material inputs (tonnes) by material category (excluding electricity and water)*
Source: FRDC and RCC Analysis.
Note: Australian Sardine-Production in the above figure is also a Bait & Fish feed input to Southern Bluefin Tuna in Aquaculture.

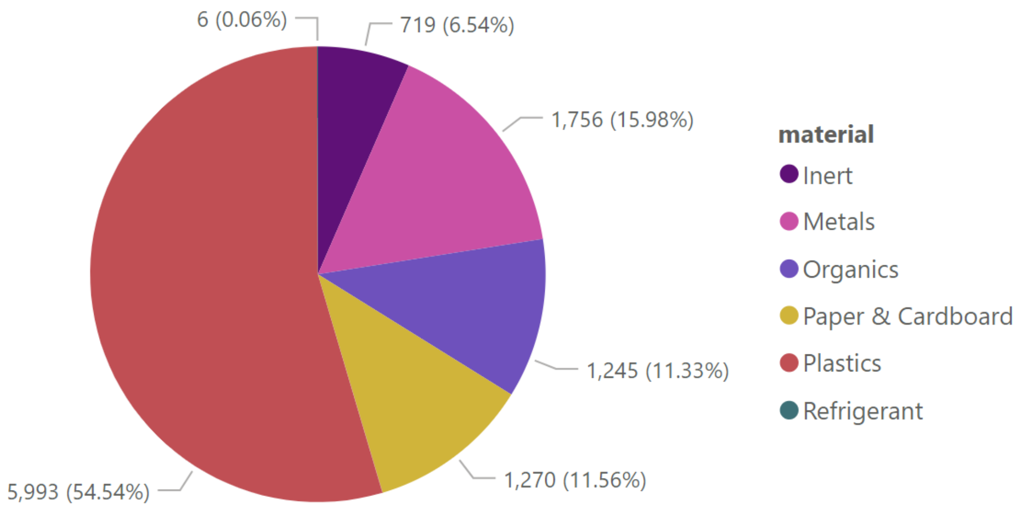

Figure 14: *Sector breakdown of a sub-set of material inputs (tonnes) by material category.*
Source: FRDC and RCC Analysis

The distribution of materials to end fates by sub-sector is outlined in Figure 15 (excluding t_{CO2_e} and t_{fish}), indicates which sub-sector has the largest annual material use. Figure 16 shows the tonnes of end fates (excluding t_{CO2_e} and t_{fish}).

The results highlight:

- The most significant end fate is loss to environment. This is predominantly due to effluent flows from aquaculture production (effluent discharge in sea cages) and bycatch in wild catch (commercial). Effluent is not included in wild catch as it is considered to occur naturally in the marine ecosystem.
- The Wild catch (commercial) sector produced 47,038 tonnes of bycatch.
- Landfilling and organics recycling are the next two largest end fates for materials. Of the total waste generated in absolute terms, approximately 26% is landfilled (61,599 tonnes), and 17% (38,748 tonnes) is sent to organics recycling per year.

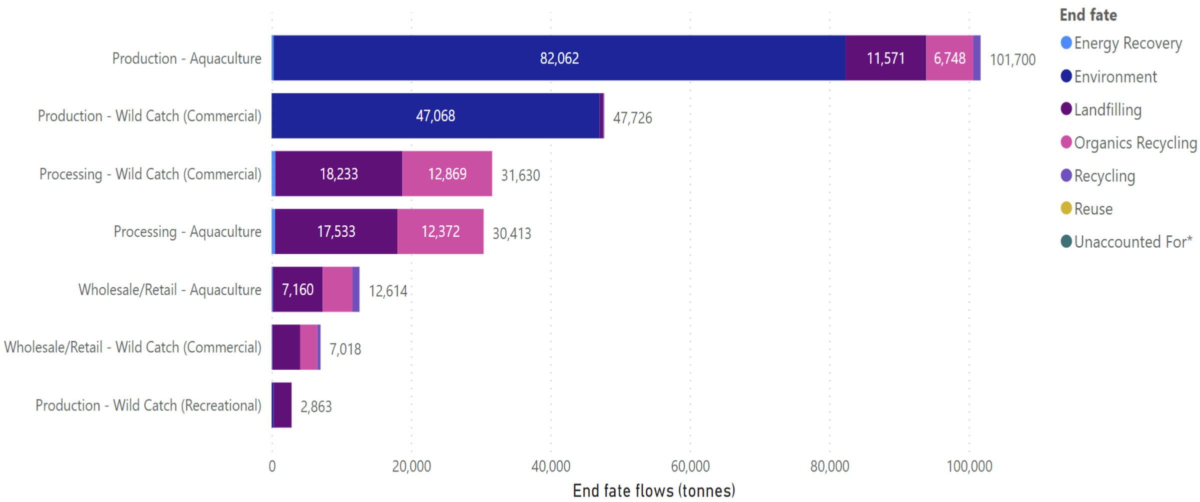

Figure 15: *Sector distribution of end fates (tonnes) by supply chain stage and sub-sector (excluding GHG emissions (t_{CO2_e}) and (t_{fish}).*
Source: FRDC and RCC Analysis.

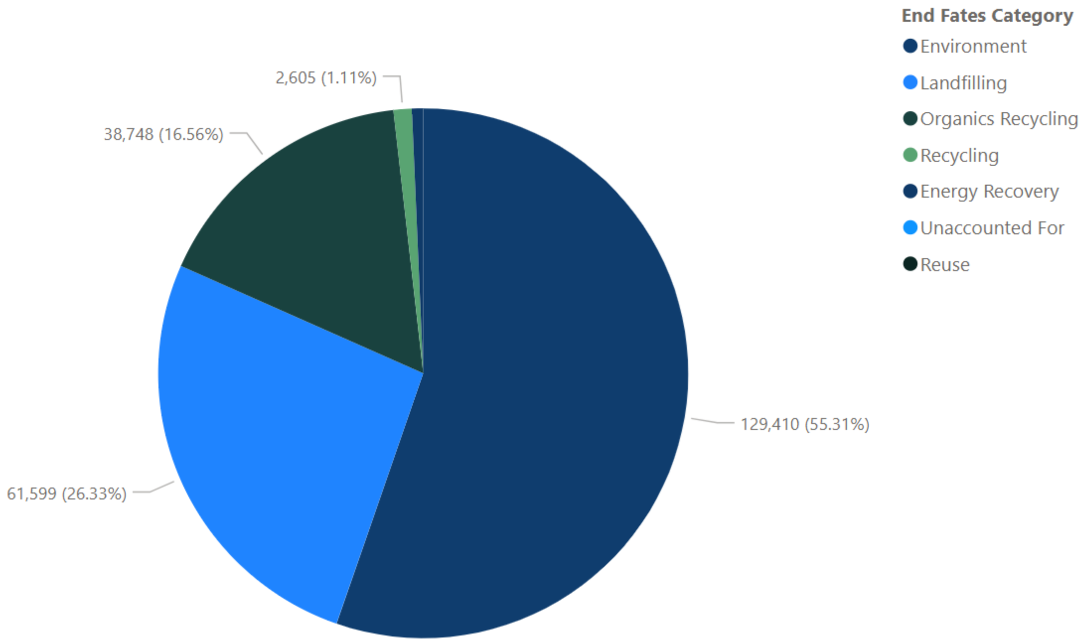

Figure 16: *End fates of material (tonnes) for the sector (excluding GHG emissions (t_{CO2_e}) and t_{fish})*
Source: FRDC and RCC Analysis

3.3 Material specific discussion

This section discusses the results from each key material category.

3.3.1 Organics

Organics are inherent to the fisheries and aquaculture sector. The production of seafood for consumption through aquaculture requires feed, and typically results in the linear production and transportation of significant quantities of organic resources. The end fate of unconsumed feed is landfill or loss to environment, potentially polluting waterways. Wasted feed represents lost value in water, nutrients, and energy. Additionally, it works counter to the circularity principle of regenerative systems by creating nutrient imbalances in local areas. Creating a circular fisheries and aquaculture supply chain for organics could reduce the depletion of valuable resources, contribute to increased food security, minimise pollution and enable the preservation of nutrient balance in waterways and at sea.

Current organics profile

In the MFA, the main components of organics inputs are:

- Bait and fish feed: which is a feedstock into the fisheries and aquaculture sector and are consumed by fish. Within the scope of this analysis, packaging associated with wild catch bait and fish feed has not been quantified due to limited data availability.
- Organic waste – by-products of fisheries and aquaculture sector activities including:
  - Bycatch
  - Mortalities
  - Offal
  - Other organic materials – including timber used for structural elements and pallets for packaging

Of the total organic material inputs into the fisheries and aquaculture sector in absolute terms (195,241 tonnes), 99% is bait and fish feed.

The remaining 1% of organic material inputted across the production and wholesale/retail stages is from timber used for structural elements of production infrastructure, such as wooden posts in oyster production and tertiary packaging in the form of pallets. Packaging, which includes timber, and paper and cardboard is discussed further in 3.3.2 Plastics and Packaging.

Bait and fish feed

Bait comes in various forms, including live and dead bait (e.g., worms and finfish). Fish feed is processed product made from whole fish, fish by-products or other animal and agricultural ingredients that have been ground into a dry granular form. Fish feed is commonly used in aquaculture as a high-protein feed for farmed fish species. Fish feed is not typically used as bait for wild catch, but rather as a nutritional supplement in the diet of farmed fish. Fish feed can be sourced from fish by-products, bycatch, or plant-based agriculture products, turning a waste product into a valuable resource.

Different subspecies have different bait and fish feed requirements. These preferences are influenced by a variety of factors including the fish's diet, habitat and sensory reception. For example, salmon in aquaculture require high quality fish feed to provide the essential omega-3 fatty acids and protein needed for growth and health.

Table 5 outlines the breakdown of bait and fish feed inputs by sub-sector and by input intensity. Sector-wide bait and fish feed input intensity is 1.4 $\frac{t}{t_{fish}}$. Bait and fish feed input substantially outweighs the contribution of other input materials for aquaculture, which is representative of the volume of fish feed needed to sustain fish growth.

Approximately 50-75% of fish feed is imported, representing a significant opportunity to investigate the use of agricultural waste and residues as ingredients into domestic fish feed production. The general composition of fish feed is approximately (26) (27) (28):

- 50-65% agricultural ingredients (wheat, soya derivatives, corn, gluten and vegetable oils)
- 15-35% land animal ingredients (rendered mixed animal by-products, meat and chicken meal, blood meal, and poultry oils)
- 5-15% fishmeal (typically offal by-products of fish processed for human consumption, not sourced from critically endangered species)
- 6-8% fish oil (typically small bony pelagic fish not fit for human consumption)

Table 5: *Summary of bait and fish feed use and intensity by sub-sector.*
Source: FRDC and RCC Analysis

	Absolute bait and fish feed input (tonnes)	Bait and fish feed intensity ($\frac{t}{t_{fish}}$)
Aquaculture	139,930	2.0
Wild catch (commercial)	13,384	0.3
Wild catch (recreational)	6,919	0.9
Sector wide	**160,233**	**1.4**

Each subspecies has a unique method of harvest and / or catch, varying in their bait and fish feed requirements. Figure 17 below shows the absolute quantity and material intensity of bait and fish feed used by subspecies.

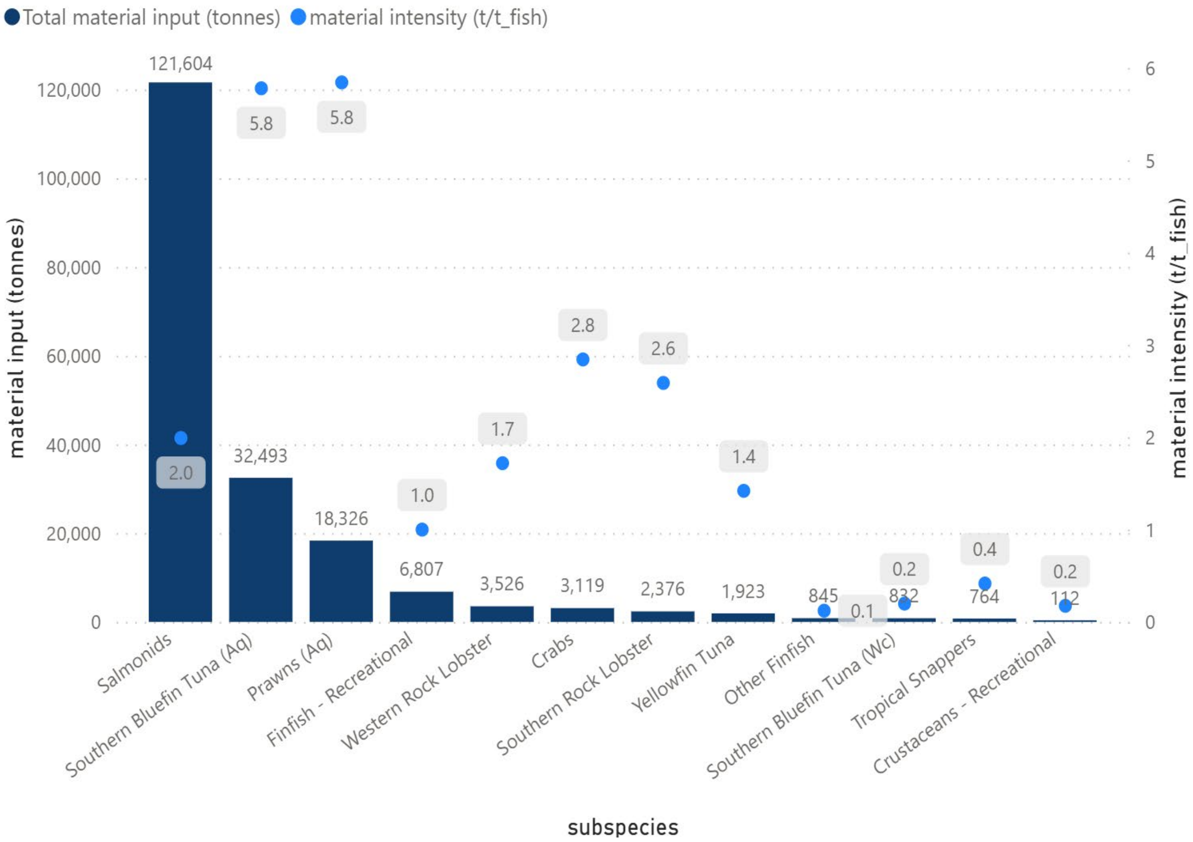

Figure 17: *Bait and fish feed absolute input (tonnes) versus material intensity ($\frac{t}{t_{fish}}$) by subspecies.*

Source: FRDC and RCC Analysis

The graph highlights:

- Bait and fish feed constitute approximately 55% of the total material use in the recreational sector, the majority for catching finfish using rod and line methods (see 3.3.1 Organics).
- Production of prawns, using earthen pond method and southern bluefin tuna are the most bait and fish feed intensive production methods. 5.8 tonnes of fish feed are required as an input for every $\frac{t}{t_{fish}}$. In absolute terms, prawns are the third highest, given there is a lower production tonne of prawns compared to salmonids.
- In absolute terms, salmon production uses almost 6.6 times the amount of fish feed compared to prawns. However, the fish feed intensity of producing salmon is lower than prawns in aquaculture. For every tonne of final fish consumed of salmonids sourced via an aquaculture method, 2.0 tonnes of fish feed is required.
- The production of southern bluefin tuna via aquaculture, using pontoons, ties with prawns for the second highest bait and fish feed intensity, with 32,493 tonnes of Australian Sardine as bait input and 5,622 tonnes of final fish consumed, with a bait and fish feed intensity of 5.8 $\frac{t}{t_{fish}}$. However, in absolute quantities, far less of southern bluefin tuna is produced than salmon.

Bait and fish feed are necessary inputs into the sector. This MFA highlights that fish feed usage, including composition and source of ingredients in aquaculture, particularly for salmon in open pen sea cages, prawns in earthen pond and southern bluefin tuna in pontoons, are likely to be areas for improved material efficiency.

Research by the Australian Prawn Farmers Association Research and Development Committee is underway to support the development of prawn feeds with lower fish feed content and alternative proteins (29). Recycling fish processing waste from other aquaculture industries, land-based proteins, bacterial proteins, and vegetable proteins are also being investigated as potential alternatives.

Production of bait and feed is a resource intensive process (see 3.3.4 GHG Emissions). There is no consolidated data for how bait and fish feed are sourced sector wide. The lack of data means it is difficult to target specific interventions. For aquaculture, it is difficult to reduce the quantity of fish feed, particularly given its necessity across the lifecycle of the subspecies. There is opportunity for the exploration of fish feed alternatives with lower environmental footprints that provide the same nutritional requirements to reduce material intensity. This could include plant proteins and oils, yeast, insects, and algae. Aquaculture research indicates that a transition to these more sustainable feeds is promising and some applications, such as use of insect meal, are close to commercialisation (30).

Organic waste generated by the sector

The total organic waste generated by the fisheries and aquaculture sector, broken down by supply chain stage is shown in the Figure 18. 89% of the total organic waste generated was offal, effluent from consumption of fish feed, and bycatch from Wild catch production. Of total offal, 80% is from offal waste produced by processing and the remaining 20% is from the wholesale/retail sector. The total absolute tonnes of each organic waste destined to each end fate is shown in Figure 19.

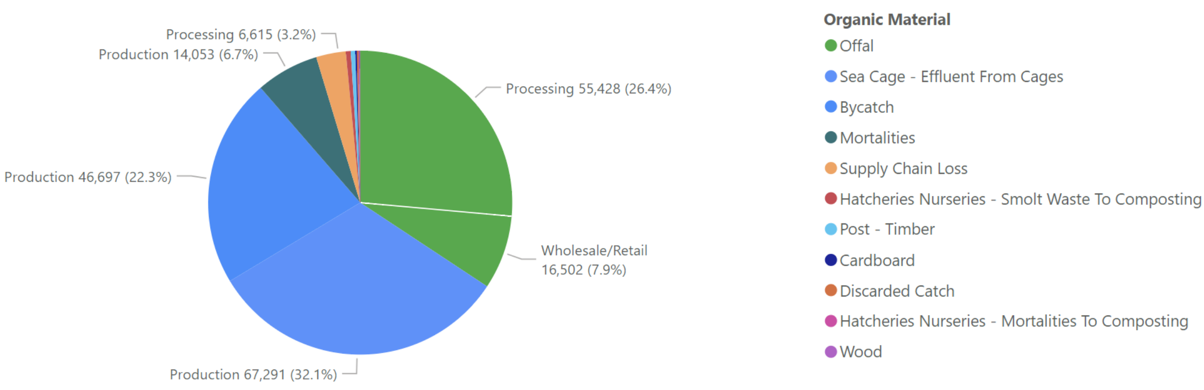

***Figure 18:** Composition of organics waste generated by the sector by material output and supply chain stage.*
Source: FRDC and RCC Analysis

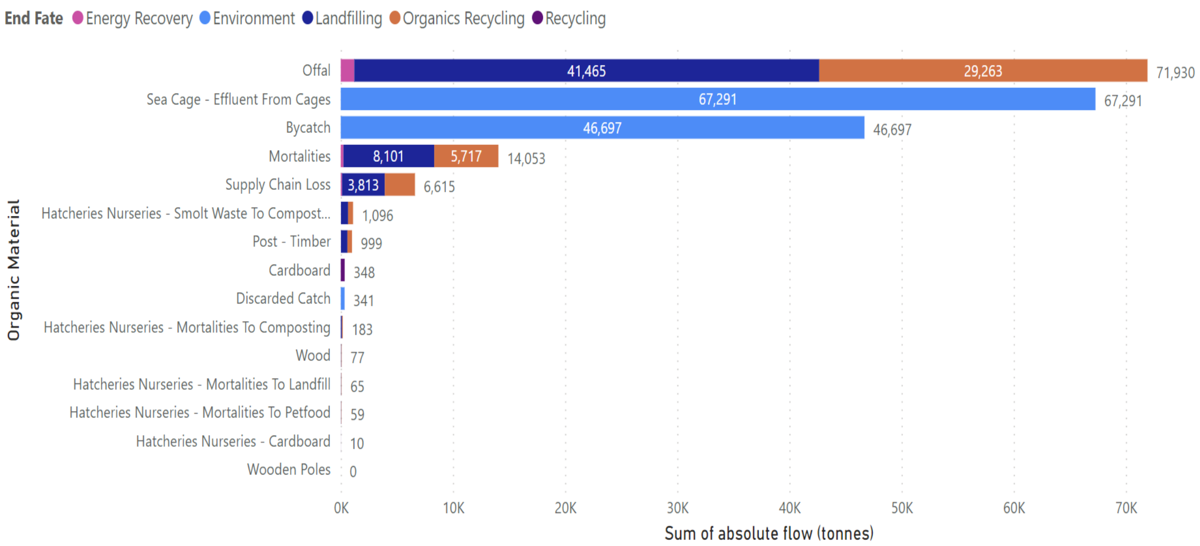

***Figure 19:** End fate of organic waste.*
Source: FRDC and RCC Analysis

Effluent discharge

Effluent discharge forms 32% (67,291 tonnes) of total organic waste generated, all of which is generated in aquaculture production, as it is directly related to the amount of seafood cultivated by the respective production methods. Effluent is produced by both wild catch and aquaculture production methods; however, effluent is only considered in aquaculture production. Effluent is considered to occur naturally in marine ecosystems for wild caught fish and thus not included.

Within aquaculture systems, effluent could potentially be utilised in polyculture activities (where two or more species are produced in the same place). For example, salmon can be grown with seaweed, muscles or oysters as filter-feeding shellfish that can eat uneaten fish feed and waste. This is a proven regenerative solution. Filter feeders reduce organic matter within the marine environment. For businesses, this enables diversification of revenue streams and has the potential to increase profitability.

Bycatch and mortalities

Bycatch (also known as discarded catch) includes the non-target species inadvertently caught. Bycatch often includes species that fishers cannot sell, are not permitted to keep, or are too small (31). Bycatch can include fish, but also other species such as sea turtles and seabirds that become hooked or entangled in fishing gear.

Mortalities are deaths of fish that occur during the production stage. Mortalities encompass all deaths that occur as a result of fishing activities, whether they involve target or non-target (bycatch) species.

Mortalities and bycatch are direct and visible impacts from the catch and harvest of commercial species. For the purposes of this MFA, mortalities and bycatch have been combined as both are unintentional fish caught and/or death in the production stage.

Bycatch is solely generated by the wild catch (commercial) production stage. Bycatch represents 35% (47,038 tonnes) of the total organic waste generated from the production stage. Bycatch is the sole source of organic waste generated by the wild catch production stage.

Mortalities are generated by the aquaculture production stage, this represents 11% (14,359 tonnes) of the total organic waste generated from the aquaculture production stage. Mortalities represents 17% of the organic waste generated by the aquaculture production stage.

Fundamentally, the aim is to reduce bycatch and mortalities as much as possible. Bycatch reduction techniques can include adaptation of fishing practices, such as avoiding protected species domains, reducing the period of longline soaks, seasonal closures and depth restrictions. Mitigation techniques can also involve changing gear, for example switching J hooks for circle hooks, which has been proven to reduce the inadvertent catch of sea turtles (32) as well as reduce post-release mortality of eels according to a German study (33). Education on improved handling practices is key to reducing post-release bycatch mortalities. Practices such as minimising the time between catch and release, and cutting the line attached to hooked bycatch rather than pulling out the hook can increase survival rates post-release (34). While bycatch management policies are present in the US, Australia and many EU countries, regulations are heavily focused on reducing the bycatch of protected species rather than bycatch in general.

A technical review of bycatch reduction devices (BRD) for midwater trawl gear found two technical solutions to reducing bycatch that have been tested and proven (35). Excluder devices are physical barriers that prevent marine mammals from becoming entrapped in the code-end of the trawl net. Acoustic deterrent devices, called pingers, emit signals that deter marine mammals from the fishing gear.

While BRD can help reduce the catch of non-target species, it is inevitable that some level of bycatch will still occur, particularly with the use of non-selective commercial fishing gear such as trawls and gillnets.

There is a significant opportunity to turn unavoidable bycatch into catch. Unavoidable bycatch is either kept and brought back to shore, or more commonly, discarded in the ocean which is harmful to marine ecosystems and an economic waste (36). The full utilisation of unavoidable bycatch outside of protected species is promoted by the Australian Government as a sustainable fishing practice in a paper published for the Organisation for Economic Co-operation and Development (OECD) (37). The economic benefits of bycatch utilisation were demonstrated in a study by CSIRO on the utilisation of bycatch in the Great Australian Bight Trawl Sector which found net profit to increase from -$182,000 to $172,000 per vessel per year (38). Bycatch utilisation pathways include processing into animal feeds, dried fish, novel foods or selling it fresh for consumption (39).

Seafood processing waste – offal

Based on demand, most seafood product is sold as easy to cook fillets. This facilitates little to no processing for the customer following purchase which is a demanded convenience. For example, salmon can be sold whole, gutted but most frequently is sold as fillets. In a typical automated filleting line, the fillets count for approximately 59-63% of the total wet weight of a whole salmon. By-products (offal) from the fillet line include the salmon frame (9-15%), head (10-12%) and trimmings (1-2%) (40).

Offal is responsible for approximately 34% (71,930 tonnes) of total organic waste generated by the sector. Of this, 23% (16,502 tonnes) is generated in the wholesale/retail stage, while 77% (55,428 tonnes) is generated by the processing stage. The overall recovery rate of offal is estimated at 42%. Given the volumes generated, this highlights that there is significant opportunity to recover the remaining 58% which is assumed to be sent to landfill.

Recovery of offal does not come without challenges. Geographic dispersion between processing and markets, handling requirements such as refrigeration on board fishing vessels (for wild catch, where processed on vessel), and associated transport costs are factors to consider for offal recovery rates to increase.

Viable local solutions to recover offal already exist. With opportunities to integrate offal waste with other streams of organics from local markets, such as high nutrient food waste or sludges. The reduction of organic waste is a priority in the Australian Government National Waste Policy Action Plan. The Plan has a target to halve organic waste sent to landfill for disposal by 2030. There are increasing commitments by states to roll out Food Organics Garden Organics (FOGO) collection services to all households and businesses. This results in an increased focus and momentum on rapidly increasing local organics processing capacity. There are likely to be increased opportunities for offal to be considered as a useful feedstock to supplement or complement other organics feedstocks.

Local solutions for local anaerobic digestion of offal to power wholesale markets directly provide innovative bespoke circular solutions. Anaerobic digestion involves the degradation of organic matter in the absence of oxygen to produce biogas, a combination of carbon dioxide and methane. The energy content of methane can then be used to produce electrical energy. In addition to reducing the quantity of organic waste matter, anaerobic digestion also produces a nutrient packed digestate that can be used in fertilizer.

Collaboration is a key enabler of circularity, and solutions for offal waste not destined for circular strategies to extract greater value, could benefit from consolidation with other suitable organic feedstocks.

Beyond energy recovery and composting, there are several opportunities for conversion of seafood processing waste into commercial products. This presents opportunity for these by-products to be used as fish bait, animal feed, textiles or as a raw material to produce cholesterol, lipids and proteins.

Case Study: Ocean2Earth

The recycling of fish waste into sustainable fertiliser is a profitable, circular solution for organic waste disposal. Ocean2Earth (O2E) is an Australian company based in Bega Valley, New South Wales that transforms marine and seafood processing waste into sea mineral compost, an example of creating value from waste. Each year, O2E diverts over 500 tonnes of seafood waste from landfill by providing local councils, seafood processers and fishermen with an alternate for seafood waste disposal. O2E offers a seafood waste collection service for seafood processers. The organic waste is then taken to O2E's composting facility in Merimbula where it is mixed with pine bark from a local sustainable pine mill plantation. The product is left to compost for 6 months until the fish is decomposed and is packaged and sold as compost.

Source: *Ocean2Earth (41)*

Large industry stakeholders are adapting to the rising trend of sustainable biofertilizers. In 2021 Incitec Pivot Fertilisers (IPF), invested $38 million AUD to build the first Australian largescale plant to develop sustainable biofertilisers. This plant will have the capacity of producing 75,000 tonnes of granular biofertilisers per year, incorporating organic waste materials from the poultry industry with carbon and fertiliser materials to create a sustainable 46 biofertiliser (42). Whilst the current focus is on collecting organic waste from the poultry industry, there is potential for IPF to expand to organic waste produced by the seafood industry, as exemplified in the O2E case study.

Circular Strategies

Eliminating pollution

Value from waste

Case Study: Oyster Shells

Discarded oyster shells are gaining recognition and momentum for their reef restoration capabilities. In 2017, South Melbourne Market established a partnership with the Nature Conservancy for the 'Shuck Don't Chuck' initiative, a seafood shell recycling project that supports the rebuilding of the lost shellfish reefs in Port Phillip Bay. Consumers and stall owners discard their mollusc shells in dedicated bins, collected weekly.

The shells are then cured through sun and wind exposure for six months at the Bellarine Peninsula. Cured shells are then combined with limestone rubble and are distributed across the sea floor in Port Phillip Bay. Juvenile Australian flat oysters and blue mussels are released over the cured shells, enabling new reefs to grow. As of 2020, over 2.5 hectares of shellfish reefs have been restored (43), a prime example of regenerative design and creating value from waste.

Source: *WHQR (44)*

Cured shells are then combined with limestone rubble and are distributed across the sea floor in Port Phillip Bay. Juvenile Australian flat oysters and blue mussels are released over the cured shells, enabling new reefs to grow. As of 2020, over 2.5 hectares of shellfish reefs have been restored (43), a prime example of regenerative design and creating value from waste.

Oyster shells are also utilised to restore eroded shorelines. OceanWatch Australia's Living Shoreline Project installs discarded oyster shells in coconut mesh bags along the eroded shorelines (45). This provides a habitat for an array of marine species, as well as a surface for oyster larvae to settle on.

Circular Strategies

Eliminating pollution

Value from waste

Regenerating nature

Case Study: By-products and offal

Fish by-products and offal constitute a significant amount of the organic waste. A number of companies have identified profitable opportunities to turn this organic fish waste into a sustainable product. All Fish for Dogs is an Australian dog treat brand that takes fish offal, fish processing by-products, and unwanted bycatch, processing these ‘waste products’ into dog treats. They take organic waste that would otherwise be landfilled and transform it into a profitable product (46).

Source: *FRDC* (46)

Internationally, Nordic Fish Leather recycles fish skin into leather (47). Fish skin is a more sustainable alternative to many mainstream materials such as polyester and cotton, as the energy and resources required to cultivate are minimal in comparison. Repurposing fish skin into leather minimises the amount of organic waste entering landfill from the fisheries and aquaculture sector.

Source: *Nordic Fish Leather (47)*

The rendering of by-products and offal into fish meal and fish oil is a circular solution that diverts organic fish waste from landfill. In August 2023, Huon announced their plan to invest $20 million in a rendering facility in Huon Valley in southeast Tasmania (48). The construction of this plant is an example of a company embracing circular interventions to improve its sustainability credentials. The plant will also produce a sludge that can be used to create compost for the agriculture sector, feeding waste products back into the supply chain.

Circular Strategies

Eliminating pollution	Value from waste	Redesign & procurement

3.3.2 Plastics and packaging

Plastic offers many benefits and has many beneficial properties including strength, durability, weight, and cost. Most plastic has been designed and manufactured with little thought for its end of life. A linear (take-make-waste) economy approach has resulted in significant amounts of plastic waste sent to landfill or lost to the environment.

Plastics are used across all aspects of fisheries and aquaculture. Plastics help improve the reliability and longevity of equipment. Their light weight reduces handling and associated costs. Their strength alleviates the costs of breakage. Various resin combinations provide the durability required for operations in harsh marine and freshwater environments.

However, challenges arises when these qualities are combined with improper waste management. The same durability can lead to long term contamination of land, freshwater and marine environments.

Current plastics profile

Plastics in this assessment include packaging (e.g. various packaging of final fish product from EPS, plastic wrap), fishing gear and equipment (e.g. fishing lines, nets, and floats). Table 6 shows the high-level breakdown of plastics input and intensity within the sector and sub-sector. Of the total 5,993 tonnes of plastic quantified in this assessment, 57% (3,388 tonnes) is used within aquaculture, 25% (1,470 tonnes) in wild catch (recreational) and 19% (1,134 tonnes) in wild catch (commercial). The sector-wide material intensity for plastic is 0.05 $\frac{t_{plastic}}{t_{fish}}$.

Table 6: *Plastic inputs and intensity by sub-sector.*
Source: FRDC and RCC Analysis.

	Absolute material inputs (tonnes)	Material intensity ($\frac{t_{plastic}}{t_{fish}}$)
Aquaculture	3,388	0.05
Wild catch (commercial)	1,135	0.03
Wild catch (recreational)	1,470	0.20
Sector Wide	**5,993**	**0.05**

Figure 20 illustrates the breakdown of plastics across two broad categories: Fishing Gear & Equipment used in production (68%), and Packaging used in markets (32%)

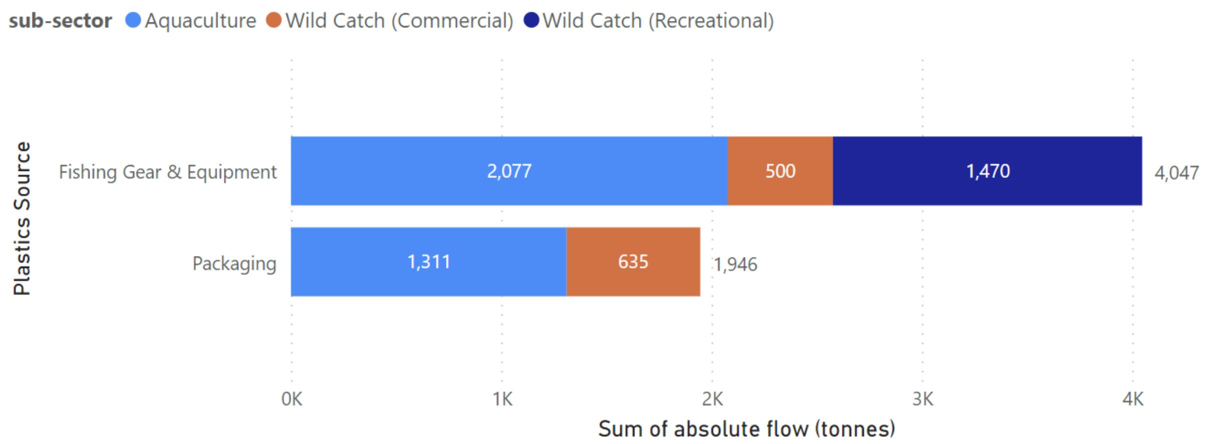

Figure 20: *Breakdown of plastic inputs (tonnes) by source.*
Source: FRDC and RCC Analysis

Plastic fishing and aquaculture gear and equipment

Figure 20 demonstrates that out of the total 5,993 tonnes in absolute terms of plastic consumed in the sector, 68% (4,047 tonnes) is allocated to Fishing Gear & Equipment. Fishing Gear & Equipment in aquaculture accounts for 35% (2,077 tonnes) of the sector's plastic inputs.

Conversely, Fishing Gear & Equipment in wild catch (commercial) production represents a smaller portion at 8% (500 tonnes), with a relatively low material intensity of 0.03 $\frac{t_{plastic}}{t_{fish}}$. Wild catch (recreational) Fishing Gear & Equipment constitutes 25% (1,470 tonnes) of the sector's total plastic consumption, exhibiting the highest material intensity at 0.20 $\frac{t_{plastic}}{t_{fish}}$.

Breaking this down further, Figure 21 below shows the quantity of absolute plastic used in each production method, against the material intensity ($\frac{t_{plastic}}{t_{fish}}$).

The results highlight:

- Wild catch (recreational) Fishing Gear & Equipment accounts for 25% (1,470 tonnes) of the sub-sector's plastic use, divided into two methods: rod and line (1,293 tonnes) and trap and net (177 tonnes). Trap and net method has the highest plastic intensity, requiring 0.274 $\frac{t_{plastic}}{t_{fish}}$.
- Open sea cages are the main production method for salmon farming. Although this method does contribute to a substantial amount of plastic, totalling 1,004 tonnes, their plastic usage per tonne of fish product is relatively low, at just 0.012 $\frac{t_{plastic}}{t_{fish}}$. Out of the 1,004 tonnes, roughly 704 tonnes are accounted for by the plastic used in feedbags for fish feed.
- Floating mesh baskets used to produce oysters are the most plastic intensive commercial production method, with a material intensity of 0.137 $\frac{t_{plastic}}{t_{fish}}$. Hexcyl baskets are a less plastic intensive production method for oyster production, with a material intensity of 0.050 $\frac{t_{plastic}}{t_{fish}}$.
- Within wild catch, demersal long line (0.109), pelagic longline (0.037) and Danish seine (0.012) are the most plastic intensive production method in $\frac{t_{plastic}}{t_{fish}}$.

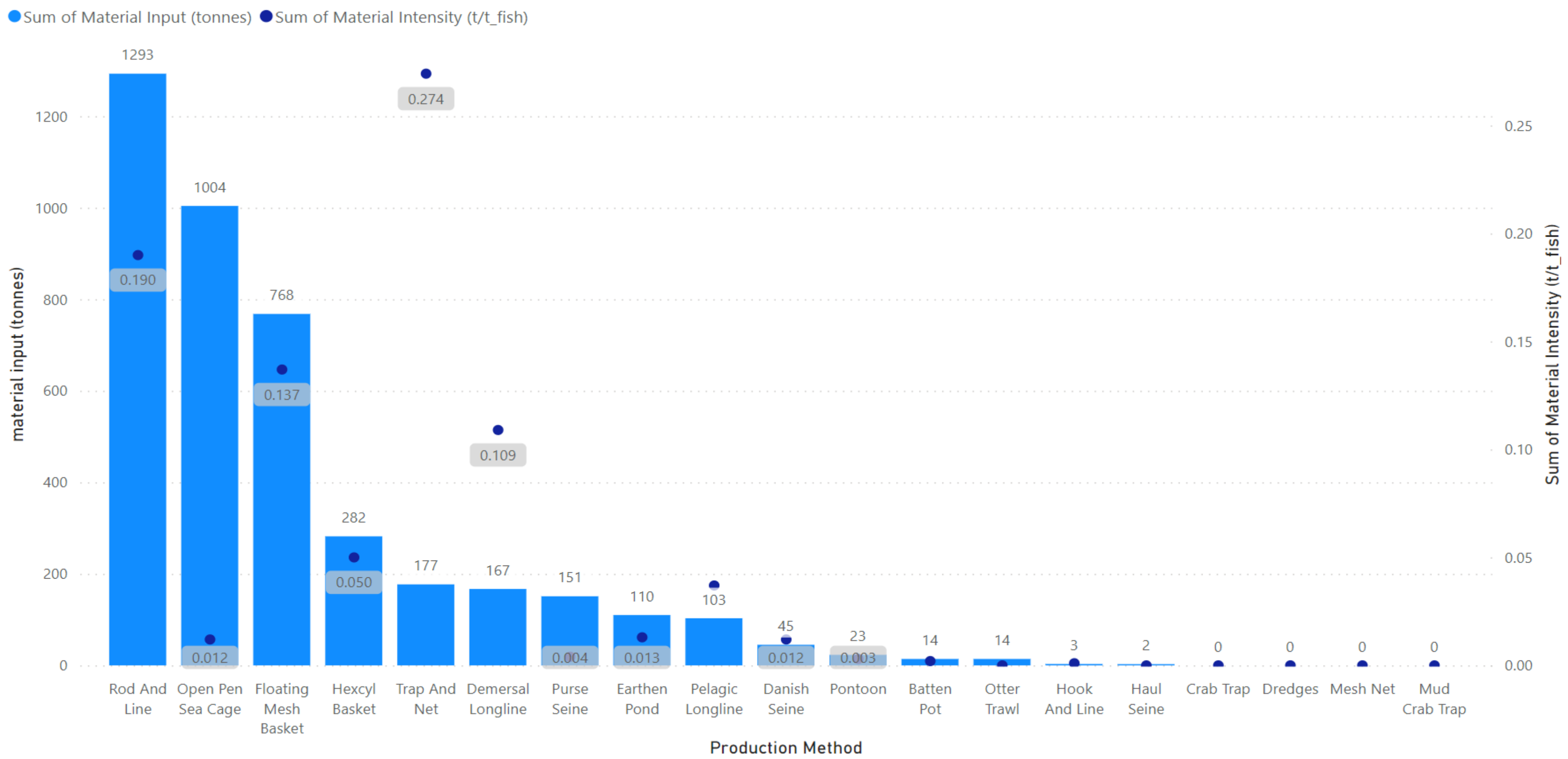

***Figure 21:** Absolute plastic used in each production method, against the material intensity figure of plastic use per tonne of fish product.*
Source: FRDC and RCC Analysis

Figure 21 and Figure 23 further explore the core plastic components used in fisheries and aquaculture gear and equipment. Within wild catch (commercial) production methods, the largest contributor to plastic use is ropes and lines, totalling 283 tonnes of plastic, followed by nets, which use 170 tonnes.

Within aquaculture, feedbags are the largest contributor to plastic waste with approximately 821 tonnes of plastic feedbags discarded annually. Feedbag recycling is particularly challenging for aquaculture entities.

Sector-wide, nets, ropes and lines account for 402 tonnes of plastics used annually and were commonly highlighted by stakeholders as an opportunity for greater collaboration when it comes to end-of-life solutions.

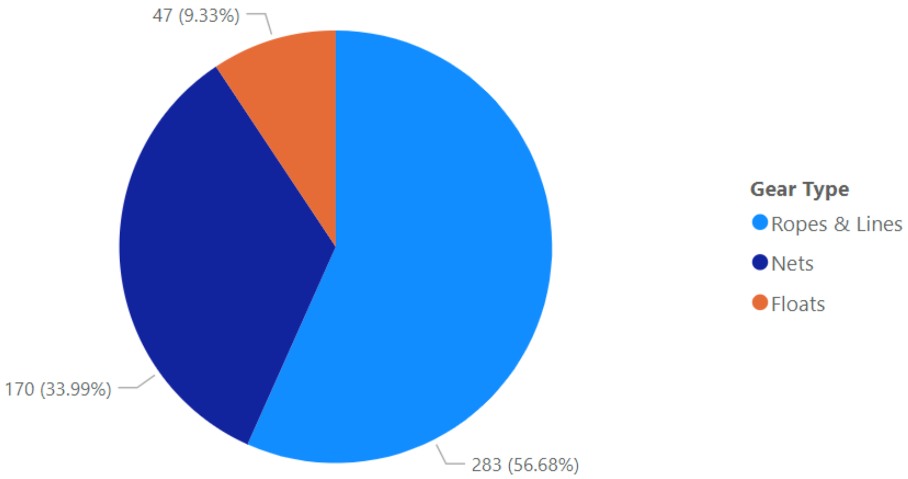

Figure 22: *Wild catch (commercial) plastic fishing gear composition.*
Source: FRDC and RCC Analysis.

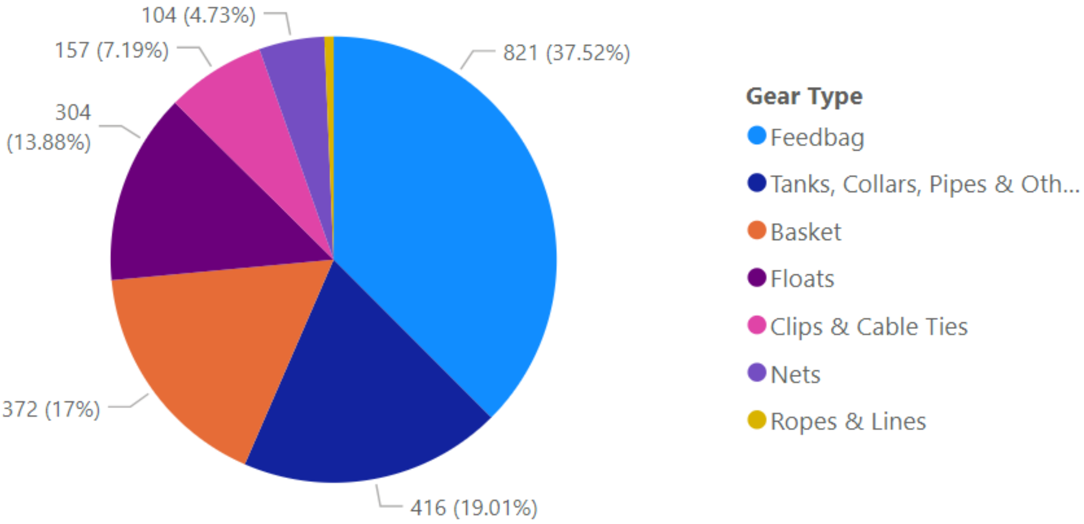

Figure 23: *Aquaculture plastic equipment composition.*
Source: FRDC and RCC Analysis

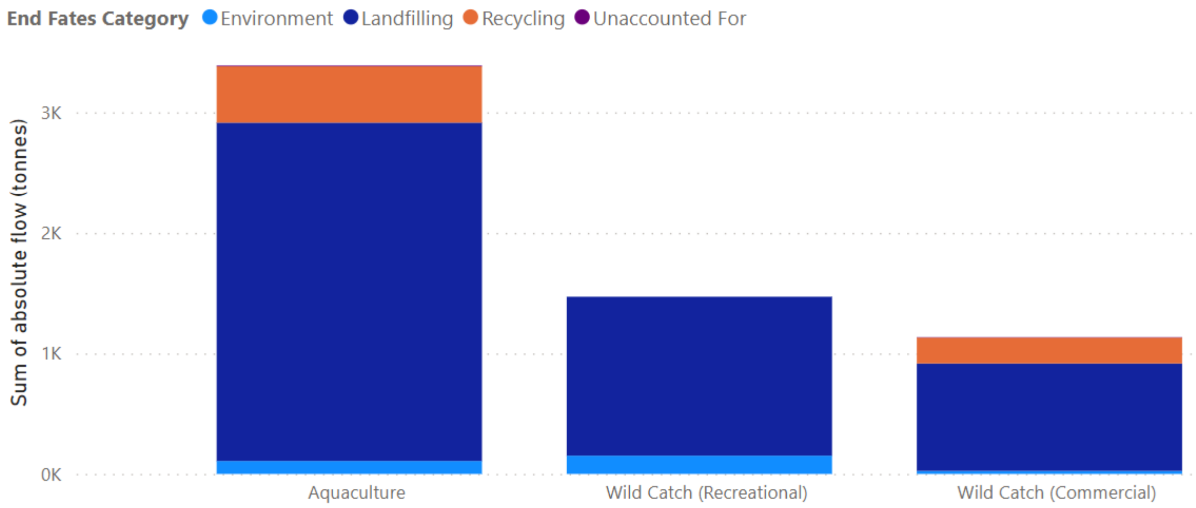

Figure 24: *End fates of fishing gear and equipment per sector.*
Source: FRDC and RCC Analysis

The end fates of plastic used in gear and equipment by sub-sector is outlined in Figure 24. The results highlight:

- The most significant end fate of plastic waste by quantity is to landfill (5,017 tonnes). Of this sectoral total, the aquaculture sub-sector was responsible for the generation of 56% (2,807 tonnes) of plastic landfill waste. The remainder is from wild catch (commercial) and wild catch (recreational), which generated 18% (891 tonnes) and 26% (1,319 tonnes) respectively.
- It is estimated that 683 tonnes of plastic used in gear and equipment is recycled annually.
- Assuming a 5% loss rate of plastics to the environment for all production methods approximately 284 tonnes of plastic gear and equipment are believed to be released into the environment annually from the fisheries and aquaculture sector. The assumption of 5% is drawn from research conducted on estimates of fishing gear loss rates (49) (50).

There are several challenges to improving the circularity of fishing gear and equipment:

End-of-life solutions: Many long-life components of fishing and aquaculture equipment, such as ropes, floats, nets and baskets are difficult to clean, due to biofouling. This makes the equipment less suitable for recycling or reuse.

There are two approaches to the recycling of fishing nets and ropes: chemical and mechanical recycling. Chemical recycling, as used by Aquafil in their de-polymerisation process, transforms a nylon fishing net back into its virgin form, enabling the company to sell a yarn similar to virgin nylon (51). If materials can be separated, mechanical recycling can be used for a range of fishing net materials, such as nylon, high density polyethylene, and polypropylene.

At end-of-life, fishing gear and equipment is often considered low value by recyclers. Equipment is classified as low value because it is often mixed with other materials such as timber and metal, contaminated by organic material and/or deteriorated through use and sun exposure.

Additionally, the distance to recycling facilities and associated transportation costs presents a challenge.

***Loss to environment**:* Despite mitigation efforts, the fisheries and aquaculture sector acknowledge the occurrence of accidental plastic losses. The main reason for marine litter from aquaculture is extreme weather and the following catastrophic impact on facilities (52). In the case of inter or sub-tidal facilities entire components e.g. floats, sea pens, nets and plastic containers can be lost directly into the sea. In both wild catch and aquaculture major components are likely to be recovered through industry led retrieval efforts and beach clean-ups, whereas smaller items are often permanently lost.

Mixed materials: Mixing materials is common practice in the formation of durable and effective equipment. Diverse material composition and complex structures can make recycling challenging. Sorting and separating the various components of fishing gear, such as integrated weighted line, nets and traps, and trawl gear, pose technical and logistical hurdles. This often renders the recycling process inefficient and costly. For instance, industry stakeholders cited identifying viable recyclers/ markets for integrated weighted line (composed of both polyethylene and a lead core) as a challenge. When separated the lead core is able to be recycled, however due to the polyethylene exterior the stripping of the line can make the recycling challenging due to biofouling, cost and lack of infrastructure and end markets.

Opportunities

Redesign

- *Material selection:* Circular fishing gear and equipment includes the use of renewable, recycled content, or reusable materials, with the gradual elimination of virgin plastics. While no biodegradable materials for fishing gear and equipment exist at present, there is a research and development opportunity to understand the potential utility and environmental impact of biodegradable materials. Manufacturers could also look to incorporate recycled plastics into the manufacturing process to reduce the demand for virgin plastics. However, alternative and recycled content products must still be able to meet the performance requirements of their virgin-based competitors.
- *Extend the lifespan:* Design fishing gear and equipment to prioritise durability and repairability. This may be enhanced through modular designs and performing regular maintenance of gear and equipment.
- *Design for disassembly:* Design products in a way that makes the separation of different materials for recycling or reprocessing easier. Mixing of different polymers within the same product reduces the likelihood of product recycling. The opportunity exists to replace polymer mix with a single polymer with broader properties. Such replacement could enhance the utility of chemical and mechanical recycling. Manufacturers may also choose to use materials that have stronger secondary markets, which will aid in the economics of recovery.

End-of-life management

- *Product stewardship:* Work with manufacturers to implement product stewardship programs, where manufacturers are responsible for the end-of-life management of their goods and support develop of end markets to ensure demand. This encourages companies to design for recyclability and invest in recycling infrastructure.
- *Implement take-back programs and collection points*: Establish systems for collecting and recycling old or damaged gear, either through manufacturer-led initiatives or partnerships with recycling companies. The focus on product stewardship encourages companies to design for recyclability and invest in recycling infrastructure. Within an Australian context, due to the geographical distribution of fishing and aquaculture activities, take back programs present an additional challenge due to costs and emissions associated with logistics and transportation.

- *Scale recovery efforts:* The industry already engages in beach clean-ups and recovery initiatives aimed at minimising the environmental impact of lost gear and equipment. The sector ought to continue to identify intervention points to prevent loss in the first instance and support recovery efforts such as the Global Ghost Gear Initiative (53). This is the world's largest cross-sectoral alliance dedicated to finding solutions to the problem of abandoned, lost or otherwise discarded fishing gear.

Case Study: Value from Waste

Odyssey Innovation in Southwest England are working with harbours to collect old nets and produce kayaks out of recycled materials. The program identified logistics, lack of regional facilities, and high dismantling costs as major obstacles in improving waste management and recycling of fishing gear. To overcome these challenges, Odyssey Innovation established centralised drop-off points for end-of-life nets and ropes, minimising storage requirements for ports and enabling ports to participate in the scheme. The collected material is then sent to a specialist recycler, Plastix, for recycling. Some of the recycled material is used to create kayaks, generating profits that fund gear collection and clean-up initiatives. Due to Odyssey Innovation's efforts, fishing ports in Newquay and St Ives now recycle up to 60% of their fishing gear (54).

Source: *Seafish* (54)

In Europe, there are two main companies working with fisheries and aquaculture to collect, dismantle and recycle fishing nets.

Source: *UNDP* (55)

- Nofir is a Norwegian company that collects, recycles, or repurposes discarded equipment from commercial fishing and fish farming (56). Collected material is transported to factories where it is dismantled and prepared for recycling. Nofir work in partnership with Aquafil's ECONYL® waste treatment center to turn the recycled nets into regenerated polymers which are then used in products such as socks, swimwear, and carpet tiles (51).
- Plastix (57) has created a recyclate called OceanIX HDPE made from discarded fishing nets. They work with global partners to collect and recycle a range of fishing gear to create their OceanIX pellets. The facility undertakes cleaning, separation, cutting and recycling of a variety of different net materials.

While Norfir and Plastix can handle logistics for sourcing nets from outside of Europe, limited information is available about companies operating in other regions utilising a similar model.

Circular Strategies

Product Stewardship	Value from waste	Recycling & Composting

Packaging

Packaging plays a crucial role in preserving seafood throughout the supply chain. Within this MFA, packaging has only been quantified for the wholesale/retail supply chain stage, due to data availability. Figure 25 shows the composition of packaging used in the sector.

The results highlight:

- Annually the fisheries and aquaculture sectors use 3,130 tonnes of packaging per year.
- Annually, nearly half, (46% or 1,445 tonnes) of packaging consumption is expanded polystyrene (EPS) boxes. This equates to around 10 million boxes each year. Of this, the vast majority 1,206 tonnes are sent to landfill. While EPS recycling efforts are in place, they are currently limited to specific locations, and end markets for recycled EPS are immature.
- Paper and cardboard consumption accounts for 40% (1,260 tonnes) of packaging used per year. This value is only a subset of the paper and cardboard used throughout the sector. For example, cardboard is likely to be a used as packaging of equipment and gear, however this upstream packaging is outside the scope of this MFA. The paper and cardboard in scope for this MFA is exclusively the wholesale sub-sector for tertiary packaging and cardboard used for domestically sold retail products. An estimated 907 tonnes (72%) are recycled. Household paper and cardboard recycling is lower than commercial recycling rates.
- Fish crates (such as the blue plastic crates at the Sydney Fish Market) exemplify a circular solution due to their high reuse rates and design for recyclability. Fish are sold in crates with a fee for the crate. The crate is re-purchased by the market when the wholesaler or retailer returns the crates.
- Wooden pallets and pooled pallets serve as reusable tertiary packaging systems with high rates of reuse. A mere 1% (34 tonnes) of wooden pallets reach the end of their lifespan each year.

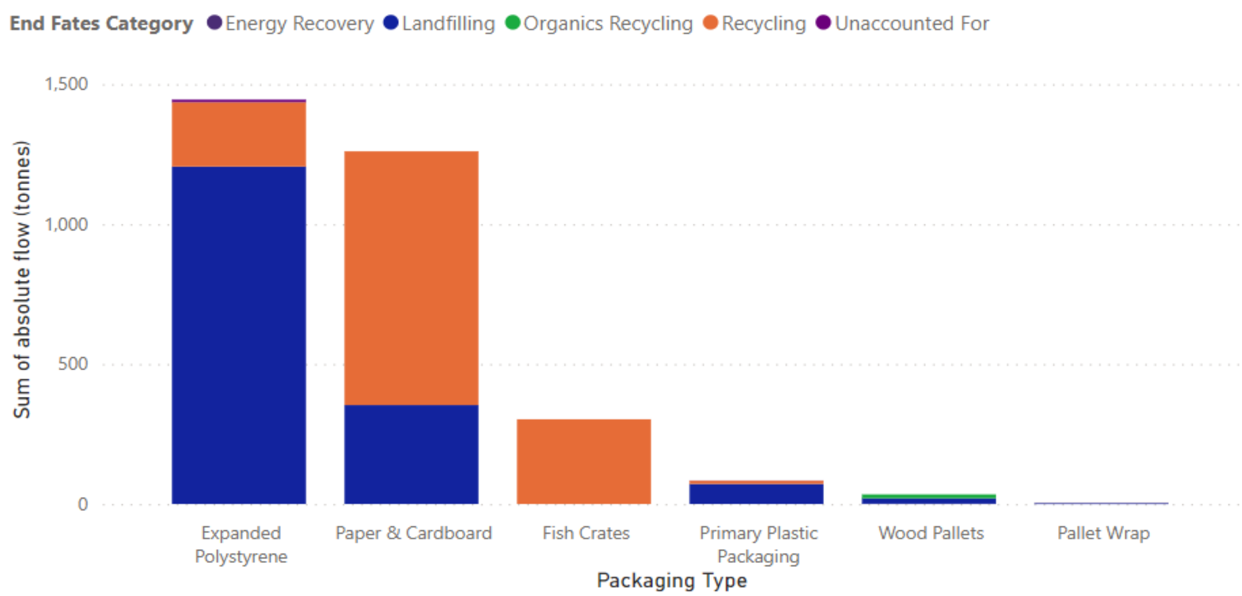

***Figure 25:** End fates of packaging.*
Source: FRDC and RCC Analysis

Challenges

Soft plastics: Soft plastics play a crucial role in efficiently transporting products due to their lightweight and functional properties. However, end-of-life solutions are limited. This is primarily due to challenges posed by the multi-polymer construction and contamination. This challenge is not unique to the fisheries and aquaculture sector but is faced by many industries globally. To address this issue there is the opportunity to transition to mono-materials, which would significantly improve recoverability. Additionally, there are initiatives underway to establish collection and recycling schemes specifically for soft plastics. Notably, pallet wrap is being redesigned to incorporate recycled and renewable materials, along with enhanced durability, ultimately reducing the overall demand for this packaging material.

Contamination: Fisheries and aquaculture packaging can often contain residues of organic matter and moisture. Contamination from residual oils, scales, and other biological matter can render conventional recycling processes ineffective. Finding methods to efficiently clean and prepare packaging materials for recycling or reuse is a critical challenge to address.

EPS boxes: The fisheries and aquaculture sector rely heavily on EPS boxes (commonly known as poly boxes) for their exceptional lightweight, durability, waterproofing, and thermal insulation capabilities. EPS boxes are a regulatory transportation packaging requirement for many export markets. However, EPS is globally recognised as problematic due to limited end-of-life recycling options and its tendency to break down and contaminate the environment. Recycling efforts are further impeded by challenges in removing food residues and odours. Industry stakeholders voiced the current difficulties in sustainable and commercially viable alternatives that match the functional properties of EPS boxes.

Mixed materials: As with gear and equipment in the previous section, combining different materials in packaging within the fisheries and aquaculture sector hinders recycling and diminishes the potential for recovery. Recovered materials from mixed packaging are of lesser quality, restricting market value.

Product protection & food safety: The primary purpose for packaging is to ensure food safety and shelf life of the product. Improving packaging circularity in the fisheries and aquaculture sector cannot come at the expense of product loss, damage, or food safety. Industry stakeholders noted that food safety policies can sometimes unintentionally hinder circular practices and felt there was an opportunity to explore real versus perceived risks to challenge single use packaging and other products such as personal protective equipment (PPE) across the supply chain.

Feedbags: The use of one-tonne bags for salmon and prawn farm feed represents a unique packaging challenge. These bags are designed to handle large quantities of high-value product. However, their sheer size and specialised material composition poses obstacles to recycling. Working with feed producers to develop dedicated reuse and recycling processes or exploring alternative materials such as recycled content or renewable alternatives for these bags is essential to reduce their environmental impact and enhance circularity within the fish feed production chain.

Opportunities

Redesign: Embracing packaging commitments in alignment with initiatives led by the APCO sets a clear path towards sustainable packaging. Industry can incorporate recycled content targets in line with national targets. Industry ought to seek the development of feasible targets to increase the use of reusable, recyclable, or compostable packaging. The framework below, developed by the Ellen MacArthur Foundation, offers a structured approach to tackle problematic packaging.

1. **Eliminate:** Eliminate unnecessary packaging by conducting a thorough assessment of packaging materials and practices, identifying areas where over-packaging can be reduced without compromising product integrity or safety.
2. **Circulate:** Keep packaging in closed loop circulation through reuse or recycling. Where applicable follow models such as pooled pallet solutions and Sydney Fish Market's reusable blue fish crates. Identifying opportunities to replicate these systems more widely could reduce single-use packaging.
3. **Innovate:** Innovative solutions should be explored for packaging that cannot be eliminated or circulated. This involves researching and adopting new packaging formats and systems for reuse or recycling in closed loops.

APCO also created a useful *Sustainable Packaging Guidelines* for Australia (7).

Additionally, bioplastics have emerged as a potential solution for the growing environmental impacts of plastic waste. Bioplastics have unique characteristics such as biobased, biodegradable, and/or compostable. However, their adoption is not without challenges given the wide range of polymer types, applications, and often confusing terminology. There is a lack of standardised labelling of bioplastics resulting in contamination across recycling and composting streams, leading many bioplastics to ultimately end up in landfills.

Collaborate and share solutions: To avoid duplication of effort and scale the impact of sustainable packaging initiatives, the fisheries and aquaculture sector should consider actively sharing successful solutions. This can include case studies, research findings, and practical experiences related to packaging reduction, reuse, and recycling to prevent duplication of research across the sector and enable faster adoption.

One example involves finding alternatives to EPS boxes. Several alternatives, such as FishCap, WoolPack, KoolPak, TempGuard, and Chilltainers, among others, have been developed and tested by industry players, both domestically and internationally. However, the lack of widespread sharing of outcomes has led to repetition of trials. Adoption of alternatives has been *ad hoc* and can impose a burden on the organisation's profitability.

3.3.3 Other Materials

As noted in 2.2.4 Inputs and End Fates, metals, inert and chemical material streams are inputs into the fisheries and aquaculture sector (Figure 10). These materials are considered lower priority for circular intervention for the sector due to both low absolute quantity and low overall impact.

Metals

Metals are used for a range of elements in the sector, for example:

- Copper alloy cages in aquaculture
- Hooks, sinkers, lures
- Various fishing rods

Metals account for 0.43% (1,756 tonnes) of total material input into the sector, all of which is used in the production stage. The majority of metals (79%) used in recreational fishing are lures, rods and reels. The overall metal recovery rate across is 17%, which is substantially lower than the national metals recycling rate of 80% as noted in the Australian National Waste Report (25). This is due to an assumption that the majority of metal generated in the recreational sector is sent to landfill. There are limited opportunities and recycling outlets for consumers to easily recycle gear and equipment. Therefore, it is assumed that a high proportion is sent to landfill. While some initiatives such as Rig Recycle exist to provide appropriate collection and recycling of recreational gear (58), there is opportunity to scale these initiatives to increase recovery efforts (see 3.4 Recreational Fishing).

The *actual* recovery rate of metals in the fisheries and aquaculture sector, is an area of uncertainty, and may not reflect the trend observed in the Australian National Waste Report (25). For example, while the Australian National Waste Report documents that approximately 10% of metals are reused (25), nationwide generalised reuse of metals is unlikely to be representative of the fisheries and aquaculture sector. Due to this it has been assumed reuse of metals does not occur in the MFA.

Given the high value of metals, there is potential to improve the actual recovery rates. To optimise the quality and ability to recycle metals, it is important to ensure metals are kept as a single material stream, have the appropriate collection infrastructure, and clear communication on collection practices.

Inert

Inert material accounts for 0.18% (719 tonnes) of total material input into the sector, examples of this include concrete from production infrastructure and ballasts weights in batten pots. These inert materials typically have a long-life span and are generally recoverable.

The key for maximising circularity for inert materials is to reduce the use of material and design for disassembly and reuse.

Chemicals

Chemicals account for an estimated 3.62% (14,000 tonnes) of total material input into the sector. Chemicals are exclusively an input into the aquaculture hatcheries and nurseries processing method. Chemicals may have other applications in aquaculture; however, these are outside the scope of this MFA. Chemicals can consist of liquid nitrogen/oxygen, ethanol, hydrogen peroxide and sodium hypochlorite.

Chemicals are used to ensure that fish grow in an optimal environment and to reduce occurrences of diseases. There are several ways to reduce chemical usage including but not limited to nutrient content management, temperature fluctuations, targeted nutrition and lighting conditions.

Stakeholder consultations informed the assumption that chemicals are used predominately in the aquaculture sub-sector and their use and management is typically controlled by stringent requirements set by jurisdictional state environmental regulators. For this reason, there are limited options for targeting circular interventions for chemicals.

3.3.4 GHG Emissions

Emissions are produced throughout the supply chain from fishing vessels fuel, energy required for refrigeration, and incineration of waste. The methodology and boundary for calculating the sectors emissions is based on the FRDC and Blueshift Consulting, *Calculating Seafood's Carbon Footprint report* (59). GHG emissions within the sector are a product of:

- **Bait and Fish feed** – Emissions produced from bait capture and feed production are derived from capture, processing, transport, and storage.
- **Fuel usage (vessels / generators**) – Emissions are created from fuel combustion in fishing vessels. Diesel fuel powers fishing vessels to and from fishing grounds, to undertake catching operations and powers onboard processing and refrigeration. Oil and lubricant usage on boats has been excluded from this analysis due to data availability.

- **Electricity** – electricity emissions are the result of powering processing and production facilities, and equipment for pumping, circulation, and other aeration requirements. Electricity for wholesale/retail facilities are not included, as the boundary adopted for this assessment was from the FRDC and Blueshift consulting report (59).
- **Transport** – Transportation emissions are generated as fish products are transported to processing facilities and wholesale/retail outlets. Transportation emissions also are derived from the transport of equipment and other materials used within operations.
- **Nitrous Oxide Emissions (N_2O)** - N_2O emissions arise from the microbial nitrification and denitrification, in bodies of water, in the context of this report, N_2O emissions are only quantified for aquaculture.
- **Refrigerants usage** - Refrigerant gases are used in vessel freezers and chillers. Most emissions derived from refrigerants are a result of accidental gas loss from equipment wear and tear of faulty componentry, or deliberate ventilation of gas into the atmosphere during vessel maintenance.

GHG emissions account for 1,530 kt $CO2_e$. Figure 26 below provides a breakdown of GHG emissions sources from largest to smallest. The top sources include:

- Bait and fish feed (31%),
- Fuel for vessels and generators (24%),
- Electricity (24%),
- Transport (15%).

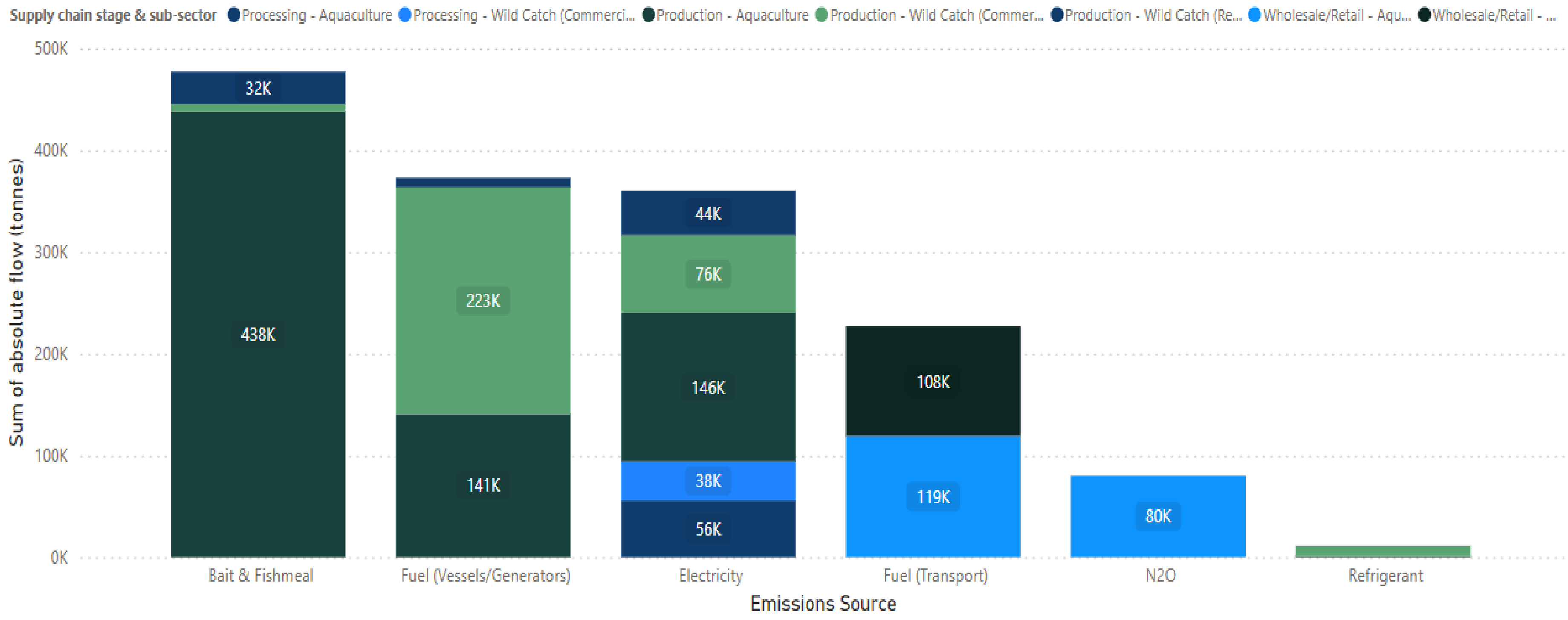

Figure 26: *Breakdown of emission sources for the sector.*
Source: FRDC and RCC Analysis

Bait and fish feed emissions are from the upstream transport and processes required for these products. These are considered Scope 3 emissions for the sector. Reducing emissions associated with bait and fish feed production and supply chain emissions, identifying alternative fuel and energy sources presents a significant area for the sector to focus its decarbonisation efforts on.

Figure 27 below shows the breakdown of emissions for the sector by supply chain stage (production, processing, and wholesale/retail) and for each sub-sector (aquaculture, wild catch (commercial) and wild catch (recreational)). The majority (47%) of total sector emissions are generated by the production processes in aquaculture. Almost all (92%) of the bait and fish feed emissions generated for the sector shown in Figure 26 are attributed to aquaculture production.

The use of electricity is spread across each sub-sector and supply chain stage. 100% of emissions generated from the aquaculture and wild catch (commercial) processing stage are from electricity. Emissions for the wholesale/retail stages are related to fuel and transportation. Electricity in the wholesale/retail stage is not included in scope of this assessment and aligns with work completed by FRDC and Blueshift Consulting (59).

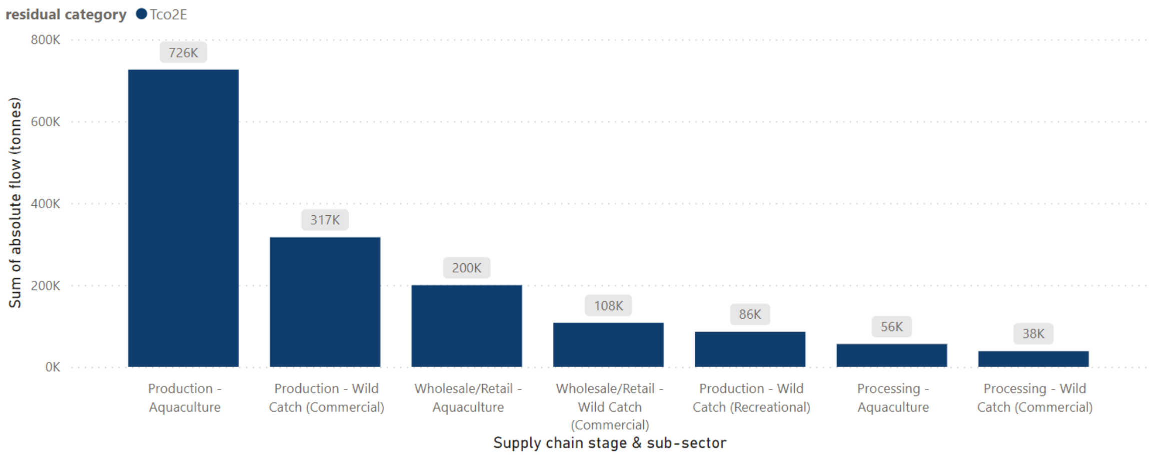

Figure 27: *Emissions by sub-sector and supply chain stage.*
Source: FRDC and RCC Analysis

Key Challenges and Opportunities

The consideration of emissions, whilst typically raised within the climate-related risk context, does have a place when assessing circularity. One of the three foundational principles of a circular economy is the elimination of waste and pollution. Emissions are in essence, pollution of the atmosphere and the processes that give rise to emissions contribute to waste production. Emissions reduction initiatives work in tandem with circularity initiatives to move towards both decarbonisation and circularity objectives.

Looking specifically at the results for the sector, a summary of key challenges and opportunities are presented below.

Awareness and data: With respect to GHG reporting, the fisheries and aquaculture sectors are typically included within the 'agriculture' aggregated industry. Within the overall aggregation, GHG reporting in the fisheries and aquaculture sector has received limited attention as it relatively small compared to the broader agricultural industry's GHG footprint. There is a low representation in public disclosure of fisheries and aquaculture carbon footprints, due to limited availability of granular data (59).

Opportunities:

- Stakeholder and market demand for carbon footprint disclosure is increasing. Understanding the emissions profile and baseline is necessary before emissions reductions can be initiated. There is an opportunity for the sector to build its measurement and reporting capabilities to better understand the emissions footprint. This is particularly relevant for larger entities that are likely to be subject to mandatory and standardised sustainability reporting requirements in Australia as well as smaller entities that sell to larger entities. This is particularly relevant for climate-related disclosure, with the International Sustainability Standards Board (ISSB) release of the International Financial Reporting Standards Standard 2 Climate-related Disclosure, which will require climate related risk and opportunity disclosure for Australia's larger entities (60).
- Emissions baselining is an opportunity for entities early in their journey to understand their environmental footprint. As part of this, entities will begin to understand the emissions footprint of their supply chain. As the focus on emissions reduction heightens, opportunities to reduce transportation, purchase less equipment, engage in leasing activities and utilise sharing or trading platforms may become more attractive.
- **Bait and fish feed:** The largest emissions contributor to the sector is bait and fish feed. This is due to various factors including (59):
  - High embodied emissions associated with the capture and storage processes of bait, and additives such as soy and grains into fish feed inputs.
  - Based on stakeholder feedback most fish feed and bait is understood to be imported from overseas.

Emissions reduction opportunities will have to consider feed production specifically in addition to wider sector reduction considerations. Given that aquaculture has overtaken wild catch in production volume this challenge is increasingly relevant.

Opportunities:

- Review the sourcing of bait and fish feed ingredients and identify local solutions, to invest in emission reduction for feed production processes. Potential initiatives could include driving collaboration with feed producers to identify low carbon additives, and pathways to reduce synthetic fertiliser use thereby reducing aquaculture feed emissions.
- Bait and fish feed are also one of the greatest organic material inputs into the sector. Opportunities to reduce emissions, should tie in with identifying innovative and efficient bait and fish feed feedstocks to also reduce the material intensity of this input to the sector.
- For any bait or fish feed that is not used or is incorrectly handled, there is the opportunity to divert the waste for use in fertiliser and compost, or into animal feed.

Geographic distances: Australia is a large land mass, and the nature of fishing operations means that they are mainly conducted in remote locations. Access to and availability of physical infrastructure and the need for transport across large distances presents a significant challenge. Transport is required to and from processing facilities, often at great distances, resulting in high transport emissions.

Opportunity:

Establish onshore processing close to main capture points to reduce road miles. The establishment of onshore processing hubs in strategic locations could further contribute to circular objectives as facilities could be shared, particularly relevant to small scale operations. An opportunity lies in the transition to electric vehicle fleets with low GHG emissions profiles and optimisation of transport routes through reverse logistics.

Unique transport requirements: Due to the unique hygiene and odour requirements, fish cannot be transported with other fresh products. As a result, seafood is often transported in dedicated vehicles. These unique transport requirements present both a challenge and opportunity. Transport for fish products can result in low optimisation of transport fleets on delivery and often empty fleets on return.

Opportunity:

- Consider a trial for alternative packaging that could yield for integration of fish into other fresh-product transportation methods, thus reducing the need for dedicated fleets.
- Explore options to diversify cargo on return trips when transporting seafood, outside of fresh produce. This could include seafood packaging materials, improved reverse logistics, reduction of empty food miles, equipment and gear or aquaculture supplies, which can contribute to a more efficient and sustainable supply chain.

Alternative fuels: Fuel emissions comprise a significant portion of the industries total emissions portfolio. Prompted by rising diesel prices alongside a push for climate resilience the industry is already exploring alternative fuels. The current 'Climate Resilient Wild Catch Fisheries' project is focused on three key areas: propulsion systems, onboard fuel storage and alternative fuels. An area of challenge for this transition is the extended time-period the wild catch fishers spend at sea (61).

Opportunity:

- Inshore fishers and aquaculture vessels have the most imminent potential for a shift away from internal combustion to electric vessels. Vessels that conduct day trips only can recharge batteries overnight as electric outboard motors are already readily available in the market. Commercially, electric motors are relatively cost-comparable to existing combustion engines, however the initial upfront cost of batteries currently limits cost parity (61).
- Build capacity in sector to approach green lending to transition, capacity in finance sector to assess F&A related investment.

Electricity: The energy needs for both fisheries and aquaculture are impacted by their location, processing methods, and seasonal demands. These considerations require facility/region specific electricity solutions. Whilst there is significant opportunity for decarbonisation of processing facilities through a transition to use of renewable energy such as solar or wind, the implementation of such systems would likely be high cost (61) (62).

Opportunity:

- Use of waste energy (e.g. converted power capture or heat capture from machinery) and identify opportunities for innovative uses such as the onboard dehydration of bycatch and offal for sale into new markets.
- Regulations related to renewable energy may be required to adapt to accommodate the evolving needs of the sector. There is an opportunity to replace fossil fuel-based powered systems with renewable energy and hybrid electric portfolios, which is increasingly feasible and economical, even in off-grid environments.

Case Study: Austral Fisheries

Austral Fisheries is among Australia's largest fully integrated commercial fishing enterprises, with a focus on harvesting prawns and the Glacier 51 Toothfish, annually they burn over nine million litres of diesel. In 2016, to address this Austral took a pioneering stance in global sustainability within the fisheries and aquaculture sector by committing to carbon emissions offsetting. Austral have been recognised as a forward-thinking company, being early adopters of the Marine Stewardship Council certification.

Source: *Carbon Neutral* (63)

Austral attained carbon-neutral certification through the Australian Government's 'Climate Active' Carbon Neutral Program. To become Climate Active certified, Austral underwent a detailed carbon footprint analysis under the National Carbon Offset Standard. Austral offsets their carbon footprint through Gold Standard credits, generated through the revegetation of Australian farmland (64). Austral plants over 220,000 diverse native species annually, actively sequestering carbon from the atmosphere. They have since planted over one million trees in collaboration with Carbon Neutral Pty Ltd in Western Australia (59).

Circular Strategies

Eliminating pollution

Regenerating Nature

3.3.5 Water

Water volumes in this MFA primarily relate to ice in the wholesale supply chain stage. Ice/water is used in other stages of the supply chain, however due to data limitations, these were not included. Ice plays a critical role in maintaining the quality and freshness of seafood from catch to consumption.

As shown in Table 7 there is approximately 231 $\frac{t_{water}}{t_{fish}}$ in the form of ice, with finfish in wild catch (commercial) using the most water. The variance in water volumes between species is due to market distribution. For example, crustaceans from wild catch are more likely to be in a wholesale environment, whereas crustaceans from an aquaculture source are more likely to go directly to retail market.

Table 7: *Water inputs to production systems by species group.*
Source: FRDC and RCC Analysis

	Crustaceans	Finfish	Molluscs
	Units = $\frac{t_{water}}{t_{fish}}$		
Wild catch (commercial)	204	251	151
Aquaculture	8	238	222

Water plays a crucial role in onshore aquaculture production, where it is used in substantial quantities. This usage predominantly takes place through two distinct methods: flow-through facilities and recirculating aquaculture systems. In adherence to stringent regulatory requirements, water employed in these systems undergoes treatment before being released back into the environment. Recirculating aquaculture systems are typically more water efficient as they demand significantly lower water input, due to their continuous water reuse process (65).

To increase water circularity for the sector there are several considerations:

- Using closed-loop refrigeration systems on fishing vessels and in cold storage facilities can help maintain a consistent temperature and reduce demand on ice.
- Innovative refrigeration solutions, such as those being trialled by EverCase, use an electric field and adds an applied magnetic field, leading to the rearrangement of water molecules to freeze product without ice crystals ever forming (66).
- Innovative packaging solutions can minimise the need for excessive ice while keeping seafood products cold during transport.
- Ice production is energy intensive. Opportunities to use energy-efficient ice making equipment can also help reduce the sector's electricity consumption and reduce emissions.
- Implementing advanced systems to treat and recycle within closed loop aquaculture systems can reduce the need for large water inputs and minimise effluent discharge.
- Rainwater can supplement freshwater requirements and reduce demand on other water sources. Rainwater harvesting can be used for various applications in aquaculture, such as pond replenishment or cleaning.
- Reduce water requirements through multitrophic, closed loop systems. Marine Garden is an indoor prawn farming enterprise using recirculating aquaculture systems through specialised filtration systems There is the opportunity to use waste produced by the prawns as nutrient dense fertiliser, while the remaining filtered ocean water can be fed back into the aquaculture process creating a closed loop water system (67).

3.4 Recreational fishing

Recreational wild catch fishing includes leisure activity where individuals or groups catch fish for enjoyment and not for commercial or primary sustenance purposes. The recreational fishing sector in Australia is the largest and most widespread recreational activity that uses a natural resource (68).

Opportunities to create a positive circular impact could include enhancing the understanding of circularity among recreational fishers through educational programs, as well as by updating the Code of Conduct to include circularity. Additionally, efforts to reduce litter from fishing activities, and improvements in the procurement and design of fishing gear and tackle can further contribute to these initiatives. Recreational material usage is included in the quantification of each material's specific deep dives above and is analysed qualitatively here given the unique challenges and opportunities that are distinct from commercial wild catch and aquaculture.

Recreational fishing is responsible for 3.15% of total material consumption, excluding fuel. It should be noted fuel usage has been excluded for recreational fishing as data relating solely to fuel usage was not available. GDP values for on the boat expenses is available, however this cannot be directly attributed to fuel usage, as illustrated in the overall sector distribution of materials in Figure 9. Figure 28 below illustrates the high-level physical material flows for the recreational sector.

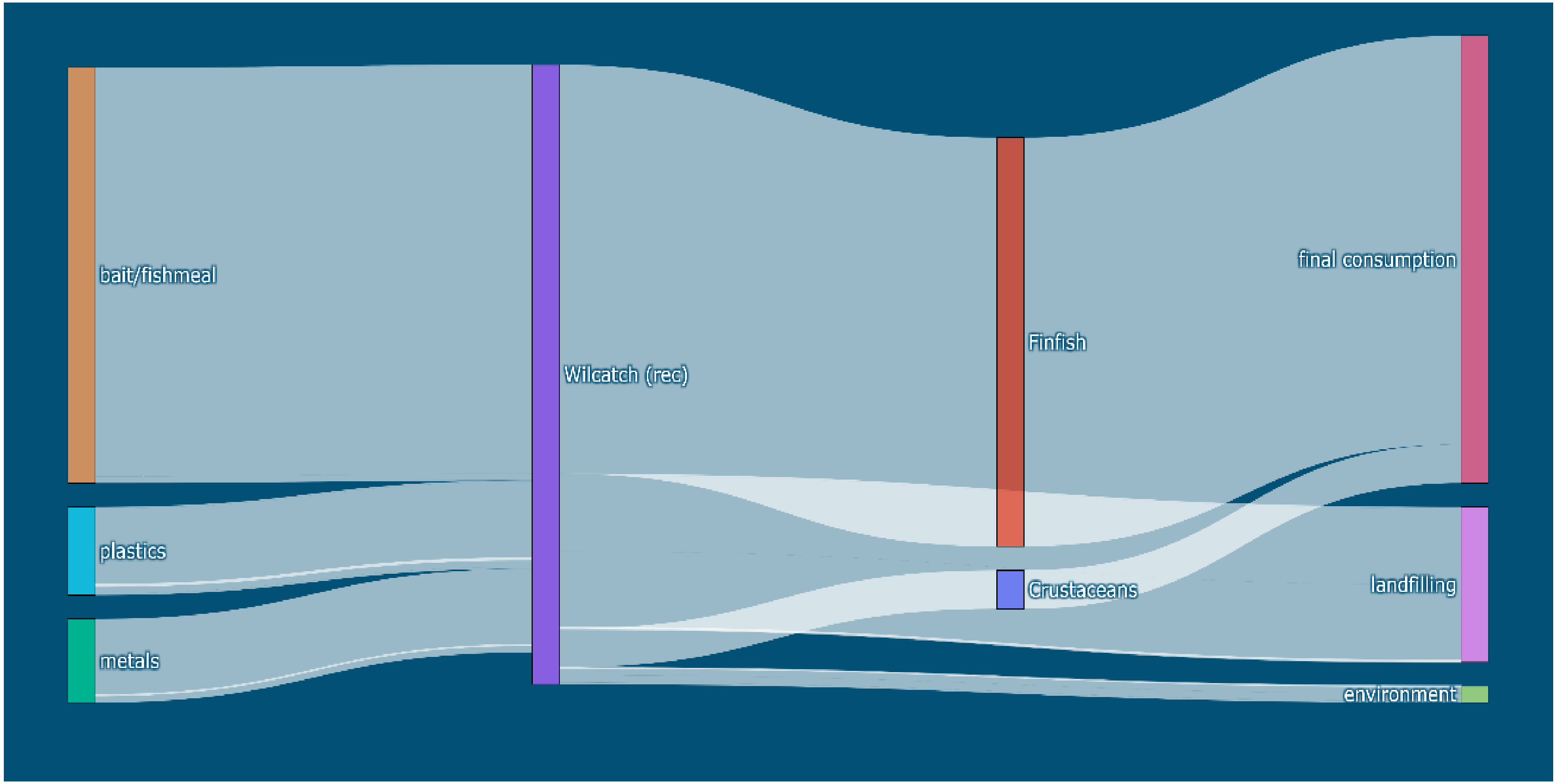

Figure 28: *Wild catch (recreational) – material inputs (excluding water, chemicals and GHG emissions) to end fates.*
Note: Units are in absolute terms in tonnes, and the analysis period is one year
Source: FRDC and RCC Analysis

On the left-hand side of the wild catch (recreational) Sankey diagram (Figure 28), inputs have been grouped under broad input material categories: bait and fish feed, plastics, and metals. For the wild catch sub-sector, bait and fish feed represents the largest quantified input (in tonnes).

Unlike the wild catch (commercial) and aquaculture Sankey diagrams, the supply chain stage is not represented here. Seafood caught is assumed to go straight from catch to consumption (i.e. t_{fish}).

All material usage (plastics and metals) is due to the use of fishing equipment and gear, such as rods, reels, lines, traps and nets. Fishing equipment and gear is either lost to the environment or sent to landfill. The majority of fish caught by this sub-sector is finfish (90%) and the remainder is comprised of crustaceans capture. Due to caught fish being classed as the final product in this sub-sector, there are no organic losses included due to processing of the seafood, although they would certainly occur.

While vessels are a significant contributor to material use in the Recreation sector, vessel construction was excluded from the system boundary scope due to vessel's relatively long lifespans and lack of available data related to material composition and end fates of vessels.

3.4.1 Key challenges and opportunities

There is an inherent challenge in quantifying, analysing, and identifying interventions for a sector made up of diverse individuals employing a multitude of different fishing practices, and preferred catch species, without consistent data collection. Material-specific discussions are provided for 3.3.1 Bait and fish feed and plastics and packaging (3.3.2 Plastics and Packaging).

More broadly, and based on the limited available data and recreational industry stakeholder consultations, the following key findings are noted:

Limited recycling infrastructure and collection systems: There are no large-scale recycling infrastructure or collection systems for recycling of recreational fishing gear. Additionally, recreational fishing gear, which can include rods, reels, nets and traps, are often not designed to be recycled, and can often be contaminated with organic matter. Therefore, unless specific product stewardship or take back schemes are adopted to increase collection avenues, opportunities for resource recovery of fishing gear and tackle, will rely on the traditional household waste and recycling systems, such as dropping off at local transfer stations.

Opportunity:

- There is a significant opportunity to design recreational fishing industry product stewardship schemes, such as those adopted for other problem materials such as batteries, tyres and agricultural silage wrap. This would create cleaner streams of material, aggregating recreational fishing gear equipment. The Rig Recycle Program (see case study below) is an example which could be scaled for further impact.
- With clean aggregated streams of recycled content, industry can consider opportunities to partner with the recycling sector to identify potential infrastructure required to recover valuable material from used gear.

Circular design of gear: Whilst gear, such as rods, typically have a multi-year life expectancy (high quality rods have a useful life of approximately 10 years, with lower quality rods expected to last approximately 1-3 years), the additional gear used, such as hooks and tackle, have a shorter lifespan. This means that some gear is purchased regularly to replace worn out or lost gear. A key design choice that can enhance the circularity of fishing gear involves reducing the diversity of materials and minimising the use of mixed materials (69). Mixed materials refer to the blending of various materials, polymers, and components in the construction of a product. Mixed materials hinder the feasibility of recycling, given that current recycling infrastructure only supports a limited number of material streams. This is due to the complexity and expenses involved in separating materials into their respective groups. As a result of this complexity, mixed materials are often landfilled.

Reducing mixed materials in gear and / or standardising the materials used in gear, will enable greater recovery rates. Similarly, reducing virgin material, non-recyclable and hazardous material use in gear design can help elevate circularity of the gear. This approach maximises the volume of material that can be recovered and recycled at the gear's end-of-life state and reduces pre-processing costs.

Opportunity:

- A key opportunity exists for recreational fishing gear and equipment manufacturers to embrace circular procurement. This can include using recycled and biobased materials to produce fishing gear and equipment. For example, Alternative Fishing Lures creates hard fishing lures from 100% recycled ocean plastic as well as biodegradable soft lures made from 100% recycled material (70).
- The industry could consider standardising materials in gear and equipment, working with all manufacturers to create consistency and enabling greater recycling rates. This could lead to a manufacturer driven product stewardship scheme.
- For less frequent recreational fishers, there is an opportunity to expand the presence of product as a service. Fishing gear rentals are an existing service around Australia that enables fishers to rent gear as opposed to buying new, which will likely be used a few times then discarded. This enables rental shop owners to retain ownership of fishing gear, giving them incentive to care for, repair and reuse their gear.

Plastic usage: Plastic use across recreational fishing includes plastic bait packaging, fishing line and lures. As with commercial fishing, plastic is used in the recreational fishing sector for its longevity and low cost. Note that packaging from the recreational sector was not modelled due to limitations. See 3.3.2 Plastics and Packaging for more detailed information on the plastic sources for the recreational sector.

Opportunity:

- Industry stakeholders noted the rise of 'biodegradable' lures and lines promoted as eco-friendly angling which can have a lower impact on the environment. However, some of these claims do not specify the timeframe or necessary environmental conditions for the material to break down, which are key features that enable a material to biodegrade. To avoid misleading consumers, claims of biodegradability should be accompanied by this information and certified by third party testing.
- Globally, TÜV Austria has developed two certifications (OK biodegradable MARINE and OK biodegradable WATER). These certifications verify the claim of biodegradability of materials or products in the marine environment. Certifications systems are critical for providing rigidity and validity to circularity claims. They ensure there is a benchmark, and 'eco-friendly' claims, meet set requirements.

Embedding circularity in the fishing Code of Conduct: Consultation with stakeholders indicated that the current national fishing Code of Conduct is outdated. The national fishing code of conduct is a voluntary living document, funded with the support of the Australian Government, and owned by the Australian Recreational Fishing Foundation. State based Codes of Conduct exist and vary in complexity and content. For instance, the Northern

Territory code of conduct is brief with only five key points: three pertaining to respect of Traditional Owners, and the other two relating to crocodile safety and general safety standards (71). Conversely, the Queensland Recreational Fishing Rules (equivalent to a Code of Conduct) includes detailed restrictions and limitations relating to fishing gear used, size and possession limits of catch, shark safety, invasive species and more (72).

Opportunity:

- There is an opportunity to update to the Code of Conduct to integrate circularity. This could be through expansion of the current stewardship pillar to focus on the whole life cycle of fishing, considering the equipment and materials used and not just the act of fishing itself.
- **Awareness of circularity through education programs:** Key to shifting cultural recreational practices and values is education. The knowledge of circular economy benefits in Australia for the recreational fishing sector is emerging. Gaps in circularity awareness limit the capability of entities and individual's willingness to embrace circular initiatives. The recreational fishing community is comprised of a diverse range of individuals with varying levels of experience, interests, languages, cultural practices, and values; thus, consideration should be taken to ensure education initiatives are appropriately tailored for varying audiences.

Opportunity:

- There are education opportunities that could be implemented, particularly within schools to encourage sustainable fishing, through expansion of programs such as 'Let's Fish' (73), which can be leveraged to inform gear care and other circular practices to extend a product's useful life.
- All education campaigns should ideally be supported with data collection and analysis to enable measurement of outcomes. In the long term, efficacy of educational programs may also present evidence of the positive environmental impact of circular fishing practices.

Case Study: Fishing Gear Product Stewardship

The 'Rig Recycle Program' (58), offers a circular solution for recreational fishing gear. The program is premised on collecting unwanted recreational fishing gear and packaging in designated Rig Recycle bins located in fishing gear and tackle stores. The waste collected is diverted from landfill. There are multiple stakeholders involved in the initiative. Tangaroa Blue collaborated with OzFish Unlimited to develop the Rig Recycle Program, as part of their ReefClean initiative. Recreational fishing gear supplier Shimano also partnered with Tangaroa Blue to produce their 'Tackle Back' product, similar to the Rig Recycle program that aims to promote anglers to dispose of their fishing waste responsibly by bringing fishing gear and tackle back to stores at end of life.

The Rig Recycle Program's first priority for disposed gear is repair and reuse. Gear such as handline reels, hard plastic lures, sinkers, and hooks are repaired if possible, and donated to social fishing charities, giving gear that would otherwise be discarded, a second life. Discarded gear such as fishing line and spools are recycled into plastic feedstock, enabling waste to be fed back into supply chains consequently reducing the use of virgin plastic. In addition to reusing and recycling discarded fishing gear the Rig Recycle Program audits all items collected in Rig Recycle bins, entering the data into the Australian Marine Debris Initiative Database.

Source: *Tangaroa Blue* (58)

The pilot programs consisted of Rig Recycle bins being placed in 12 different Boating, Camping, Fishing stores across Queensland, where anglers were able to dispose of old hooks, sinkers, lures, swivels, gloats, line and line spools to be recycled or repaired. As of May 2023, there are 60 Rig Recycling bins across Victoria, 40 bins across NSW, funded by Sustainability Victoria and the NSW Recreational Fishing Trust. Tangaroa Blue collaborates with various recreational supply chain providers. The bins draw in additional business as recreational fishers have the opportunity to purchase new gear from the stores they visit to recycle their old gear.

Circular Strategies

Product Stewardship | **Redesign & procurement** | **Recycling and Composting**

3.5 Indigenous fishing

Fishing is an important part of the cultural and economic life for Indigenous communities. Fishing and access to the many and varied water resources is a critical element of the relationship between Indigenous people and country.

In the management of country and water, Indigenous peoples hold rights for various fishing practices. These include the right to maintain and develop cultural practices to address spiritual, cultural, social and economic needs, and the right to determine courses of action in relation to use and management of aquatic biological resources. The Fisheries Management Act 1994 (the Act) aims "*to recognise the spiritual, social and customary significance to*

Aboriginal persons of fisheries resources and to protect and promote the continuation of Aboriginal cultural fishing.” (74) Aboriginal fishing encompasses a range of activities including both cultural and commercial practices.

Cultural fishing: Indigenous cultural fishing is defined in the Act as “*fishing activities and practices carried out by Aboriginal persons for the purpose of satisfying their personal, domestic or communal needs, or for educational or ceremonial purposes or other traditional purposes, and which do not have a commercial purpose*” (74). Cultural fishing can involve a small number of people fishing on behalf of many and in ways that are not recognised as permitted activities under existing fishing rules.

Commercial fishing: Indigenous commercial fishing falls within the governance of the wider sector and is not accounted for separately. Commercial fishing provides a source of employment and economic opportunity for Indigenous communities. Indigenous fishers hold varying views on the nexus of commercial fishing and cultural fishing. Some Indigenous fishers feel that they are always culturally fishing, while others feel there is a distinction between commercial and cultural fishing.

Traditional practices / provisions: Across Australia, First Nations communities have developed specialised tools and methods for fishing, which vary region to region (75). Generally, traditional practices involve beach and shallow pool fishing alongside digging for shellfish. For smaller scale fishing, rockpools are utilised as tidal fish traps, and at a larger scale stone weirs are designed to trap fish in shallow lagoons (76). For example, the Maningrida people use basket traps for river and creek fishing and the Murruŋga people still utilise fish traps made of twined pandanus leaves (76). In modern practices nylon nets are utilised, the same weaving techniques can be used for nylon as was previously used for natural fibres. Traditional practice is based on knowing where and when to fish, described by the Yolŋu people as seasonal knowledge (76). In Indigenous communities cultural fishing rules are dispersed orally through generations, resting on the key tenet of “take only what you need”. Natural resources, such as fish, are traditionally monitored through clan law and collected sustainably in order to ensure the future availability of the resource (76).

Indigenous knowledge: There is an opportunity to learn from Indigenous practices in the transition to a circular economy. Examples of this include:

- Seasonal calendars, a cornerstone of Indigenous wisdom, mirror the cyclical nature of resource utilisation and preservation, ensuring that harvesting aligns with natural abundance and regeneration.
- The concept of totems, which embody a deep spiritual connection to specific species, promote respect and sustainable management, akin to the circular economy's emphasis on responsible resource allocation.
- The notion of 'Caring for Country' embodies a holistic approach, where custodianship of the land and waters transcends generations. This sentiment harmonises seamlessly with the principles of circular economy, emphasising the intergenerational responsibility of stewarding resources for long-term prosperity.

By integrating these Indigenous practices, this can further support a sustainable future for the fisheries and aquaculture sector that respects both the environment and the cultural heritage of Indigenous communities.

Case Study: Recycling Fishing Gear

The Bowraville recycling project in NSW focuses on the recycling of discarded fishing gear (primarily oyster barrels) into plastic feed pellets (77). This project is one of many under the Sea Country Ranger program, which aims to increase the participation of Indigenous people in the environmental management of Sea Country. This is achieved by providing Indigenous communities with training related to land and sea management and activities such as marine debris removal and rehabilitation of coastal and marine habitats.

The Bowraville recycling project is run by a Gumbaynggirr man and his team of MiiMi Rangers. Together they collect oyster barrels, tuna longlines, fishing nets and plastic bottles washed up in the Nambucca River. The discarded fishing equipment is taken to Bowraville Recycling Facility to be cleaned and broken down in a granulator. The plastic granules are then sent to Port Macquarie to be turned into plastic pellets which are sold to local manufacturers to be turned into recycled plastic items such as park benches and bollards. This project enables waste to be fed back into the supply chain, reduces the use of virgin plastic, removes discarded fishing gear from polluting the natural environment and provides a viable income for four individuals.

Engaging Indigenous communities in projects which provide opportunities to care for their Country has a positive impact on both the individuals involved and the environmental outcomes.
MiiMi ranger Zac Stadhams stated that:

"There is a self-pride about this job. Just being a young Indigenous man giving back to this Country…It's been satisfying to clean the Country back up. I just want to see my Country beautiful again".

Source: *NSW Marine Estate* (77)

The inclusion of Indigenous communities in these projects supports the protection the Indigenous cultural values of the marine estate.

Circular Strategies

Eliminating pollution | **Redesign & procurement** | **Recycling and Composting**

Case Study: Regenerating Nature through Seaweed Farming

South Coast Seaweed is an organisation committed to using traditional knowledge and harvesting methods to produce sustainable products from sea kelp harvested along the South Coast of NSW. South Coast Seaweed's main product is seaweed flakes for tea, lotion, soap and gardening. Additionally, South Coast Seaweed host cultural eco-tours that focus on sharing indigenous knowledge and advocating for the vital role seaweed plays in marine ecosystems and habitat restoration. They emphasise the indigenous principle of taking only what is necessary and leaving resources for future generations, a principle that aligns with the circular strategy of regenerating nature (78).

Source: *South Coast Seaweed* (78)

Around half of global CO_2 fixation occurs in the oceans. Seaweed farming is an emerging sector in aquaculture, with potential for scaling due to its wide array of uses. Seaweed can be used in food products, healthcare supplements, skincare products, textiles, bioplastics, and fertilizer.

Additionally, seaweed is increasingly being recognised for its contribution to inshore and offshore carbon sinks *(79)*.

Circular Strategies

Regenerating Nature

4 Sector-wide barriers to adopting a circular economy

While there is significant enthusiasm and current mainstreaming of the circular economy, there are real and perceived challenges that prevent greater adoption of circular practices in the fisheries and aquaculture sector. This section outlines sector wide barriers, irrespective of material type, that constrain the transition to greater circularity for fisheries and aquaculture. Barriers were developed based on insights from industry stakeholder workshops.

4.1 Data, policy and regulation

Industry stakeholders identified policy and regulatory hurdles inhibiting the uptake of circular economy initiatives across the supply chain.

Coordination across government: Industry stakeholders noted that circular economy initiatives are not well coordinated across government departments. This was found to hinder approval processes and stall progress on circular initiatives. For example, in Victoria, fisheries are managed by the independent Victorian Fisheries Authority, and the Minister responsible for fisheries in Victoria is the Minister for Outdoor Recreation, with the Department of Transport responsible for coordination and strategic policy– creating a disconnect with circular economy activities undertaken by the Department of Environment, Energy and Climate Action.

Disparities in circular economy incentives and programs across all levels of government further contributes to this issue. A report on Australia's Circularity (80) found varying levels of circular economy planning among local governments:

- only 3 out of 100 surveyed marked that they had fully implemented (the concept is central to the department),
- 31 had somewhat implemented (incorporated some aspects),
- and 65 were in the early stages (considering and not yet implemented)

Industry expressed concern regarding the time-consuming regulatory approvals and requirements, deterring businesses from non-standard activities, and potentially stifling innovation.

Biosecurity regulation: Biosecurity regulation was also identified as a hurdle to achieving circular outcomes in some instances. Industry pointed out that disposal requirements for items used offshore hinder exploration of potential recovery options. The Quarantine Regulations 2000 defines quarantine waste as:

- material used to pack or stabilise cargo
- galley and food waste human
- animal or plant waste (e.g. sewage, ***animal by-products,*** soil and plant by-products)
- refuse or sweepings from the holds or decks of a vessel or installation.

The treatment procedures and facilities used for the destruction of quarantine waste are the same regardless of waste source. Approved treatments for quarantine waste are limited to linear disposal methods and include deep burial, autoclave, high temperature incineration, chemical treatments, irradiation and export (81). Regulation inhibiting the reuse of animal by-products from fishing activity was particularly frustrating as industry saw ample opportunity for the resources to be utilised as bait or in feed. Industry have identified that there is an opportunity to review biosecurity rules and regulations with a more holistic approach to ensure that biosecurity risks were weighed up with environmental impacts and related risks.

4.2 Time, resources and collaboration

Time & Education: The knowledge of circular economy models, principles, and practices among businesses and customers is steadily emerging in Australia. However, gaps in circular awareness still limit innovation. The uptake of circular economy in the fisheries and aquaculture sector is further challenged by limited knowledge as a well as a lack of time or resources. Some industry stakeholders expressed the view that the pursuit of circular economy/sustainability initiatives is a privilege reserved for larger organisations. The time and resources needed to implement initiatives can be substantial, especially for small-scale fishers and aquaculture operators who already operate under tight budgets and schedules. Addressing these barriers through education, training, and the provision of necessary resources is essential to promoting circular collaboration and practices.

Collaboration & Resource Sharing: Embracing circular economy will require extensive collaboration. The sharing of resources and the adoption of standardised designs to optimise recovery efforts facilitated by well-connected networks, becomes essential. However, within this industry, competition is deeply ingrained. Collaboration does not always come easily. Overcoming these competitive barriers and fostering a collaborative ecosystem presents a key challenge.

Limited Knowledge Transfer: Many stakeholders shared the innovative solutions they tested and discovered. However, industry stakeholders expressed concern that, most entities tend to keep these findings within their own organisation, for competitive edge. This lack of knowledge sharing can lead to redundant efforts being undertaken within the sector. An example of this is research into alternatives to polystyrene boxes. While various entities noted that they are experimenting with substitutes, many have found the alternatives unsuitable for industry. These findings have not been disseminated to the wider community, resulting in unnecessary replication of research efforts.

4.3 Economic impacts

Lack of procurement drivers: Industry stakeholders noted that traditional procurement practices in the sector prioritise cost-efficiency and short-term gains with limited motivation for businesses to invest in circular procurement. Without proper procurement incentives, which could include preferential treatment for suppliers embracing circularity or penalties for those perpetuating wasteful practices, the industry will likely continue to prioritise cost in procurement decisions. Circular procurement strategies can include prioritising product as a service models or products with take-back schemes, products manufactured with renewable or recycled material and designed for durability, repairability and recycling. Without market demand for circular solutions, these offerings will struggle to establish a commercially viable market presence.

Costly alternatives: Leading on from procurement, it is important to acknowledge that circular alternatives within the fisheries and aquaculture sector can often be costly. These alternatives may involve investments in new technologies, infrastructure, or changes in operational practices that can incur higher upfront expenses. In an industry where profit margins are often tight and competition is fierce, the immediate financial burden of transitioning to circular practices can deter businesses from taking the necessary steps. For example, significant electricity costs (associated with the storing of organic waste until appropriate volume is reached for reprocessing) made the initiative commercially unfeasible.

Markets: Another barrier hindering the adoption of a circular economy in the fisheries and aquaculture sector is the absence of markets for by-products and waste streams. In a circular system, waste materials are repurposed or reintegrated into new products or processes, reducing overall waste generation. However, the current limited demand for such by-products, and recycled content can make it financially unfeasible for businesses to invest in the infrastructure and processes required for their efficient utilisation. Creating markets for these by-products through increased consumer awareness, innovative product development, and regulatory and procurement incentives is essential. Establishing a market for these materials not only reduces waste but also creates economic opportunities and encourages the industry to explore more circular approaches to their operations and procurement decisions.

4.4 End-of-life management

End-of-life management for gear and equipment, packaging and organics poses one of the most complex challenges for the fisheries and aquaculture sector and was one of the most frequently cited challenges by stakeholders.

Material recyclability: There are several challenges that impact on the recyclability of gear and equipment used within the fisheries and aquaculture sector, including:

- Large and irregular shapes and sizes of gear and equipment can be uneconomical to transport and often requires specialised equipment for recycling (e.g. rope shredders or chainsaws).
- Mixed materials requiring separation which can be time consuming and often unachievable.
- Biofouling (the accumulation of marine organisms on gear and equipment) requires extensive cleaning pre-recycling. This additional and time-consuming step, combined with limited subsequent end of life applications due to health and safety requirements, reduces the economic viability. Current recovery solutions are not fully circular, with a tendency towards recycling into less valuable materials or incineration rather than recycling to an equivalent value.

Access to infrastructure: Where recovery solutions do exist, it was highlighted that at a national level there is limited infrastructure. There are fragmented examples of solutions being deployed which have either been integrated within larger companies or alternatively facilitated at a local level in sparce locations. There is a need for research and co-ordination across the sector to understand the solutions and infrastructure that are viable, taking into consideration geographies, collection, and transport.

Design for circularity: Historically little consideration is taken for end-of-life when designing products used within the sector as priorities are focused on functional performance. In recent years, there has been an increased focus on end-of-life considerations in packaging, specifically problematic plastics such as polystyrene and soft plastics. Motivated stakeholders within the industry are researching alternatives for these while simultaneously searching for viable end-of-life solutions, however there is no co-ordinated approach and often the majority of products are purchased from overseas. Designing for circularity can be complicated for Australian divisions of large multi-national companies, when Australia only represents a small share of their market.

5 Potential Circular Interventions

Transitioning to a circular economy presents a promising pathway to address increasing environmental challenges, resource constraints and consumer expectations while enhancing economic resilience.

This chapter provides a summary of potential interventions, based on the areas of lost value as identified in the MFA results (Table 8). Alongside the findings, the table identifies material-specific interventions as well as:

- The sector and supply chain stage that the intervention focusses on (target area)
- The relevant circular strategies for each potential intervention
- The estimated high-level potential 'cost' to implement:
    - This is a high-level indicator of the net commercial impact associated with the intervention ($$$ = high cost, $$ = medium cost and $= low cost).
    - The high-level potential 'cost' to implement is based on an assessment of a range of factors such as effort to implement (sector wide versus at company level), and implementation timeframe (short-term versus long-term).

Table 8: *Summary of prioritised interventions based on the MFA results to enhance circularity in the sector*

Priority area	Key findings	Target area	Potential interventions	Circular Strategy	Cost
Bait and fish feed	Bait and fish feed form the most significant input into the sector at 47.26% of total material inputs. Bait and fish feed form 99% of total organic input into the sector. Fish feed usage, particularly for salmon in open pen sea cage and prawns in earthen pond are likely to be areas for improved material efficiencies.	Aquaculture - Production	**Alternative sources** Investigate alternative baits or protein sources from sustainable sources. Conduct a detailed study into bait and fish feed sourcing, local solutions and research and development to provide higher value nutrients while using less and/or identify current waste streams as potential sources for bait and fish feed.	**Redesign and procurement** **Eliminating pollution** **Regenerating nature**	$$$
		Wild catch (commercial) – Production Wild catch (recreational)	**Storage and shelf life** Guidance and greater awareness on best practice handling of bait to ensure storage and extended shelf life. Continued improvements in best practices including storage and transport technologies.	**Eliminating pollution** **Extending lifespan**	$
Decarbonisation	The most significant end fate of the sector is emissions. Emissions constitutes 85% of total tonnes of total material end fate. The four highest contributors to emissions were: Bait and fish feed contribute 35% of the sectors total emissions, Emissions from fuel for vessels and generators contributes 23% of total emissions. Electricity contributes 22% of total emissions. Fuel for transport contributes to 14% of total emissions.	Aquaculture - Production	**Reduce bait and fish feed carbon footprint** Review the key suppliers and current bait and fish feed emissions profile. Identify strategies to reduce energy requirements, e.g. decentralised local production to reduce transport emissions and reliance on imports.	**Redesign and procurement** **Eliminating pollution** **Regenerating nature**	$$
		Aquaculture – Production Wild catch – Production	**Electrification and alternative fuels** Investigate, particularly for inshore and close to shore vessels, how feasibility of electric vessels can be expanded or encouraged. Investigate feasibility and conduct horizon scan of alternative fuels.	**Eliminating pollution**	$$$
		Aquaculture – Production	**Energy rebates**		$$$

Priority area	Key findings	Target area	Potential interventions	Circular Strategy	Cost
		Wild catch – Production, Processing	Funding to support renewable energy adoption by entities and further work to understand the regulatory implications of entities becoming 'energy producers' and removal of any related barriers.	**Eliminating pollution**	
Effluent discharge	Effluent forms 41% (67,290 tonnes) of total organic waste by the sector and is generated in aquaculture production and is assumed to be lost to environment. Effluent is directly related to the amount of seafood grown by the respective sub-sector.	Aquaculture – Production	**Circular effluent options** Investigate opportunities to utilise effluent in polyculture activities (where two or more species are produced in the same place). Further understand the costs and benefits of commercialising these opportunities.	**Regenerating nature** **Eliminating pollution** **Value from waste**	$$
Offal	Offal is responsible for approximately 48% (78,549 tonnes) of total organic waste generated by the sector. Of this, 21% is generated in the wholesale/retail stage, while 79% is generated by processing. The overall recovery rate of offal is estimated at 42%. Given the volume generated, this highlights that there is significant opportunity to recover the remaining 58% which is assumed to be landfilled.	Processing Wholesale / retail	**Aggregate and process organic waste** Provide funding for local partnerships (e.g. markets, regional areas) to aggregate volumes and develop composting or co-digestion solutions. Support navigation of regulatory barriers and licensing for small-scale solutions. Facilitate trading between offal producers and local organic waste feedstock providers.	**Value from waste** **Sharing and trading** **Recycling and composting**	$$
		Processing Wholesale / retail	**Foster organic waste innovation** Support piloting and commercialisation of conversion of seafood processing waste into commercial products such as fish bait, animal feed, textiles or as a raw material for instance to produce cholesterol, lipids and proteins.	**Value from waste**	$$

Priority area	Key findings	Target area	Potential interventions	Circular Strategy	Cost
Fishing gear & equipment	69% of plastics inputs are from gear and equipment used in production. • This is mostly made up of aquaculture and wild catch (recreational) gear. • This is predominantly coming from feedbags, baskets, floats, followed by nets, ropes and lines.	Aquaculture – production Wild catch (commercial)	**Standardisation and circular design** Research and development to standardise materials in gear and equipment and reduce use of mixed materials. This should prioritise design for durability and repairability. Identify ways to increase the use of recycled and biobased materials in procurement.	**Redesign and procurement** **Eliminating pollution** **Extending lifespan** **Value from waste**	$$$
		Wild catch (recreational and commercial)	**Product stewardship** Establish and scale up product stewardship schemes (for example, the Rig Recycle Program) and work with industry, government, and consumers to develop long-term scheme solutions. Partner with the recycling sector to identify material recovery gaps and consider localised solutions.	**Product stewardship** **Recycling and composting** **Sharing and trading**	$$$
		Wild catch (recreational)	**Expand gear rental services** Consider opportunities to expand rentals (product as a service model) and facilitate sharing of gear. Fishing gear rentals are an existing service around Australia that enables infrequent fishers to rent gear as opposed to buying new gear. Sharing could also be explored through the creation of a gear sharing platform.	**Product as a service** **Sharing and trading**	$$

Priority area	Key findings	Target area	Potential interventions	Circular Strategy	Cost
Packaging	Plastics forms 54% of the physical (excluding bait and fish feed, chemicals/water and emissions related inputs) flows into the sector. • 31% of plastics inputs are from packaging in wholesale/retail. • The majority of this is from EPS, followed by paper and cardboard. • A smaller quantity of packaging is for fish crates and primary packaging.	Processing, wholesale & retail	**APCO alignment** Align with APCO's targets (6) and commit to 100% reusable, recyclable, or compostable packaging. Identify and redesign problematic packaging across the supply chain following APCO's guidelines (7) and prioritise reusable models.	**Redesign and procurement** **Extending lifespan** **Sharing and trading** **Recycling and composting**	$$

6 Potential Circular Enablers

To support the transition to a circular economy for the fisheries and aquaculture sector, eight potential enablers have been documented below to prioritise sector-wide action, bringing together the specific findings from the MFA, with timeframes, and roles and responsibilities. Theses enablers address some of the key barriers as determined through stakeholder workshops and the MFA process.

Underpinning these enablers is the importance of collaboration and knowledge sharing across different sectors to collectively explore and develop solutions to avoid duplication of efforts. Any actions taken in pursuit of a circular economy should be firmly rooted in data-driven decision-making and systems-thinking to prevent any unintended flow on effects or the pushing of responsibility downstream. The economic viability of initiatives must also be considered.

6.1 Policy levers and Government engagement

Priority: High
Timeframe: Short to medium term
Stakeholders: Government at federal and state levels, cross departmental, peak bodies, and fisheries and aquaculture sector.

Industry stakeholders noted that currently there is limited direct government involvement in the efforts of the fisheries and aquaculture sectors efforts to transition towards a circular economy. Government policies and enabling regulations are critical in accelerating the transition. Government could play a greater role to support the sector comply with regulations, while fostering innovation and research and development and collaboration, for example, through evaluating how existing regulations, such as biosecurity laws, interact with or can be adapted to facilitate a circular economy.

The perception of the industry stakeholders engaged was that there can be a disconnect between the circular economy activities of the Government and fisheries and aquaculture policy, which can be partly attributed to the division of responsibilities among various government departments. For instance, in Victoria, fisheries are managed by the independent Victorian Fisheries Authority, and the Minister responsible for fisheries in Victoria is the Minister for Outdoor Recreation, with the Department of Transport responsible for coordination and strategic policy. This leaves a potential disconnect with the circular economy policy work which is administered through the Department of Environment, Energy and Climate Action.

The *National Fisheries Plan 2022-2030,* already commits to Sustainability as one of nine sector priorities, and a number of initiatives (82). Some of these initiatives already complement work that would be required to advance a circular economy, such as Initiative 2.3, which involves supporting projects to protect, enhance and sustain healthy aquatic ecosystems, through means such as restoration projects, adaptive stocking strategies and artificial reef programs. However, certain initiatives such as Initiative 2.4 in the Plan, centring on implementing systems and building capacity to manage biodiversity threats, does not fully recognise the imperative of supporting a sector seeking new opportunities for organic reprocessing and recycling.

Additionally, policies can have cascading effects that can influence and impact the fisheries and aquaculture sector. For example, the growing momentum into 'right to repair', could see legislation that provides consumers with practical means to repair and modify products to keep them in use for longer. While not specifically targeting the fisheries and aquaculture sector, such policy interventions have the potential to bring circularity design practices for gear and equipment manufacturers to the forefront.

There is an opportunity for FRDC to collaborate with government and consult with the sector to map and categorise the various specific regulatory and economic obstacles and gaps that are creating barriers for industry to easily adopt circular practices. This could help develop a stronger narrative of the problems the sector is facing and inform development of policy proposals for specific levers (such as subsidies, guidelines, and / or bans).

6.2 Funding accessibility

Priority: High
Timeframe: Short to long term
Stakeholders: Government, industry associations, research institutions, private sector

Government and industry associations should continue to allocate resources to support research, innovation, and infrastructure development. Industry stakeholders emphasised the importance of improved funding opportunities, particularly for small to medium enterprises. Currently, there is a lack of small grants (less than AU$100,000) that would enable them to innovate, experiment with new approaches, or scale up gradually (16). This is particularly important, considering the diverse range and scale of organisations that operate in the sector. There are many smaller, local fishing organisations that would struggle to implement initiatives on their own. The Circular Economy Business Support Fund, established by the Circular Economy Business Innovation Centre (CEBIC), by the Victorian Government, is one example of how a funding program could be designed to support research and development and scaling up commercial opportunities.

Another key funding opportunity lies in developing a product stewardship scheme. As highlighted in 3.3.2 Plastics and Packaging there are limited reprocessing infrastructure and systems to capture used gear and material. Product stewardship, or take-back, is a core circular strategy. There are already successful schemes set up, such as the Rig Recycle scheme (58), and numerous other initiatives for difficult to recycle materials, such as batteries and paint, which can be considered for lessons learnt and approaches to inform one for the fisheries and aquaculture sector. Product stewardship initiatives can be scaled to suit the needs of the region; hence funding could be available for smaller scale recreational initiatives, or larger scale sector-based stewardship.

6.3 Centralised coordinating bodies

Priority: Medium to High
Timeframe: Short term
Stakeholders: System-wide representation

To structure the transition to a circular economy within the industry a sector-wide coordination body ought to be appointed. This formal governance body would oversee the implementation of circular initiatives and provide guidance on priority actions. A governing body provides oversight and will maintain a forward-looking view, supporting stakeholders and monitoring the effectiveness of transition strategies.

Further support of the transition will be derived from working groups, or round tables, established to address specific circular economy challenges at different geographic scales. A community of practice style model that includes regular dialogue with players from all over at multiple regional specific scales. Key areas identified through this MFA could be areas of focus for these working groups – bait and fish feed consumption, alternative fuel, end-of-life equipment and packaging. Working groups could also be established to focus on the key sector-wide barriers identified in adopting a circular economy (see 4. Sector-wide barriers to adopting a Cicular Economy). Groups could be facilitated by the FRDC, or other entities, with an appointed programme coordinator to guide the groups in tackling the key issues.

Membership of both the coordination body and working groups should include representatives from diverse stakeholder backgrounds including government, suppliers, industry bodies, business, research institutions and indigenous representatives. Including stakeholders from across the industry and value-chain can assist with facilitating interventions that are fit for purpose, catered to the unique challenges and opportunities the industry aims to tackle.

6.4 Material traceability and recovery pathways

Priority: Medium
Timeframe: Short to long term
Stakeholders: Industry associations, government agencies, research institutions, technology providers

This report emphasises the importance of enhancing data collection throughout the sector. While the MFA offers high-level insights into material flows, gathering more detailed data may help to target efforts towards specific material streams. In addition, infrastructure mapping could be carried out to consolidate understanding of the current industry. Establishing a baseline is crucial for setting targets and data to monitor the sector's progress. The initial MFA data presented in this report not only informs decision-making but also tracks the industry's advancement towards achieving circularity targets. It is recommended that complete datasets are compiled, and this MFA is updated and revised every 5 years, to review the sector's progress.

It is also recommended that comprehensive mapping of the existing recycling infrastructure and detailed mapping of end fates is undertaken. Within this MFA, assumptions and general material recovery rate datasets were used to produce the end fate profile for the sector in this MFA. However, mapping of existing recycling infrastructure and actual end fates will yield more accurate representation. End fate mapping should be followed by an economic feasibility analysis for end-of-life solutions, which will help identify potential areas for improvement and investment.

As the fisheries and aquaculture sector is part of the global supply chain, there are elements of its circularity that will be difficult to address. Priority should be placed on domestic facilities and projects that have the potential to enhance circularity at the local level. Incorporation of circularity at the local level allows for flexible solutions that can be adapted regionally to suit the needs of the industry.

6.5 Sector decarbonisation

Priority: High
Timeframe: Short to long term
Stakeholders: All stakeholders

Decarbonisation both complements and enables progress towards, circular outcomes. The key challenges and opportunities for the sector to decarbonise are outlined in 3.3.4 GHG Emissions. Enabling decarbonisation will be driven by policies, as mentioned in prior enablers and incentives such as funding.

To encourage participation from stakeholders for decarbonisation, targeted funding or incentives can be offered for initiatives such as solar panel installation of the adoptions of renewable energy solutions. Similar funding schemes are already available from government such as the Advancing Renewables Program and the Powering the Regions Fund both managed by the Australian Renewable Energy Agency (ARENA) (83).

The transition will be further supported through the promotion of renewable fuel sources for vessels and fuel efficiency. Promotion of fuel efficiency within the industry works alongside government efforts to develop a fuel efficiency standard and lower Australia's overall fuel emissions (84).

As mentioned in 6.4 Prioritisation of Regional Infrastructure, prioritisation of regional infrastructure is key to ensuring regionally appropriate solutions are implemented. A similar local focus could be adopted when attempting sectoral decarbonisation. Local markets could be prioritised and supported to reduce transportation and refrigeration emissions. Insights gained from the regional infrastructure mapping can be leveraged to develop infrastructure where necessary to reduce transportation to processing facilities.

6.6 Circular supply chain innovation

Priority: High
Timeframe: Medium to long term
Stakeholders: Industry associations, research institutions, technology start-ups, businesses across the sector

Development of new solutions across the supply chain can occur across two pathways, the scaling and utilisation of pre-existing solutions, and investment into the development of new solutions. There is pre-existing circularity in the industry in low-impact and regenerative sectors such as molluscs and seaweed farming. Supporting the scaling of these industries facilitates increased intra-industry circular outcomes building on pre-established operating models. Ultimately, new solutions will be required for a circular transition of the industry. Greater emphasis on research and development could be carried out, and invested in, to produce the new solutions that will drive a successful transition.

A core aspect of this will be embracing industry 4.0 technology, moving from traditional processes to processes that incorporate smart technology. There are existing studies explaining and supporting the use of such technologies, specifically for use in aquaculture. These technologies are already leveraged globally with 4.0 solutions being developed within the European fisheries and aquaculture sector, the transition being termed "Aquaculture 4.0" (85). Whilst the European focus has been aquaculture, the management strategies implemented can be extended to fisheries contexts, especially management strategies for data collection and computing processes (86).

To support greater circularity, end markets could be further developed for prioritised material streams. The development of end markets goes towards overall resource optimisation, a key tenant of circularity. Aside from the negative environmental impacts, waste is also a financial burden - fish/shell waste can cost up to $230AUD per tonne to dispose of in Australia (16). Designing appropriate end markets for high impact material streams will not only promote circularity but can work towards decreasing the financial burden the utilisation of the current waste-stream creates. To support the innovation within the fisheries and aquaculture sector the RCC and the FRDC have established a Circularity Accelerator programme to encourage creative circular economy problem-solving and support further testing and validation of existing circular initiatives.

6.7 Utilise existing channels or certifications

Priority: Medium
Timeframe: Short to medium term
Stakeholders: Industry associations, certification bodies, sustainability initiatives

Utilising existing channels created by industry, associations and initiatives means that the progression of the transition is not reliant on entirely new processes. Certifications, such as those outlined in Table 9 below exist already globally and within Australia. These can be leveraged to integrate circular economy principles. There are a number of sustainability related initiatives that the principles of circularity can be integrated into, coordination should be considered between initiatives to avoid duplication and promote best practices. As sustainable fishing movements already have developed processes and established outreach, leveraging those systems and incorporating circular principles will facilitate a quicker transition to circularity. Where possible, working within existing channels reduces cost and time.

Table 9: *Australian and global certifications*

Certification	Jurisdiction	Description
Marine Stewardship Council (MSC)	Global	Focuses on assessing the sustainability of wild capture fisheries worldwide against specific criteria. Many seafood products with the MSC label are available globally.
Aquaculture Stewardship Council (ASC)	Global	Primarily pertains to farmed seafood, scrutinising the environmental and social performance of aquaculture operations. ASC-certified products are accessible worldwide.
Friend of the Sea (FOS)	Global	Certifies both wild caught and farmed seafood. Maintains a presence in various countries and enjoys recognition from retailers and consumers globally.
Australian Fisheries Management Authority (AFMA) Certification	Australia	AFMA is Australia's federal agency responsible for sustainable management of Commonwealth fisheries. They have their own certification programme to ensure fisheries comply with sustainability standards.
Australian Sustainable Seafood (ASS) Certification	Australia	Managed by the Australian Marine Conservation Society (AMCS), it certifies Australian seafood products based on sustainability criteria, helping consumers make informed seafood purchases.
Best Aquaculture Practices (BAP)	Global	Encompasses various aspects of responsible aquaculture, including environmental and social considerations. BAP certification is recognised internationally.
Global G.A.P. (Good Agricultural Practices)	Global	While not seafood specific, Global G.A.P. offers certification for diverse agricultural practices, including aquaculture. It emphasises food safety, sustainability, and traceability in agriculture.
Naturland Certification	Global	Widely acknowledged organic certification for various agricultural products, including organic aquaculture. Naturland focuses on organic and sustainable agricultural practices.
Climate Active	Australia	A government backed certification that organisations and businesses can obtain once they have achieved carbon neutrality against the Climate Active Carbon Neutral Standard requirements.

6.8 Knowledge sharing and capacity building

Priority: Medium
Timeframe: Short to medium term
Stakeholders: Industry associations, research institutions, knowledge-sharing platforms

Capacity building and knowledge sharing will be an important step to increase buy-in and understanding of the transition to a circular economy for the fisheries and aquaculture sector. Building circular capacity within the industry will improve decision making capabilities, enhancing the effectiveness of the circular solutions being implemented.

Fostering knowledge sharing can be facilitated well through the formation of, and contributions to, Communities of Practice (CoP). The existing CoP established by RCC and the FRDC is a forum to improve knowledge stewarding, providing body of knowledge for the community to draw from, and innovation, which creates new ideas and practices. Through these CoPs circular outcomes and solutions can be shared across the sector.

Celebration of wins and success stories will also support in building momentum and motivation. Existing awards could be leveraged, or new awards created to recognise circular achievements. Celebration is another form of knowledge sharing, and insights gained can be used to inform future strategies and encourage best practice.

7 Stakeholder acknowledgement

The RCC and FRDC acknowledge the significant and valued input from industry entities, organisations and individuals, who contributed to a broad range of experience on circular economy practices and the fisheries and aquaculture sector in Australia.

Many of the stakeholders who participated in our project workshops or interviews and provided data or other information, run their own businesses and we acknowledge their time and resources are limited and precious. We appreciate the generosity and openness of all the participants.

8 Appendix 1 - Detailed MFA Methodology

An MFA is a point in time assessment that quantifies the physical flow of matter and energy in an isolated system boundary. MFAs can be used to evaluate efficiencies for managing environmental impact and resources (23). Through quantification of the total material usage and end-of-life practices, the existing material consumption activities, areas where there is lost value, or high consumption can be identified. Additionally, MFAs provide useful information on the relationship between material flows (including energy) and activities that occur at different stages of a process. Results are illustrated through a ‘Sankey diagram’, which visualises the movement and magnitude of material through the system boundary.

This detailed methodology includes:

- Overview
- Functional unit definition
- System boundary
- Inputs and end fates
- Key data sources
- Wild catch and aquaculture: production, processing and wholesale and retail
- Wild catch (recreational)
- Greenhouse gas emissions

8.1 Overview

The initial system boundary assessment involved the identification of the in-scope subspecies and the most common methods (termed production methods) of capture or cultivation. For each production method, key products, materials and energy inputs (collectively referred to as materials or inputs) are categorised as illustrated in Figure 1.

Within each production method, useful life is assigned to each element to determine yearly output or waste. Waste is then assigned across various end fates to gain an understanding of their eventual destination. The eventual destination is the final destination of a material (i.e., how and where the material is disposed of, recycled, consumed or repurposed).

Given the multitude of materials across methods, materials were aggregated into general classifications. The classifications were then used when generating the flows for wild catch and aquaculture respectively. We then identified how and where the materials flowed from production to processing to wholesale/retail.

This MFA is primarily based on calendar year 2021 ABARES fisheries and aquaculture statistics, recreational fishing surveys, commonwealth fishing logbooks, catch disposal records and catch effort data (20). This data represents the most holistic public summary of fisheries and aquaculture production available at the time of analysis. We recognise that there may be anomalies within the dataset due to potential disruptions due to the COVID-19 pandemic. Recent research from the FRDC on the impacts of COVID-19 on the fisheries and aquaculture sector found that there was a large variance in the impacts across the sector. There were both positive and negative impacts, such as increases in domestic retail and takeaway seafood demand and decreases in exports of seafood and dine-in food service, across the sector, effecting how organisations operate (24).

Given that 2021 provided the most holistic data availability across multiple data sets, it was established as the period of analysis.

The sector was grouped into four sub-sectors as per Table 10 below.

Table 10: *Definitions of fisheries sub-sectors.*
Source: FRDC and RCC Analysis.
** Please note: Indigenous fishing activities are captured within wild catch (both commercial and recreational) and aquaculture activities, as there is no distinction between Indigenous and non-Indigenous fishing within the available data sets.*

Fisheries sub-sectors	Definition
Aquaculture	Cultivation and farming of fish, shellfish, and aquatic plants, in controlled environments for commercial purposes. Depending on the species being farmed, aquaculture can be carried out in freshwater, brackish water, or marine water. There are different systems that can be used for aquaculture, including ponds, tanks, pens and floating cages.
Wild catch (commercial)	Process of catching, capturing, or harvesting fish and shellfish, from their natural habitats in oceans, rivers, lakes, or other bodies of water for commercial purposes.
Wild catch (recreational)	Leisure activity where individuals or groups catch fish for personal enjoyment and not primarily for commercial or primary sustenance purposes.
Indigenous*	Fishing and aquaculture activities by Indigenous peoples, who have a special relationship with their traditional lands and waters. Indigenous fishing encompasses a range of activities including both cultural and/or commercial practices.

The methodology for wild catch (commercial) and aquaculture are similar, while wild catch (recreational) and Indigenous were analysed separately.

8.2 Functional Unit Definition

The functional unit of this study is ‘1 tonne of in-scope subspecies ready for customer purchase’ (final fish consumed or t_{fish}). Results that are normalised by the functional unit do not have a time frame associated with the unit. Results presented in absolute terms are calculated for the calendar year 2021. Materials and energy consumption intensities (tonnes of material consumed per tonne of final fish consumed or $\frac{t_{material}}{t_{fish}}$) are derived for each production, processing method and wholesale/retail method. The derived material and energy consumption intensities methods were used to estimate total material and energy consumption for the in-scope subspecies. Results were scaled for actual production based on the available production datasets to provide a sectoral view.

8.3 System boundary

The system boundary is shown in Figure 4 which illustrates the geographical boundary of this assessment and the supply chain stages including production for both wild catch and aquaculture. Within this sector, there are three sub-sectors that will be covered:

- Wild catch (commercial)
- Wild catch (recreational)
- Aquaculture

The following supply chain stages were considered for both wild catch and aquaculture:

- production
- processing
- wholesale / retail

Once caught or grown/harvested the captured or cultivated species then undergo processing and are then transported to market (wholesale/retail or export). Exported seafood is excluded from this MFA.

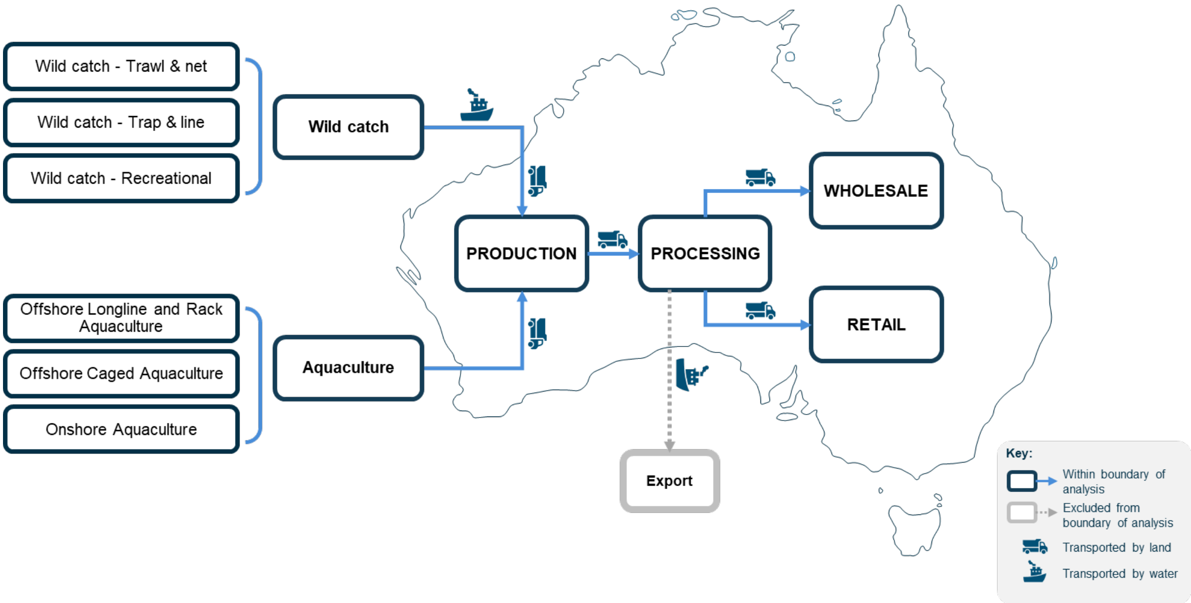

***Figure 29:** Australian fisheries and aquaculture sector system boundary*

8.3.1 In-scope subspecies

To quantify material use, materials and energy are assigned to each subspecies in order to understand a materials intensity metric for each subspecies.

The total quantity of fish production in Australia was determined from the 2021 ABARES Australian Fisheries and Aquaculture data (20) and recreational fishing surveys. Fish production in Australia can be broadly divided into four key categories, outlined below and illustrated in Figure 30.

- Imports (41.6%)
- Domestic commercial production (56.9%)
- Domestic recreational fisheries production (1.5%)
- Exports (assumed to be contained within domestic commercial production and are thus separated in Figure 30)

For the purposes of the MFA, imports have been excluded to allow recommendations to focus on driving impacts within Australia. Therefore, the MFA has focused on 304,235 tonnes of

Australia's wild catch and aquaculture and an additional 8,029 tonnes of recreational fishing production.

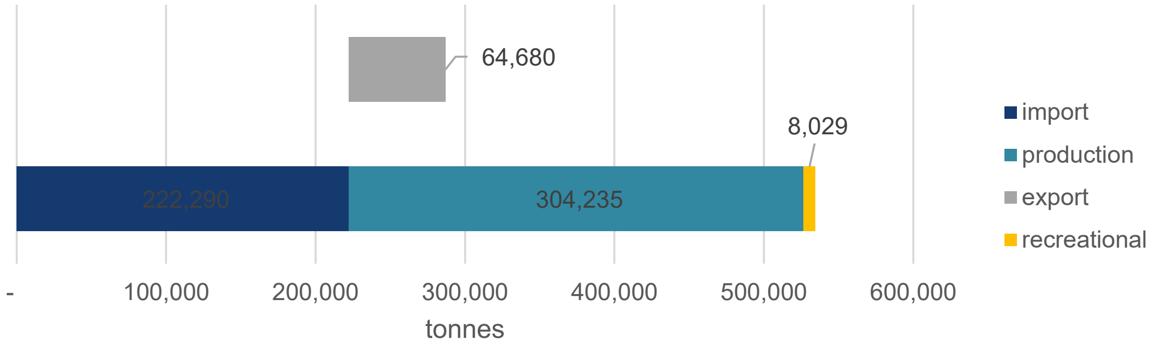

Figure 30: *Sector-wide production, imports and exports (2021).*
Source: ABARES 2021 (20) and Recreational fishing surveys

Determining in-scope subspecies from domestic commercial production

The species groups of crustaceans, finfish and molluscs represented 90% of total domestic commercial production tonnes. The top 80% of subspecies within crustaceans, finfish and molluscs species' groups are 'in-scope subspecies' (see Figure 31).

Southern bluefin tuna (SBT) did not meet the 80% volume inclusion threshold for aquaculture finfish. However, southern bluefin tuna was included in the MFA due to the volume of wild caught Australian sardines used the aquaculture production of southern bluefin tuna.

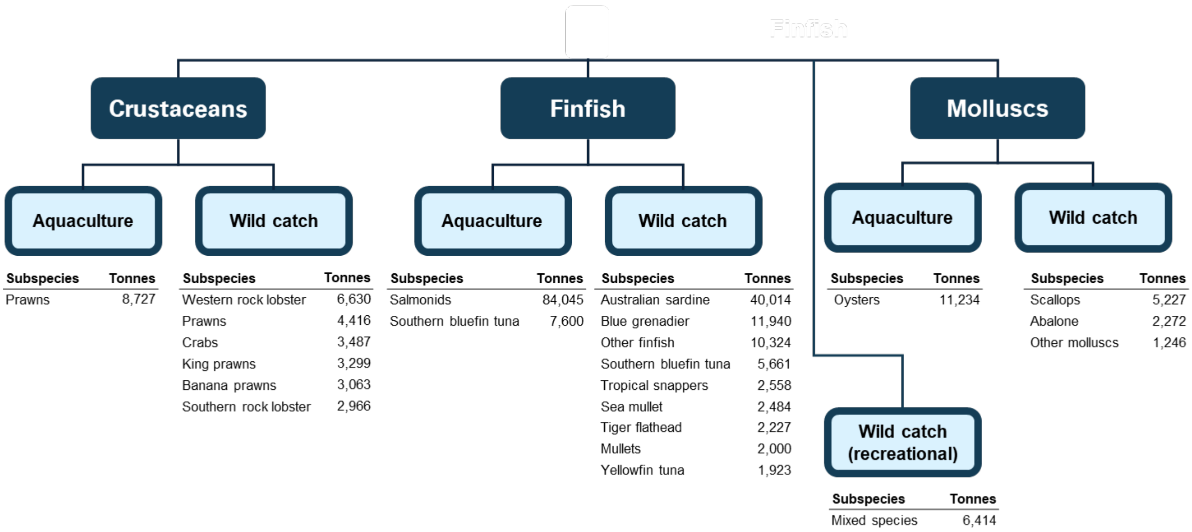

Figure 31: *Production tonnes of in-scope subspecies.*
Source: ABARES Fisheries and Aquaculture data 2021 (20) and recreational fishing surveys (see Appendix A for individual sources)

Overall, the MFA represents approximately 76% of the domestic commercial production and domestic recreational fisheries production.

This system boundary was reviewed and validated with the industry through an MFA methodology workshop held in July and August 2023.

8.4 Inputs and End Fates

The aggregated material and energy inputs and end fates that the MFA considers are outlined below in Figure 32. Material inputs have been classified into groups. For example, “Metals” would include (but not limited to) steel, aluminium, and lead.

Various materials and waste products are generated as outputs throughout the supply chain, such as offal as a by-product of the processing stage. This waste is assigned an end fate group as it is generated, depending on how the waste flows through the supply chain.

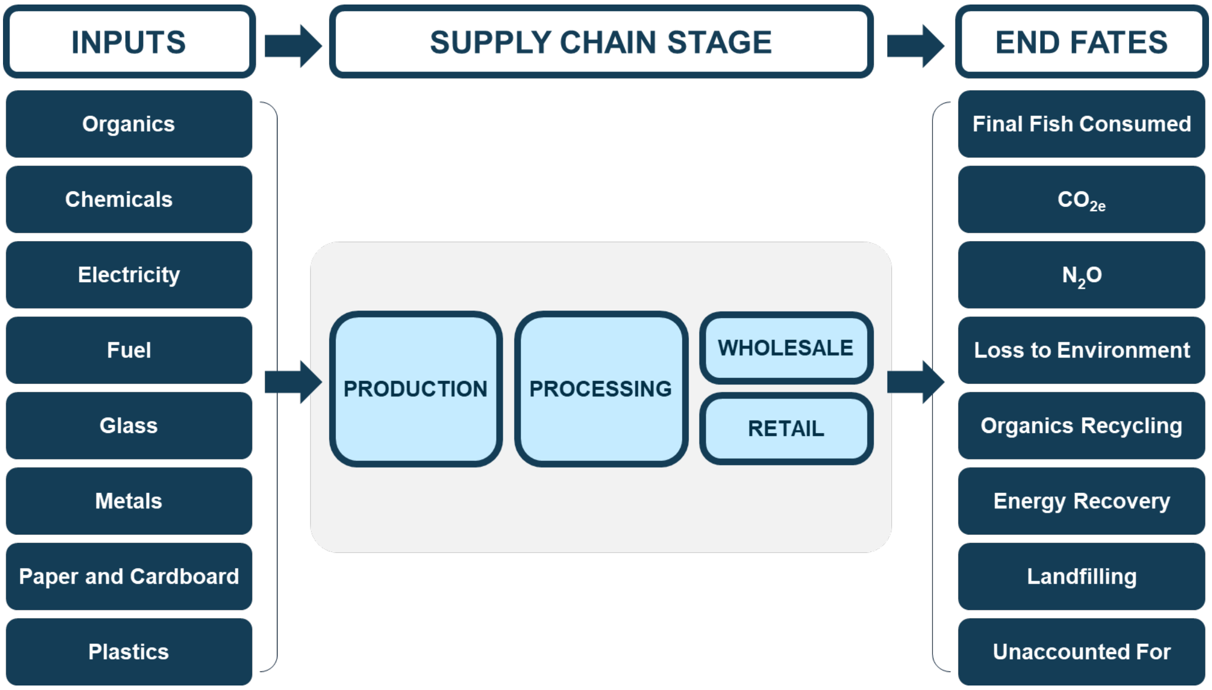

Figure 32: *Aggregated material input categories and output (end fate) categories of the MFA*

Further details on the definition of each input or end fates (outputs) and the specific materials included for each input and end fate category are outlined below in Table 11.

These categories are a result of data collection and feedback from industry stakeholder workshops held in July to August 2023.

Table 11: *List of MFA inputs and end fate definitions and elements.*
Source: FRDC and RCC Analysis

Category	Definition	Examples of specific elements
INPUTS		
Chemicals	Various substances with distinct molecular compositions	• Refrigerants • Liquid oxygen
Electricity	Energy generated from sources such as fossil fuels, hydroelectric dams, solar panels, or wind turbines. In the fisheries and aquaculture sector, electricity is used for a range of purposes including pumps, aeration systems, lighting, refrigeration, and equipment.	• Grid electricity

Category	Definition	Examples of specific elements
Fuel	Substances, such as gasoline, diesel, and biofuels that are burned to produce energy. In the fisheries and aquaculture sector, fuels are used for transportation (boats and vehicles), heating, and running machinery such as generators.	• Diesel for vessel engines and generators • Land based transportation
Metals	Range of elements, including but not limited to iron, aluminium, and copper. In the fisheries and aquaculture sector, metals are utilised for construction of equipment, vessels, cages and infrastructure.	• Lead Lines • Hooks • Rope and net components • Sinkers • Otter boards • Dredges • Anchors • Crab traps
Organics	Biodegradable materials of biological origin, such as plant matter and animal waste. .	• Bait • Fish feed • Timber posts
Paper and Cardboard	Materials derived from wood pulp and used for packaging, documentation.	• Packaging
Plastics	Synthetic polymers made from petrochemicals. There are various applications within the fisheries and aquaculture sector including packaging, equipment such as nets, traps, and gear.	• Packaging components • Floats / buoys • Nets • Lead lines • Ropes • Oyster baskets
Water	Salt and fresh water are a fundamental resource in fisheries and aquaculture. Water serves as the habitat for aquatic organisms, a medium for transport, and a key component in various processes across the aquaculture lifecycle and seafood processing.	• Ice • Potable water • Seawater
END FATES		
Final fish consumed (t_{fish})	Final fish consumed encompasses the consumption of seafood products by end consumers (humans and other species as bait or fish feed), including households, restaurants, and other entities.	• Seafood
CO_2e (GHG emissions)	A measurement used to express the global warming potential of various greenhouse gases, such as methane and nitrous oxide in terms of the amount of carbon dioxide that would have the same impact.	• Scope 1 emissions • Scope 2 emissions
N_2O	A greenhouse gas released from sources including agricultural activities and waste decomposition.	• Scope 1 Emissions
Energy recovery	The process of extracting useful energy from waste materials through techniques such as incineration or anaerobic digestion. In the fisheries and aquaculture sector, this could involve generating energy from organic waste or by-products.	• Electricity

Category	Definition	Examples of specific elements
Loss to environment	Materials that are released or lost into the environment that does not provide a beneficial use or contribute to productive processes. This could include unintended spills, leaks, or emissions that can have negative impacts.	• Bycatch discarded overboard • Equipment: nets, hooks, sinkers, fishing line lost at sea
Landfilling	Disposing of waste materials by burying in designated landfills.	• Packaging components • Organic matter • Fishing equipment at end of life
Organics recycling	The process of converting organic materials, such as food waste or agricultural residues, into useful products such as compost or bioenergy.	• Offal
Recycling	The process of collecting, processing, and reusing materials (other than organics) to produce new products. In the fisheries and aquaculture sector, recycling involves reusing materials such as plastics or metals from equipment or packaging. Key to recycling is the end market that the recycled content is sold into.	• Packaging • Fishing equipment at end of life
Unaccounted for	Portion of materials that cannot be accurately tracked or measured within the MFA. This could include losses due to inefficiencies, errors in data collection, or other factors that make quantification challenging.	• Miscellaneous

Each input was assigned an end fate or eventual destination or end fate outlined below in Table 12. The eventual destination is the final end fate of a material (i.e., how and where the material is disposed of, recycled, consumed or repurposed). End fates were sourced from the Australian National Waste Report 2022 (25) and the headline economic value for waste and materials efficiency was used (87) when actual data was unavailable.

Changes to end fate proportion assumptions were adjusted based on industry stakeholder workshops and one-on-one interviews. For example, metals and plastic end fate distributions were adjusted in the production stage to reflect the likely lower recycling rates due to biofouling:

- Metals: 5% loss to environment, 15% landfilling and 80% recycling
- Plastics: 5% loss to environment, 90% landfilling and 5% recycling

Table 12: *Assumed end fate distributions for the MFA.*
Note. Columns do not add to 100% due to rounding.
Source: Australian National Waste Report (25) and FRDC and RCC Analysis.
** 80% of metals are recycled. 10% metals was allocated to reuse to more accurately reflect the very low likelihood of direct metals reuse, whilst 10% was identified going to landfill across the fisheries and aquaculture sector.*

Eventual destination	Glass	Metals	Organics	Paper and cardboard	Plastics
Energy recovery	-	-	1%	-	-
Landfilling	44%	10%	58%	39%	86%
Organics recycling	-	-	41%	-	-
Recycling	56%	90%*	-	61%	14%
Unaccounted for	-	-	-	-	1%

Loss to environment is an additional end fate category developed to reflect when gear is lost to environment, bycatch or in instances such as when fish effluent is released after treatment.

The MFA has been calculated for the calendar year 2021; hence this represents a steady-state condition in which the input and output of materials within a system are matched or balanced during the calendar year 2021. Due to the homogeneous nature of an MFA, stockpiling of items has been excluded from this analysis.

The full lifespan of inputs has been considered at each stage, meaning reuse where re-use occurs, such as for fishing gear and shipping pallets has been accounted for before the product is assigned a final end fate.

8.5 Key Data Sources

Key data sources for the development of the MFA include:

- *Australian fisheries and aquaculture statistics* – ABARES (20)
- *Australian Fish Names Standard AS5300* – FRDC (88)
- *Commonwealth fisheries annual logbook, catch disposal records and catch effort data* – AFMA (89)
- *Australia's First National Bycatch Report* – FRDC (31)
- *Survey of recreational fishing in NSW, 2019/20 – Key Results* – NSW Government Department of Industries (90)
- *The State of Recreational Fishing in Victoria* – Victorian National Parks Association (91)
- *Queensland Recreational Fishing Surveys* – Queensland Government – Department of Agriculture and Fisheries (92)
- *Survey of Recreational Fishing in South Australia in 2021-22* – Government of South Australia, Department or Primary Industries and Regions (93)
- *Fisheries Research Report No. 327* – Government of Western Australia, Department of Primary Industries and Regional Development (94)
- *2017-18 Survey of Recreational Fishing In Tasmania* - University of Tasmania and IMAS (Institute for Marine & Antarctic Studies) (95)
- *Survey of recreational fishing in the Northern Territory: 2018 to 2019* – Northern Territory Government (96)

- *A Life Cycle Assessment of New Zealand mussels and oysters* – Fisheries New Zealand & thinkstep-anz (97)
- *Life Cycle Assessment of New Zealand farmed king salmon* – Fisheries New Zealand & thinkstep-anz (98)
- *Headline economic value for waste and materials efficiency* – Centre for International Economics (87)

When determining whether a data point should be utilised, the following elements were considered:

- Is the relative magnitude of production volumes materially significant?
- How accurate is the data point? As outlined in the assumptions and exclusions below, inputs varied in data validity and integrity. Inclusion or exclusion of data was considered based on the reliability and verifiability of data points. In the complete absence of data, some data gaps were filled by unverified assumptions.
- Time relevance of data points was considered, with the preference for data during from the 2021 calendar year.

8.6 Material quantification method for wild catch (commercial) and aquaculture

8.6.1 Production

Production, catch for wild catch (commercial) and growth / harvest for aquaculture, is the first stage of the supply chain. The sector does not have a standardised approach to categorising the methods utilised to catch and cultivate seafood (i.e. subspecies). A bespoke approach was developed to quantify the materials utilised in production of each in-scope subspecies.

Step 1: Determine generic production method(s) most representative of the in-scope subspecies (e.g. otter trawl for the production of banana and king prawns).
Step 2: Determine the volume produced by each production method.
Step 3: Document the processes, equipment and materials required for each production method.
Step 4: Repeat this process for all in-scope subspecies.

Step 1: Determine generic production method(s) most representative of the in-scope subspecies

A list of production methods for each subspecies was developed via a combination of desktop research, consultation with industry representatives via industry stakeholder workshops, one-on-one interviews and standardised for the purposes of this MFA.

- The proportion each production method contributed to the production of the subspecies was identified.
- Any production method that contributed to 5% or less of subspecies production tonne was deemed materiality insignificant and excluded from analysis.
- This was completed for both wild catch and aquaculture subspecies to form a short-list of *in-scope fishing methods* (see Table 13).
- For example, 40,014 tonnes of Australian sardines caught annually. Five different of Australian sardine production methods were identified: beach seine, Danish seine, otter trawl, tangle net and purse seine. Of these methods, purse seine is responsible for 90% of the catch and is considered in scope. The remaining four methods were responsible for 2.5% of the sardine catch respectively. Of these four methods, tangle

net and beach seine, are excluded from the MFA as they were not responsible for 5% or more of any other subspecies production. Danish seine and otter trawl were included in the MFA as they contributed to more than 5% of production within other subspecies.

See Table 13 for a list of in scope fishing methods for wild catch (commercial) and aquaculture, including tonnage contribution of each subspecies.

Table 13: *Production methods by In-scope subspecies (values are percentages)*

Subspecies	Production Methods																						
	batten pot	crab trap	danish seine	demersal longline	diving and hand collection	dredges	haul seine	hook and line	mesh net	mud crab trap	net	otter trawl	pelagic longline	purse seine	running net	stow net	Rod and line	trap and net	Open pen sea cage	Earthen pond	Pontoon	Hexcyl basket	Floating mesh bask
Australian Sardine			5									5		90									
Blue Grenadier												100											
Other Finfish			7					30				63											
Western Rock Lobster	100																						
Southern Bluefin Tuna (WC)													15	85									
Prawns (WC)							11					81			2	6							
Crabs		23							34	31		4											
King Prawns												100											
Banana Prawns												100											
Southern Rock Lobster		100																					
Scallops (Commonwealth)						100																	
Tropical Snappers			10	60								30											
Sea Mullet							100																
Scallops (WC)												100											
Abalone					100																		
Tiger Flathead			34									66											
Mullets							100																
Yellowfin Tuna													100										
Other Molluscs						100																	
Finfish - Recreational																	100						
Crustaceans - Recreational																		100					
Salmon																			100				
Prawns (AQ)																				100			
Southern Bluefin Tuna (AQ)																					100		
Oysters																						50	50

Please note: the colour gradient from red to green highlights from the fishing methods which produce the greatest tonnage from largest to smallest for wild catch and aquaculture production methods
Sources: ABARES 2021 Fisheries and Aquaculture Data (20), AFMA Logbook and Catch Disposal Records Data (89), National Bycatch Report (31), Status of Sustainable Fish Stocks (99) & Queensland Qfish data (100)

Step 3: Document the processes, equipment and materials required for each production method

a) The key components (e.g., nets, ball bearings, rope) of each production method were identified.
b) The average dimensions (e.g., length, width and mass) and material composition of the each item (e.g. steel, polyester, nylon) was identified.
    i. Dimension and composition identification was based on averages or representative examples and does not account for the variability in dimensions and unique gear that may be used under any one method.
c) Based on the information collected in steps a - b, the total weight of each production method component was estimated.
d) Each component was assigned an input and end fate category per the material categories identified in Table 11.
e) The average life of elements was researched to understand how much gear would reach its end of life per year.
f) A materials consumption intensity metric for each subspecies was then calculated (tonnes of material consumed per tonne of fish production), based on the equation below.

$$(Total\ weight\ of\ each\ element) \times \left(\frac{Expected\ number\ of\ elements\ that\ reach\ end\ of\ use\ per\ year}{Final\ consumption\ tonnes\ per\ year}\right) = material\ consumption\ intensity\ per\ subspecies$$

**Additional calculations vary depending on method to account for boat days, catch per effort, retained catch.*

Key Assumptions, Exclusions and Limitations

Key assumptions, exclusions and limitations for the production stage of wild catch (commercial) and aquaculture include:

- In-scope subspecies represent 80% of the seafood produced from the top 90% of species groups: crustaceans, finfish, and molluscs. All other species are excluded from this MFA.
- Any production method that contributed 5% or less to a subspecies' s production was deemed materiality insignificant and excluded from the MFA.
- There is no standard list of production methods for each subspecies. This list was derived from research, consultation with industry representatives and standardised for the purposes of this MFA. The proportion that each fishing method contributes to the production of the subspecies was identified. Attempts were made to corroborate data, however, due to data unavailability, data gaps were filled with verified assumptions, estimations and when necessary, unverified assumptions and estimations.
- Where market share of a method was dominated by one or two companies, stakeholder consultation was targeted to obtain accurate information from the respective companies.
- Material use for vessel construction was excluded due to vessel's relatively long lifespans, lack of available data related to material composition and end fates of vessels.
- Packaging for gear used in aquaculture and wild catch (commercial) is excluded.
- Within the MFA, it has been assumed that the National Waste Report metal reuse percentage is unlikely to be representative of the fisheries and aquaculture sector.

- The metals and plastic end fate distributions were adjusted from the National Waste Report for the production stage to reflect the likely lower recycling rates:
  - Metals: 5% loss to environment, 15% landfilling and 80% recycling
  - Plastics: 5% loss to environment, 90% landfilling and 5% recycling

8.6.2 Processing

Processing is the supply chain stage, where seafood is prepared (e.g. filleting on the cutting floor) before being sold as consumable product in wholesale/retail markets.

In practice, processing is conducted on vessels or onsite, and is not considered as a separate supply chain stage. However, for the purposes of quantification and analysis in this MFA, processing is separated.

A processing method was allocated to each subspecies based on industry stakeholder workshops and one-on-one interviews. Where no information was available, a generic assumption was used. The processing method table for each subspecies is provided below at Table 14 Appendix 1.

Table 14: *Processing method by market and subspecies.*
Source: Lifecycle Assessment study of NZ farmed king salmon (98), Lifecycle Assessment of NZ mussels and oysters (97)

Market	Subspecies	Finfish	Finfish	Finfish	Finfish	Finfish	Finfish	Molluscs	Molluscs	Molluscs	Crustaceans	Crustaceans	Crustaceans	Crustaceans	Crustaceans
		Whole	Gutted, Head On	Gutted, Head Off	Frozen	Fillets	Other	Live	Frozen	Other	Raw / Fresh	Boiled / Cooked	Frozen	Tails (Shell On)	Tails (Peeled)
Export	Abalone								100%						
	Australian Sardine				100%										
	Banana Prawns												100%		
	Blue Grenadier				100%										
	Crabs										100%				
	King Prawns												100%		
	Mullets				100%										
	Other Finfish				100%										
	Other Molluscs								100%						
	Oysters								100%						
	Prawns (Aq)												100%		
	Prawns (Wc)												100%		
	Salmonids		100%												
	Scallops								100%						
	Sea Mullet				100%										
	Southern Bluefin Tuna (Aq)		100%												
	Southern Bluefin Tuna (Wc)				100%										
	Southern Rock Lobster										100%				
	Tiger Flathead				100%										
	Tropical Snappers				100%										
	Western Rock Lobster										100%				
	Yellowfin Tuna		100%												
Supermarkets	Abalone								100%						
	Australian Sardine	100%													
	Banana Prawns											50%	50%		
	Blue Grenadier					93%	7%								
	Crabs											50%	50%		
	King Prawns											50%	50%		
	Mullets					93%	7%								
	Other Finfish					93%	7%								
	Other Molluscs								100%						
	Oysters							67%	30%	3%					
	Prawns (Aq)											50%	50%		
	Prawns (Wc)											50%	50%		

Market	Subspecies	Finfish	Finfish	Finfish	Finfish	Finfish	Finfish	Molluscs	Molluscs	Molluscs	Crustaceans	Crustaceans	Crustaceans	Crustaceans	Crustaceans
		Whole	Gutted, Head On	Gutted, Head Off	Frozen	Fillets	Other	Live	Frozen	Other	Raw / Fresh	Boiled / Cooked	Frozen	Tails (Shell On)	Tails (Peeled)
	Salmonids		11%	43%	3%	41%	2%								
	Scallops							50%	50%						
	Sea Mullet					100%									
	Southern Bluefin Tuna (Aq)					100%									
	Southern Bluefin Tuna (Wc)					100%									
	Southern Rock Lobster											50%	50%		
	Tiger Flathead					100%									
	Tropical Snappers		100%												
	Western Rock Lobster											50%	50%		
	Yellowfin Tuna					100%									
Wholesalers	Abalone							100%							
	Australian Sardine	100%													
	Banana Prawns										100%				
	Blue Grenadier		100%												
	Crabs										100%				
	King Prawns										100%				
	Mullets		100%												
	Other Finfish		100%												
	Other Molluscs							100%							
	Oysters							100%							
	Prawns (Aq)										100%				
	Prawns (Wc)										100%				
	Salmonids		100%												
	Scallops							100%							
	Sea Mullet		100%												
	Southern Bluefin Tuna (Aq)		100%												
	Southern Bluefin Tuna (Wc)		100%												
	Southern Rock Lobster										100%				
	Tiger Flathead		100%												
	Tropical Snappers		100%												
	Western Rock Lobster										100%				
	Yellowfin Tuna		100%												

Assumptions: Assumed 100% frozen if exported, except crustacean exports where they are assumed to be 100% exported life, retail market distribution assumed to be 50/50 split between frozen and another form of presentation to the market, if presented to a wholesale market, assumed that 100% of species presented as whole, gutted head on, live or raw. To ensure the fidelity of naming classifications categorisation within ABARES data, certain species are detailed by either the species name or the species group.

The Life Cycle Assessment of New Zealand Mussels and Oysters (97), identified an approximately 10% processing loss for product of mussels and oysters which have been damaged or pass their expiry date and are thereby lost. In the absence of data, a 5% loss of product in the supply chain between processing and wholesale retail was assumed.

To determine the quantity of each subspecies processed into a useable product (e.g. where a fish is filleted and the offal is not used), a conversion factor, using FRDC species specific conversion ratios and data from the Food and Aquaculture Organisation of the United Nations (FAO), for each subspecies was applied (101). The end fate of offal was assumed to align with the Australian National Waste report (25).

Key Assumptions, Exclusions and Limitations

- In practice, processing is not considered as a distinct stage in the supply chain. Therefore, data collection for this specific stage was significantly limited and the approach was based on consultation with industry stakeholder workshops and one-on-one interviews, available data, and generic verified and unverified assumptions.
- There is significant variety in the packaging of each in-scope subspecies and their respective points of sale (end markets). In the absence of data, generic assumptions have been applied across all subspecies.
- The end fates of some waste at the processing stage, such as offal, may be sold as by-products. However, for this MFA the Australian National Waste report end fate proportions have been applied to provide consistency in the absence of sector specific available data.
- PPE or materials relating to clothing, foul weather gear or accessories used by fishers and staff during processing are excluded.

8.6.3 Wholesale and Retail

The wholesale/retail stage is the final supply chain stage. Wholesale and retail involve the packaging and distribution of seafood products for sale to consumers and businesses for consumption.

Market Allocation Table

The market distribution of each in-scope subspecies was categorised into:

- Wholesale – fish markets or other wholesale
- Retail – supermarkets, restaurants, and other retailers
- Export – shipped overseas

The market distribution allocation was based on industry provided data through consultation and the Australian Seafood Industry Export Market Strategic Plan (102), and exports from the 2021 ABARES data (20). Where no data was available, a generic assumption was used. The market distribution allocation (Table 15) is outlined below.

Table 15: *Market allocation distribution table.*
*The remaining percentage is being fed into Southern Bluefin Tuna (AQ) as a circular flow and does not make it through to wholesale/retail stage

Subspecies	Export	Retail - Supermarkets	Wholesalers	Grand Total
Abalone	87.8%	0.0%	12.2%	100.0%
Australian Sardine	10.0%	0.0%	0.0%	10.0%*
Banana Prawns	37.0%	56.5%	6.5%	100.0%
Blue Grenadier	10.0%	0.0%	90.0%	100.0%
Crabs	15.5%	10.0%	74.5%	100.0%

Subspecies	Export	Retail - Supermarkets	Wholesalers	Grand Total
King Prawns	37.0%	57.0%	6.0%	100.0%
Mullets	0.0%	0.0%	100.0%	100.0%
Other Finfish	20.0%	10.0%	70.0%	100.0%
Other Molluscs	33.0%	10.0%	57.0%	100.0%
Oysters	0.4%	12.0%	87.6%	100.0%
Prawns (Aq)	0.0%	96.4%	3.6%	100.0%
Prawns (Wc)	91.1%	8.9%	0.0%	100.0%
Salmon	29.1%	10.0%	60.9%	100.0%
Scallops – state wild-catch	5.0%	0.0%	95%	100.0%
Scallops – commonwealth fisheries	5.0%	10.0%	85.0%	100.0%
Sea Mullet	0.0%	0.0%	100.0%	100.0%
Southern Bluefin Tuna (Aq)	90.0%	0.0%	10.0%	100.0%
Southern Bluefin Tuna (Wc)	0.0%	0.0%	100.0%	100.0%
Southern Rock Lobster	95.0%	0.0%	5.0%	100.0%
Tiger Flathead	10.0%	10.0%	80.0%	100.0%
Tropical Snappers	20.0%	10.0%	70.0%	100.0%
Western Rock Lobster	93.0%	0.0%	7.0%	100.0%
Yellowfin Tuna	80.2%	10.0%	9.8%	100.0%

Retail

The material consumption in retail was determined separately from wholesale and export. To determine the quantity of primary packaging of seafood products, a review of Australian supermarket seafood packaging was conducted via desktop, in-person retailer visits and interviews.

Key data was collected including country of origin, seafood mass vs consumable mass, composition of packaging material (e.g. plastic, metal, paper and cardboard, dimensions of product). This methodology approach for a single example of hard plastic, film and labels is illustrated Figure 33 (please note this is not inclusive of all retail packaging data).

A supermarket loss factor was also assigned to each product. Supermarket loss occurs when a product is not sold due to degradation, expiry, or end of life at use by date. The New Zealand Life Cycle Assessment for salmon (98) utilises a 10% loss factor. In the absence of other data, a 5% loss factor was applied to all fish subspecies.

Step	Parameter	Hard Plastic	Film	Label	Seafood mass
A	Dimensions (cm)	18 (W) x 14 (H) x 5 (D)	18 (W) x 14 (H)	6.5 (W) x 11.5 (H)	
B	Thickness (cm)	0.01	0.007	0.007	
C	Material type	Plastic	Plastic	Plastic	Organics
D	Material conversion factor	1000 kg / m^3	910 kg / m^3	910 kg / m^3	0.460 kg / product
E	Mass (kg)	A x Conversion factor (cm^3 to m^3) x C			0.460

Figure 33: *Example of how primary fish product packaging information was collated.*
Source: FRDC and RCC Analysis.

Secondary packaging can range from plastics to cardboard. For this MFA, it was assumed that all domestically sold products are packaged in EPS boxes, rather than cardboard boxes. This was considered reasonable as metal cans or long-life seafood products, which are likely to have cardboard boxes as secondary packaging are predominately imported into Australia, and therefore out of scope.

Tertiary packaging includes pallets and pallet wrap.

To estimate the quantity of secondary packaging (polystyrene) and tertiary packaging (pallet and pallet wrap), desktop research was undertaken to review how many EPS boxes of fish can generally fit on one pallet. Through discussion with industry stakeholders and site visits to fish markets, data was collected on the average kilograms of fish and ice contained in one polystyrene box. Based on this it was then estimated how many pallets and pallet wrap are used by the sector.

The end fate of pallet wrap and polystyrene boxes was assumed to align with the Australian National Waste Report (25). For pallets, it was estimated that each pallet could be reused on average 12 times, based on research on the use of wooden pallets (103).

Wholesale

Three types of packaging were identified in the wholesale supply chain segment – blue polypropylene containers, polystyrene boxes, and cardboard boxes. It is assumed that cardboard box use is negligible as no data was available. Based on information provided by a large Australian fish market, a 70% of wholesale tonnes was assumed to use blue polypropylene containers, and 30% use EPS boxes.

Information provided by a large Australian fish market on total packaging, offal waste and fish for sale, which flows through the market was used to calculate an intensity value and scaled for the sector to determine total packaging, offal, and ice consumption.

The end fate of the waste generated from packaging was assumed to align with the Australian National Waste Report (25). Reuse and recycling rates at wholesale markets may be higher than rates documented in the National Waste Report, as there are typically greater opportunities for scaled collection and collaboration at markets.

In the absence of nation-wide end-fate data at wholesale markets, the National Waste Report end fate estimations were used.

Key Assumptions, Exclusions and Limitations

Key assumptions, exclusions and limitations for the wholesale and retail supply chain stage include:

- There are significant data gaps in the market allocation distribution table for the subspecies. In the absence of specific data, generic unverified assumptions were used, these assumptions are found in Table 15 Appendix 1.
- Information provided by the largest wholesale fish market in Australia (104) was used to extrapolate the approximate material consumption for all wholesale.
- Water volumes in this MFA primarily relate to ice in the wholesale supply chain stage.
- Water and ice are used at other points throughout the supply chain, however due to data unavailability, water and ice outside of the wholesale supply chain stage was excluded.

8.7 Wild catch (recreational)

To quantify the fish produced in the wild catch (recreational) sector, data on catch per effort and the tonnes of fish caught was collected from state and territory recreational fishing surveys. The following surveys were used to quantify the tonnes of seafood caught by recreational fishers per year:

- *Survey of recreational fishing in NSW, 2019/20 – Key* Results – NSW Government Department of Industries (90)
- *The State of Recreational Fishing in Victoria* – Victorian National Parks Association (91)
- *Queensland Recreational Fishing Surveys* – Queensland Government – Department of Agriculture and Fisheries (92)
- *Survey of Recreational Fishing in South Australia in 2021-22* – Government of South Australia, Department or Primary Industries and Regions (93)
- *Fisheries Research Report No. 327*– Government of Western Australia, Department of Primary Industries and Regional Development (94)
- *2017-18 Survey of Recreational Fishing In Tasmania* – University of Tasmania and IMAS (Institute for Marine & Antarctic Studies) (95)
- Survey of recreational fishing in the Northern Territory: 2018 to 2019 – Northern Territory Government (96)

The estimated tonnes of retained catch per year by recreational fishers is found in Table 16 below.

Table 16: *Tonnes of retained catch per year by state.*
Dashes indicate where there was no data available. Source: See sources listed below.

State / Territory	Finfish (tonnes)	Crustaceans (tonnes)	Molluscs (tonnes)	Sharks & Rays (tonnes)	Total Retained Catch (tonnes)
NSW (90)	778	15	-	-	793
VIC (91)	1,121	34	44	155	1,354
QLD (92)	2,469	143	23	9	2,645
SA (93)	900	385	242	17	1,544
WA (94)	663	50	-	-	713
TAS (95)	563	-	55	28	646
NT (96)	313	18	1	2	334

To quantify the amount of recreational fishing gear used per year, data from the Norwegian Environment Agency's (NEA's) report *Basis for investigating the producer responsibility scheme for fisheries and the aquaculture industry* (105) and the FAO (106) was utilised. The NEA study provided data on the total recreational fishing gear discarded in 2016, as well as the amount of fishing gear imported into Norway between 2002 and 2016. FAO published data on the total amount of fish caught by Norwegian recreational fishers in 2009. To estimate the Norwegian recreational fish caught in 2016, the percentage change in mass imports of fishing gear into Norway across 2009 and 2016 was used as a potential correlational indicator of the growth in the economy recreational fishing industry in Norway across that time. The 2009 Norwegian recreational fish catch data provided by FOA was increased by this percentage change. The total recreational fishing gear discarded in 2016 was normalized by the amount of fish caught in 2016 to generate a tonne per fishing gear lost per tonne produced values ($\frac{t}{t_{production}}$). This was then applied to Australian data to calculate the amount of fishing gear used and ultimately lost per year.

The Norwegian Environment Agency's report contains details on the following recreational fishing equipment:

- Lobster, crab pots and fish traps
- Gillnets
- Rods and reels
- Line
- Lure

Data on equipment includes the total number of units in use per year, the total weight of each units, the amount of gear discarded per year, the of gear amount lost to sea per year. The materials classification of the gear used is outlined below in Table 17.

A per tonne metric for the amount of gear discarded and the amount of gear lost to sea. Leveraging the data and methodology in the Norwegian Environment Agency's Report and the total retained catch from the Australian state and territory recreational fishing survey, the total amount of gear sent to landfill or lost to the environment was calculated for each gear type, see Table 17.

Table 17: *Recreational fishing gear consumption per tonne of retained fish.*
Dashes indicate where there was no data available. Source: Norwegian Environment Agency's report (96)

Gear	Landfill (t/t_prod)		Lost to Environment (t/t_prod)	
	Plastic	Metal	Plastic	Metal
Traps and Pots	0.0000	-	0.1859	0.1859
Gillnets	0.0394	-	0.0492	-
Rods and Reels	0.1859	0.1859	-	-
Line	0.0041	-	-	-
Lures	-	-	-	0.0011

8.7.1 Key Assumptions, Exclusions and Limitations

Key assumptions, exclusions and limitations for recreational fishing include:

- It was assumed that recreational fishing surveys from previous years are approximately representative of the in-scope assessment period (2021).
- In the absence of Australian specific recreational fishing gear data, it was assumed that gear used in Norway is approximately indicative of the Australian recreational fishing industry.
- It is assumed that the percentage change in the mass imports of fishing gear into Norway overtime correlates to the potential growth of the recreational fishing industry.
- Upstream packaging for gear in the recreational sector has not been included.

8.8 Greenhouse Gas Emissions

In 2022, FRDC and Blueshift Consulting (59) assessed energy use and carbon emissions in the Australian fisheries and aquaculture sector. The report provided GHG emissions for fuel use, refrigerants, electricity and purchased feed for eleven defined fish species, and the production tonnes of the defined fish species.

Based on the *Calculating Seafood's Carbon Footprint Report* (59), a GHG emissions per tonne of fish intensity metric was calculated for the eleven defined fish species detailed in the report.

The intensity metrics were converted to produce an input intensity metric (unit / t_prod) for fuel, refrigerants and electricity using the Australian National Greenhouse Accounts (NGA) Factors for 2021 (107). The bait and fish feed intensity metric was quantified using Ecoinvent 3.9[1]. Input Intensity metrics can be found in Table 18.

Table 18: *GHG input intensity metrics.*
Source: FRDC and RCC Analysis

Classification	Fuel - vessels/ generators (t/t_prod)	Bait and fish feed_GHGe (t/t_prod)	Refrigerants (t/t_prod)	Electricity (kWh/t_prod)	Electricity - Process (kWh/t_prod)	Fuel - transport (t/t_prod)
Salmon	0.3133	1.0000	-	882.3529	0.5000	0.3133
Tuna	0.3133	2.6144	-	2352.9412	0.6411	0.6266
Oysters	0.6118	0.1671	-	1176.4706	0.6411	0.3133
Barramundi	0.3133	1.0000	-	8235.2083	0.6412	0.3133
Prawns AQ	0.1567	1.3072	-	9411.7647	0.6410	0.3133
Sardines	0.1567	-	-	441.1730	0.6410	0.0940
Other Finfish	0.6266	-	0.0001	1176.4706	0.6410	0.3133
Prawns WC	1.3081	-	0.0001	1176.4706	0.6410	0.3133
Rock Lobsters	1.2936	0.1743	-	1176.5441	0.6686	1.5666
Scallops	1.2533	0.0000	-	1176.4706	0.6411	0.3133
Shark rays	0.4677	0.1626	0.0001	878.2074	0.4786	0.2339

[1] The Ecoinvent Database is a Life Cycle Inventory (LCI) database that supports various types of sustainability impact assessments. Ecoinvent 3.9 is the latest release of this database

The calculation of the output intensity metrics ($\frac{t_{material}}{t_{prod}}$) in Table 19 are quantified using the total emissions per species and normalising that value by the production tonnes found detailed in Stage 1: Production.

***Table 19:** GHG output Intensity Metrics.*
Source: FRDC and RCC Analysis
** Nitrous oxide (N_2O) is only produced in aquaculture operations, as these emissions are considered additional to those that would otherwise be produced in the wild catch sector.*

Classification	Fuel - vessels/ generators	Bait and fish feed GHG_e	Refrigerants	Electricity	Electricity - Process	Fuel - transport	N20*
Unit	$\frac{t_{CO2_e}}{t_{prod}}$						
Salmon	1.0000	4.5900	0.0100	0.6882	0.5000	1.0000	0.8000
Tuna	1.0000	0.0000	0.0099	1.8353	0.5001	2.0000	0.8000
Oysters	1.9527	0.7672	0.0099	0.9176	0.5001	1.0000	0.8000
Barramundi	1.0000	4.5900	0.0099	6.4235	0.5001	1.0000	0.8001
Prawns AQ	0.5000	6.0000	0.0099	7.3412	0.5000	1.0000	0.8000
Sardines	0.5000	0.0000	0.0100	0.3441	0.5000	0.3000	0.0000
Other Finfish	2.0000	0.0000	0.2000	0.9176	0.5000	1.0000	0.0000
Prawns WC	4.1751	0.0000	0.2000	0.9176	0.5000	1.0000	0.0000
Rock Lobsters	4.1286	0.8000	0.0000	0.9177	0.5215	5.0000	0.0000
Scallops	4.0000	0.0000	0.0100	0.9176	0.5001	1.0000	0.0000
Shark rays	1.4929	0.7464	0.1493	0.6850	0.3733	0.7464	0.0000

Calculating Seafood's Carbon Footprint was limited to eleven defined fish species. To align with the in-scope subspecies of this MFA, the eleven species were mapped against the MFA's in-scope subspecies, outlined below in Table 20.

***Table 20:** Species classifications between report datasets.*
Source: FRDC and RCC Analysis.
** Subspecies naming conventions are drawn from raw ABARES data under the data item of 'species subgroup'. The full capitalisation is presented in this table for various subspecies, as drawn directly from the raw data (20).*

Species group	Subspecies*	GHG Species classification	Assumptions
Crustaceans	Western rock lobster	Rock Lobsters	-
	Prawns	Prawns WC	-
	Crabs	Prawns WC	In lieu of crab data, wild caught prawns GHG output intensity metrics have been used as given both species are from the same species group.
	King prawns	Prawns WC	-
	Banana prawns	Prawns WC	-
	Southern rock lobster	Rock Lobsters	-
Finfish	Australian sardine	Sardines	-
	Blue grenadier	Other Finfish	-
	Other finfish	Other Finfish	-
	Southern bluefin tuna	Sardines	-
	Tropical snappers	Other Finfish	-
	Sea mullet	Other Finfish	-

Species group	Subspecies*	GHG Species classification	Assumptions
	Tiger flathead	Other Finfish	-
	Mullets	Other Finfish	-
	Yellowfin tuna	Other Finfish	-
Molluscs	Scallops	Scallops	-
	Abalone	Scallops	In lieu of abalone data, scallop GHG output intensity metrics have been used as given both species are from the same species group
	Other molluscs	Scallops	In lieu of other molluscs data, Scallops GHG output intensity metrics have been used as given both species are from the same species group
Crustaceans	Prawns	Prawns AQ	-
Finfish	Salmon	Salmon	-
Molluscs	Oysters	Scallops	In lieu of oyster data, Scallops GHG output intensity metrics have been used as given both species are from the same species group
Finfish	Southern bluefin tuna	Tuna	-

To quantify the total GHG emissions associated with the sector, the values found above in Table 18 and 19 have been used with the total production tonnes of the in-scope subspecies.

8.8.1 Key Assumptions, Exclusions and Limitations

Key assumptions, exclusions and limitations for GHG emissions include:

- It is assumed that GHG emissions intensities in $\frac{t_{CO2_e}}{t_{fish}}$ are the same across Australia, across production facilities, processing, and retail and wholesale.
- Assumptions have been made to classify the species provided in the original FRDC and Blueshift Consulting GHG emission report (59) and the MFA subspecies as detailed in Table 20.

9 Appendix 2 – Definitions and acronyms

9.1 Definitions

Phrase	Definition
Absolute flow	The total materials used/consumed/lost/disposed for the fisheries and aquaculture sectors in year of assessment
Bycatch / discarded catch	Non-target species caught in the wild catch sub-sector
Circular economy	The circular economy is an economic system where value is derived from maximising the embedded value within products and materials, rather than increasing consumption. In a circular economy, waste and pollution are designed out, resources are kept in use and nature is regenerated.
Circular strategies	Strategies that adopt a regenerative model, utilising processes that reduce waste and improve resource efficiency to keep products and materials in use for as long as possible.
Domestic commercial production	Fish that is harvested through wild catch in the ocean and aquaculture for commercial sale
Domestic recreational fisheries production	Fish that is caught by individuals who fish for sport or as a recreational activity
Effluent	Liquid waste from fish and feed, including microalgae and suspended solids produced and discharged by aquaculture production
End fates	The processes waste goes through once they reach end of life. End fates include: • Final fish consumed (i.e. t_{fish}) • CO2e • N2O • Loss to Environment • Organics Recycling • Energy Recovery • Landfilling • Unaccounted for
Final fish consumed (t_{fish})	Amount in tonnes of 'in-scope subspecies' ready for customer purchase and consumption. This is the functional unit of this study that is utilised to normalise and thus compare different areas of the sector.
Fish produced	The mass of fish caught or produced prior to any processing (for example filleting)
Material Flow Analysis	A point in time assessment that quantifies the physical flow of matter and energy in an isolated system
Material intensity	The tonne of material used to create one tonne of fish for final consumption (t_{fish})
Organic waste	Waste comprised of animal or plant matter that is biodegradable
Primary packaging	Primary packaging is the packaging that touches (or makes direct contact) with food (6).
Recreational fishing surveys	This term refers to the following recreational fishing surveys: • *Survey of recreational fishing in NSW, 2019/20 – Key Results* – NSW Government Department of Industries (90) • *The State of Recreational Fishing in Victoria* - Victorian National Parks Association (91)

Phrase	Definition
	• *Queensland Recreational Fishing Surveys* - Queensland Government – Department of Agriculture and Fisheries (92) • *Survey of Recreational Fishing in South Australia in 2021-22* – Government of South Australia, Department or Primary Industries and Regions (93) • *2017-18 Survey of Recreational Fishing In Tasmania* - University of Tasmania and IMAS (Institute for Marine & Antarctic Studies) (95) • Survey of recreational fishing in the Northern Territory: 2018 to 2019 – Northern Territory Government (96) These surveys were utilised to estimate the 2021 calendar year wild catch (recreational) fishing production in tonnes.
Sankey diagram	Visualisation used to depict the movement and magnitude of materials and energy through a given system.
Scope 1 emissions	Scope 1 greenhouse gas emissions are the emissions released to the atmosphere as a direct result of an activity, or series of activities at a facility level. Scope 1 emissions are specified under the NGER legislation and must be reported (108).
Scope 2 emissions	Scope 2 greenhouse gas emissions are the emissions released to the atmosphere from the indirect consumption of an energy commodity. Scope 2 emissions are specified under the NGER legislation and must be reported (108).
Secondary packaging	Secondary packaging includes the materials used to contain single or multiple primary packed products (6).
Sector	This reference to the Australian Fisheries and Aquaculture sector inclusive of recreational fishing.
Supply chain stages	Material inputs and outputs are calculated under the following stages for each in-scope subspecies: • Production • Processing • Wholesale • Retail • Export
Sub-sector	The different source of production in the sector: • Wild catch (commercial) • Wild catch (recreational) • Aquaculture
Subspecies	These are synonymous with “species subgroups” in the ABARES 2021 production data.
System boundary	The mass of fish caught or produced prior to any processing (for example filleting).
Tertiary packaging	Tertiary packaging includes materials used to distribute packaged and unpackaged products, including pallets, wrapping stretch film, shippers, shrink film, strapping, and cartons (6).

9.2 Acronyms and Units

Acronym	Definition
ABARES	Australian Bureau of Agricultural and Resource Economics and Sciences
AFMA	Australian Fisheries Management Authority
AMCS	Australian Marine Conservation Society
APCO	Australian Packaging Covenant Organisation
AQ	Aquaculture
ARENA	Australian Renewable Energy Agency
ASC	Aquaculture Stewardship Council
ASS	Australian Sustainable Seafood
BAP	Best Aquaculture Practices
C/N	Carbon/Nitrogen
CEBIC	Circular Economy Business Innovation Centre
CoP	Communities of Practice
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DAWR	Department of Agriculture and Water Resources
DAFF	Department of Agriculture, Fisheries and Forestry
DCCEEW	Department of Climate Change, Energy, the Environment and Water
DISR / DISER	Department of Industry, Science and Resources (previously Department of Industry, Science, Energy and Resources)
EMM	Environmental Ministers Meeting
EPS	Expanded Polystyrene
FAO	Food and Agriculture Organisation
FOGO	Food Organics Garden Organics
FOS	Friend of the Sea
FRDC	Fisheries Research and Development Corporation
G.A.P	Good Agricultural Practices
GHG	Greenhouse Gas. This has the same meaning as Section 7A of the National Greenhouse and Energy Reporting Act 2007
GVP	Gross Value Product
IPF	Incitec Pivot Fertilizers
ISSB	International Sustainability Standards Board
LCI	Life Cycle Inventory
MFA	Material Flow Analysis
MSC	Marine Stewardship Council
NGA	National Greenhouse Accounts
O2E	Ocean2Earth

OECD	Organisation for Economic Co-operation and Development
SBT	Southern Bluefin Tuna
PIRSA	Department of Primary Industries and Regions South Australia
PPE	Personal Protective Equipment
RCC	Regional Circularity Cooperative
t	Tonnes
t_{fish}	Tonnes of final fish consumed. This value represents the edible parts of the seafood leftover after all losses back up the supply chain.
$t_{material}$	Tonnes of material either input to a process or output from a process and sent to an end fate. Throughout the report, materials, or end fates will be explicitly described alongside any values presented in tonnes.
WC	Wild catch

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