Broadscale microplastic assessment of NSW estuaries

Technical report 2026

Department of Climate Change, Energy, the Environment and Water

Acknowledgement of Country

Department of Climate Change, Energy, the Environment and Water acknowledges the Traditional Custodians of the lands where we work and live.

We pay our respects to Elders past, present and emerging.

This resource may contain images or names of deceased persons in photographs or historical content.

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Glossary of terms

Aquatic systems and estuary types

Back dune lagoon: Lagoon behind coastal dunes, which is ground water fed.

Barrier river: River behind a barrier like a sand bar or barrier island.

Bay: Broad inlet of the sea.

Creek: Small stream or minor tributary.

Drowned river valley estuary: Estuary formed by rising sea levels flooding river valleys.

Estuary: Where the freshwater from the river meets the saltwater from the ocean.

Estuary type: Classification based on geomorphology and water flow.

Lagoon: Shallow body of water periodically separated from a larger sea.

Lake: Large receiving body, often separated from the ocean by a barrier like a sand dune.

Degradation and breakdown processes

Biodegradation: Decomposition by microorganisms.

Fragmentation: General term for breaking plastics into smaller particles.

Hydrolysis: Breakdown by reaction with water.

Mechanical abrasion: Physical wear and tear causing material breakdown.

Mechanical fragmentation: Physical breakdown into smaller pieces (for example, by abrasion).

Photodegradation: Breakdown of plastics by sunlight, especially UV radiation.

Thermal oxidation: Decomposition due to heat and oxygen.

UV radiation degradation: Breakdown of plastic materials under UV light.

Environmental impacts

Altered nutrient cycling: Disruption of the natural movement of nutrients.

Benthic communities: Organisms living on or near the seabed.

Bioaccumulation: Build-up of substances in an organism over time.

Biomagnification: The process where the concentration of a substance, often a toxin or pollutant, increases as it moves up the food chain from one trophic level to the next.

Carbon sequestration: Capture and storage of atmospheric carbon.

Essential ecosystem services: Natural processes benefiting humans, such as clean water or pollination.

Food webs: Interconnected food chains in an ecosystem.

Nutrient cycling: Transfer and transformation of nutrients through ecosystems.

Reduced nutrient absorption: Impaired ability to uptake essential nutrients.

Trophic levels: Hierarchical levels in a food web, based on feeding position.

Trophic transfer: Movement of substances through the food chain.

Environmental terms

Anthropogenic pressures: Human-caused environmental stresses.

Baseline: Initial data used as a reference point.

Baseline dataset: Original data against which future comparisons are made.

Benchmarks: Standards or points of reference.

Concentration: Amount of a substance in a given volume.

Heterogeneity: Diversity or variety within a dataset or environment.

Intra-site variability: Variation within a single sampling location.

Liquid trade waste: Industrial or commercial liquid waste discharged into sewers.

Nutrient absorption: Uptake of nutrients by organisms.

Nutrient load: Amount of nutrients (for example, nitrogen, phosphorus) entering an ecosystem.

Pollution hotspots: Areas with high concentrations of pollution.

Typologies: Classification systems based on characteristics.

Genetic impacts

Altered gene expression: Changes in how genes are activated or silenced.

DNA damage from exposure to pollutant: Structural harm to DNA molecules.

Epigenetic modifications: Reversible changes in gene activity without altering DNA.

Genetic and epigenetic effects: Changes in gene function caused by pollutants.

Geographical and regional terms

Northern Rivers: encompassing the waters from the Tweed River in the north to Wooli River in the south.

North Coast: encompassing the waters from Station Creek in the north to Camden Haven in the south.

Mid North Coast: encompassing the waters from Manning River in the north to Karuah River in the south.

Hunter–Central Coast: encompassing the waters from Tilligerry Creek in the north to Brisbane Waters in the south.

Hawkesbury–Sydney: encompassing the waters from Hawkesbury River in the north to Wattamolla Creek in the south.

Illawarra–Shoalhaven: encompassing the waters from Towradgi Creek in the north to Burrill Lake in the south.

Eurobodalla: encompassing the waters from Durras Lake in the north to Tilba Tilba Lake in the south.

Bega: encompassing the waters from Wallaga Lake in the north to Nadgee Lake in the south.

NSW: New South Wales, a state in Australia.

NSW marine estate: Coastal and marine waters under NSW jurisdiction.

Measurement and statistics

Centimetres (cm): Metric unit of length.

Density: Mass per unit volume (g/cm^3).

Extreme values: Extremely high or low values in a dataset.

Grams: Basic unit of mass in the metric system.

Mean: Arithmetic average.

Median: Middle value in a sorted dataset.

Outliers: Values significantly different from the rest of the dataset.

Standard deviation: Statistical measure of variability.

Units of water density: Typically measured in grams per cubic centimetre (g/cm^3).

Variability: The extent to which data values differ.

Microplastic types

Primary microplastics: Intentionally manufactured small plastics (e.g., microbeads, nurdles).

Secondary microplastics: Result from breakdown of larger plastic debris.

Monitoring, sampling and equipment

300 µm mesh: Netting with holes 300 micrometres wide, used to capture microplastics.

Broadscale microplastic assessment (BMA): Large-scale monitoring program of microplastic contamination.

Codend: The collection container at the end of a sampling net.

Flow meter: Device measuring the volume of water passing through the net.

Manta net: Surface-trawling net used to collect microplastics from water.

Marine debris threat and risk assessment (MDTARA): The systematic evaluation of potential threats from, and risks posed by, marine debris to environmental assets and social values (particularly in its regional implementation New South Wales).

MP/m^3: Number of microplastics per cubic metre of water.

Nile Red: Fluorescent dye used to identify plastic particles under UV light.

Sentinel sites: Specific locations where long-term monitoring and research are conducted to understand ecosystem changes and provide early warnings about environmental threats.

Sodium chloride (NaCl): Commonly known as salt, is an ionic compound composed of sodium and chloride ions. Used in density separation of microplastics.

Threat and Risk Assessment (TARA): The systematic evaluation of potential threats and the associated risks they pose, in terms of their likelihood of occurrence and potential consequences.

µm: Micrometre; one-millionth of a metre.

Plastics and microplastics

Artificial turf: Synthetic grass often made from plastic fibres.

Covalent bonds: Strong chemical bonds formed when atoms share electrons.

Foam: Light, airy plastic material such as polystyrene foam.

Microplastic morphology: The shape and form of microplastic particles, such as fragments, fibres, films and pellets.

Monomers: Small molecules that can join to form polymers.

Natural plastics: Polymers derived from natural sources like plants or animals (e.g., rubber, shellac, cellulose).

Plastic fibres: Thread-like plastic strands, often from textiles.

Plastic film: Thin, flexible plastic in sheets or pieces.

Plastic fragments: Broken pieces of larger plastic items.

Plastic pellets (nurdles): Small, raw plastic beads used in manufacturing.

Plastic type: The classification of plastic based on polymer composition (e.g., PET, HDPE).

Polymerisation of monomers: Chemical process where monomers bond to form polymers.

Semi-synthetic plastics: Modified natural polymers, such as cellulose acetate.

Synthetic plastics: Man-made polymers created through chemical processes, for example, polyethylene, PVC.

Synthetic polymers: Large molecules made from repeating units (monomers) synthesised chemically.

Abbreviations and definitions

Abbreviation	Full form	Definition
AIMS	Australian Institute of Marine Science	Research agency focused on marine ecosystems
BMA	Broadscale microplastic assessment	Survey of microplastic concentrations in coastal surface waters
CSIRO	Commonwealth Scientific and Industrial Research Organisation	Australia's national science agency
DCCEEW	Department of Climate Change, Energy, the Environment and Water	NSW government department responsible for climate and environmental policy
DNA	Deoxyribonucleic acid	Genetic material found in living organisms
EPA	Environment Protection Authority	New South Wales's independent environmental regulator
FTIR	Fourier Transform Infrared Spectroscopy	An analytical technique used to identify plastic polymer types
GIMP	GNU Image Manipulation Program	Free software for photo editing and graphic design
GPS	Global Positioning System	Satellite navigation system for determining location
GPT	Gross Pollutant Trap	A device used to capture large litter and debris in stormwater systems
HDPE	High-density polyethylene	Durable plastic used in containers and piping
ICOLL	Intermittently Closed and Open Lakes and Lagoons	Coastal lagoons alternate between open and closed states
IMOS	Integrated Marine Observing System	Australian national ocean monitoring system
KOH	Potassium hydroxide	A strong base used in sample digestion and cleaning
LDPE	Low-density polyethylene	Flexible plastic used in bags and film wraps
MEMS	NSW Marine Estate Management Strategy	The NSW MEMS 2018 – 2028 outlines how to protect and enhance our waterways, coastline, and estuaries over the next 10 years

Abbreviation	Full form	Definition
MP	Microplastic	Small plastic particles less than 5 mm in size
NR	Nile Red	Fluorescent dye
NSW	New South Wales	A state on the east coast of Australia
OEH	Office of Environment and Heritage	The former NSW agency for environment and heritage management
PET	Polyethylene terephthalate	A common plastic used in drink bottles and containers
PP	Polypropylene	A plastic used in packaging, textiles, and automotive parts
PS	Polystyrene	Lightweight plastic used in foam products and containers
PVC	Polyvinyl chloride	Versatile plastic used in construction and plumbing
QGIS	Quantum Geographic Information System	Open-source GIS software for spatial data analysis
SD	Standard deviation	Statistical measure of data spread or variability
UV	Ultraviolet	Type of electromagnetic radiation from the sun
WWCS	Water, Wetlands, and Coastal Science	Team within the department

Summary

The *Broadscale microplastic assessment,* is the first large-scale study of its kind in Australia, systematically evaluating microplastic contamination across 120 coastal waterways in New South Wales. Commissioned by the NSW Environment Protection Authority (NSW EPA) under the NSW Government's *Waste and Sustainable Materials Strategy*, this initiative was designed in response to the NSW *Marine debris threat and risk assessment* (MDTARA).

The MDTARA identified microplastics (plastic particles smaller than 5 mm in size) as a priority threat to the NSW marine estate, with significant knowledge gaps identified including a lack of microplastic distribution and abundance data. This has led to an inability to spatially assess microplastic contamination and associated threat in a similar manner to that undertaken for other priority threats.

Acknowledging knowledge gaps and the growing threat that microplastics have on aquatic environments, in particular critical ecosystems like estuaries, the *Broadscale microplastic assessment of NSW estuaries* was initiated and undertaken by the department. This study had 4 core objectives:

1. to establish a statewide baseline of microplastic concentrations in 120 NSW coastal waterways
2. to develop a grading system for microplastic contamination that allows comparative assessment across waterways
3. to produce a spatial heat map to identify microplastic contamination hotspots
4. to characterise dominant microplastic types to inform targeted management.

Between 2021 and 2024 surface water samples were collected during summer months using manta net tows. Microplastics sized 0.25 to 5 mm were extracted, stained with Nile Red, photographed, and counted via automated image analysis. Larger particles (>2 mm) were visually classified by morphology into 5 categories: fragments, foam, film, artificial turf and pellets.

The results revealed widespread microplastic contamination in NSW coastal waterways, with all 120 waterways containing detectable levels of microplastic. Across all waterways, mean concentrations ranged from 0.02 to 34.80 microplastics per cubic metre (MP/m^3), with a median of 0.38 MP/m^3.

A percentile-based grading system (Grades A–E) was applied to classify microplastic contamination. Most waterways received a moderate contamination grade (C), while 23 of the 120 waterways surveyed exceeded 1.3 MP/m^3 and were categorised as Grade E (very high microplastic contamination). This 1.3 MP/m^3 measurement is equivalent to an Olympic swimming pool (~2,500 m^3) containing approximately 3,250 microplastics. These highly contaminated sites were primarily in densely urbanised areas, reinforcing the relationship between land-use intensity, population density and microplastic contamination.

Urbanised waterways in the Hawkesbury–Sydney region, exhibited the highest levels of microplastics contamination. This was notable in Cooks River (mean = 19.89 MP/m^3), Dee Why Lagoon (mean = 22.45 MP/m^3), and Duck River (mean = 34.80 MP/m^3). These mean microplastic concentrations are concerning when placed in an international context, as urbanised waterways around the world have often reported far lower mean microplastic concentrations. For example, studies undertaken in the River Seine in Paris found mean concentrations of between 0.28–0.47 MP/m^3, and those undertaken in Tampa Bay in Florida and the Yangtze River estuary in China found concentrations of 4.5 MP/m^3 and 1.01 MP/m^3,respectively.

In contrast, less disturbed areas in New South Wales such as Myall Lake and Nadgee Lake recorded much lower concentrations (0.02 MP/m^3 and 0.08 MP/m^3, respectively), aligning with levels observed in offshore Australian waters (0.02–0.13 MP/m^3).

Microplastic abundance was inversely related to size when considering the 31,966 particles counted (0.25–5 mm) in the *Broadscale microplastic assessment of NSW estuaries.* Smaller sized particles (>0.25 – <1 mm) were the most abundant, accounting for 68% of all particles. Medium sized particles (1 – <2 mm) accounted for 18%, and large particles (2 – <5 mm) accounted for 14% of all particles.

Among larger particles, foam and hard fragments were most abundant (37% each), followed by film (19%), artificial turf (5%), and pellets (2%). Foam, artificial turf fragments and pellets were considered priority items due to their traceable sources.

These microplastics collectively accounted for 44% of all characterised particles and offer a practical target for future intervention. Pellets used in industrial plastic manufacturing were detected in 9% of surveyed waterways. Artificial turf fragments, primarily originating from synthetic playing fields, were present in 17% of surveyed waterways.

Several waterways with consistently high microplastic contamination are considered priority waterways for microplastic management including Cooks River, Parramatta River and its tributaries, Dee Why Lagoon and Manly Lagoon. These systems require further investigation and targeted mitigation strategies to help reduce microplastic loads.

Despite its significance, this study had several limitations, including seasonal sampling bias, limited replication, a focus on surface waters and the exclusion of particles <0.25 mm. These limitations have led to an underestimation of the total contamination and bioavailability of microplastics in coastal estuaries.

Future monitoring should be expanded to include seasonal variation, sediment and subsurface sampling, smaller particle size classes, and chemical composition analyses.

Overall, this assessment has provided a scientifically rigorous foundation for statewide monitoring and management of microplastic contamination. It highlights the need for a long-term monitoring program, expanded ecosystem risk assessment and targeted policy interventions, particularly in high-risk urban catchments.

By establishing a benchmark for microplastic contamination, the *Broadscale microplastic assessment of NSW estuaries* strengthens the ability of the NSW Government to track trends, evaluate management efficacy and inform regulatory and planning decisions.

As estuarine systems face increasing pressures from urbanisation, population growth and climate change, sustained investment in monitoring and intervention will be critical to protecting the ecological health and resilience of NSW waterways.

1. Project background

1.1 Project overview

Microplastics (plastic particles less than (<) 5 mm in size), are an emerging contaminant of concern and have been identified as a significant threat to the New South Wales (NSW) marine estate (NSW Department of Planning and Environment, 2022). In 2022, the *NSW Marine debris threat and risk assessment* (MDTARA) identified microplastics as the highest-priority marine debris threat item with significant threats to both environmental assets and social values (NSW Department of Planning and Environment, 2022).

While microplastics were identified as a high threat item, the MDTARA also identified the critical challenge associated with the lack of distribution and abundance data within the NSW marine estate. This results in an inability to spatially assess microplastic concentration and associated risk in a similar way to that undertaken for other priority threats (NSW Department of Planning and Environment, 2022).

Establishing robust distribution and abundance datasets is essential for assessing spatial risks, informing management decisions and prioritising mitigation efforts to effectively reduce the threat of microplastic contamination in the NSW marine estate (NSW Department of Planning and Environment, 2022). Addressing these knowledge gaps is important for the development of evidence-based mitigation strategies.

The NSW Environment Protection Authority (EPA) plays a key role in regulating and managing waste across the state, delivering initiatives under the *NSW Waste and Sustainable Materials Strategy*. This $356 million strategy includes policy reforms, such as the phase out of problematic single-use plastics, and allocates $38 million towards litter prevention programs.

Waterway protection is a key area of focus given their well-established role as a ‘sink’ for environmental litter. The NSW Government has also committed funding to plastics research through the *NSW Plastics Action Plan*, with one of the objectives aiming to enhance our understanding of microplastic pollution and guide future management actions.

As part of the NSW EPA’s commitment to reducing waste impacts and supporting a circular economy, measures are currently being implemented to improve water quality and reduce pollution in waterways. These initiatives seek to protect public health, safeguard aquatic ecosystems and ensure the long-term sustainability of New South Wales’s water resources while supporting economic resilience. Effective pollution management requires targeted interventions based on scientifically rigorous and comprehensive data.

To achieve this, the NSW EPA funded the *Broadscale microplastic assessment of NSW estuaries* to address existing knowledge gaps and guide strategic management actions. This initiative aims to achieve 4 key objectives.

Objectives

1. **Establish a baseline dataset** for microplastic concentrations across the NSW marine estate.
2. **Develop microplastic contamination grades** to facilitate comparative assessments.
3. **Create a spatial heat map** to identify microplastic contamination hotspots.
4. **Characterise microplastic polymer types** to inform prioritisation of management interventions.

This *Broadscale microplastic assessment of NSW estuaries* focused on the collection and analysis of microplastic samples taken from across 120 coastal waterways. It aimed to generate robust datasets required to evaluate contamination levels, identify pollution hotspots and assess the spatial distribution of microplastic contamination.

The outcomes of this study will inform current initiatives led by the NSW EPA, supporting the protection of marine ecosystems and contributing to the objectives of the *NSW Waste and Sustainable Materials Strategy* and the *NSW Plastics Action Plan*.

By achieving these goals, the *Broadscale microplastic assessment of NSW estuaries* will help deliver valuable scientific evidence on the extent of microplastic contamination in New South Wales, strengthen the foundation for evidence-based decision-making and support targeted interventions to reduce the environmental impacts of microplastics in NSW waterways.

1.2 Plastic pollution

1.2.1 Introduction to plastic pollution

Plastic pollution is widely recognised as one of the most pressing environmental challenges of the 21st century (Horton, 2022) (see Photograph 1 as an example of plastic pollution).

Projections suggest that by 2050, plastic waste in the ocean may surpass the biomass of fish, highlighting the severity of the issue (World Economic Forum, 2016). Despite growing awareness of the impacts of plastic pollution, global plastic production continues to increase, with the petrochemical industry expected to triple plastic production by mid-century. This escalation is projected to account for 15% of the total global carbon budget by 2050 (World Economic Forum, 2016).

Photograph 1 Plastic pollution at Plane Spotting Beach, Botany Bay, NSW. Samantha Lynch/DCCEEW

1.2.2 Composition and classification of plastics

Plastics are synthetic or semi-synthetic polymers produced through the polymerisation of monomers derived from natural resources like petrochemicals or increasingly from renewable sources such as corn starch or sugarcane sources and often combined with various chemical additives (Kumari et al., 2023).

Plastic monomers are typically composed of carbon and hydrogen and sometimes include additional elements such as oxygen, nitrogen, or halogens in various functional groups. Plastic monomers combine via covalent bonds to form long-chain polymers. The resulting polymer structure determines the material's physical and chemical properties.

Common monomers used in plastic manufacturing include ethylene and propylene, which contribute to the lightweight and versatile properties of plastic materials (Hassan et al., 2022).

Plastics play a vital role in various industries including health care, technology, construction and textiles, due to their advantageous properties such as low cost, durability, high strength, corrosion resistance and thermal insulation (Andrady and Neal, 2009).

Plastics have also replaced materials sourced from endangered wildlife such as ivory, tortoiseshell and fur (in textiles), reducing the demand for these natural materials (Horton, 2022).

Plastics can be classified based on multiple factors, including their origin, molecular structure, polymerisation mechanism and thermal behaviour.

Classification by origin divides plastics into 3 categories (Pilapitiya and Ratnayake, 2024):

- **Natural plastics**, derived from biological sources such as lignin, chitin and starch.
- **Semi-synthetic plastics**, which are chemically modified natural polymers such as cotton and polyester mixtures (Kroon et al., 2018).
- **Synthetic plastics**, produced from petrochemicals including polyethylene and polystyrene (Khan and Majeed, 2019; Napper and Thompson, 2020).

This study focuses on synthetic plastics in surface waters. Examples of synthetic plastic categories, characteristics and their use are outlined in Table 1.

Table 1 A list of the most common plastic types, their abbreviations, and densities

Plastic type	Abbreviation	Density (g/cm^3) *	Use
Polyethylene terephthalate	PET	1.37 – 1.45	Drink packaging, clothing
High-density polyethylene	HDPE	0.94 – 0.97	Grocery bags, milk jugs, recycling bins, agricultural pipes
Low-density polyethylene	LDPE	0.91 – 0.94	Plastic film, plastic bags, six-ring packs, dispensing bottles, snack and confectionary packaging, bread bags
Polyvinyl chloride	PVC	1.10 – 1.40	Building and construction
Polypropylene	PP	0.86 – 0.92	Bottle caps, straws, plastic food containers, textiles
Polystyrene	PS	0.96 – 1.05	Beverage cups, insulation, packing materials
Other Polycarbonate Nylon (Polyamide) Teflon	 PC PA PTFE	1.20 – 2.30	Phones, sunglasses, safety goggles, cable ties, cookware coatings

*Density of surface ocean water is 1.03 g/cm

1.2.3 Pathways of plastic pollution into aquatic environments

Despite the existence of recycling systems, most plastic waste is sent to landfill or is, incinerated. Plastic waste also escapes formal waste management systems entirely. The World Economic Forum's 'New Plastics Economy' report estimated that approximately 32% of all plastic packaging escapes collection systems and leaks into the environment (World Economic Forum, 2016).

This 'leakage' occurs through pathways such as littering, stormwater runoff, illegal dumping, landfill overflow and wind dispersal. Plastics lost in urban areas are particularly prone to entering waterways via drains, creeks and stormwater infrastructure (Ahmad et al., 2025).

1.2.4 Environmental persistence and degradation of plastics

Plastic waste is an increasingly pervasive environmental issue, and plastic debris is found across all ecosystems from urban landscapes and beaches to remote islands and deep-sea environments (Bucci et al., 2020). The persistence of plastics in the environment is attributed to their chemical stability, high molecular weight, complex three-dimensional structures and resistance to biodegradation (Cai et al., 2023).

Despite their long-term stability, plastics undergo various degradation processes when exposed to environmental conditions. These processes include photodegradation, thermal oxidation, hydrolysis, biodegradation and mechanical fragmentation.

Plastic degradation contributes to the formation of smaller plastic particles over time (Oh and Stache, 2024). Despite degradation the ubiquity of plastics remains evident across diverse ecosystems including deserts, agricultural fields, mountaintops and marine environments (see Photograph 2) (Cózar et al., 2014; Li et al., 2025).

Photograph 2 Microplastics found on the dune face of Blossoms Beach, Western Australia. Samantha Lynch/DCCEEW

1.2.5 Classification of plastic pollution by size

Plastics found in the environment can be categorised into 4 primary classes based on particle size (Table 2) (Gigault et al., 2018; Wootton et al., 2025).

Table 2 Classification of plastic by particle size

Plastic Pollution Classification	Size
Macroplastics	>25 mm
Mesoplastics	≥5 mm to 25 mm
Microplastics	≥1 µm to <5 mm
Nanoplastics	<1 µm

1.3 Microplastics

1.3.1 Introduction to microplastics

Microplastics, plastics less than (<) 5 mm in size, are present in many environments and come from both primary and secondary sources (Photograph 3).

Primary sources

Microplastics that are intentionally manufactured at a microscopic size (≤5 mm), such as:

- microbeads
- plastic feedstock (nurdles)
- fibres

Secondary sources

Microplastics that originate from the breakdown of larger plastic materials due to environmental degradation, such as the fragmentation of plastic bottles or bags.

Photograph 3 Microplastics (2 – 5 mm). Jaimie Loa/DCCEEW

Primary microplastics directly enter the environment through wastewater discharge, industrial spills or improper disposal. Secondary microplastics are formed in the environment through physical, chemical, and biological processes such as exposure to UV radiation, mechanical abrasion and microbial activity (CSIRO, 2020; Song et al., 2017).

Most plastic waste entering marine environments originates from terrestrial sources. This can be due to improper waste disposal, stormwater runoff, littering and inadequately managed landfills.

Other entry mechanisms include runoff from sports fields, liquid trade waste, sewage treatment facilities, plastic manufacturing plants and litter arising from recreational activities such as fishing (Cole et al., 2011, CSIRO, 2020).

Once in the environment, microplastics are transported by hydrodynamic and atmospheric processes which facilitate their distribution across diverse ecosystems including rivers, estuaries, and open oceans (Cózar et al., 2014).

1.3.2 Environmental and ecological impacts of microplastics

Microplastic pose significant threats to aquatic organisms (Palmer and Herat, 2021). The primary threats include ingestion and physical impacts. Many species, including fish, birds, marine mammals and invertebrates ingest microplastics leading to digestive blockages, reduced nutrient absorption and malnutrition.

Microplastics can also enter the food chain, starting from primary producers such as phytoplankton and algae, and then progress through various trophic levels (Liu and Li, 2025). Recent studies have provided valuable insights into the potential consequences of microplastic contamination on various organisms and ecosystems, such as:

Potential disruption of food webs

Microplastics affect organisms at lower trophic levels, reducing their growth, productivity and availability as prey for higher consumers. For instance, microplastics have been shown to impair photosynthetic efficiency and alter chlorophyll concentrations in primary producers (Cao et al., 2022; Mao et al., 2018; Wu et al., 2019). *Chlorella vulgaris* exhibited oxidative stress under microplastic exposure (Fu et al., 2019), while *Microcystis aeruginosa* showed altered gene expression (Zhou et al., 2021). Furthermore, microplastics have been detected in zooplankton such as copepods and daphnids (Swain et al., 2025), with sustained exposure in *Eurytemora affinis* shown to reduce reproductive success, survival and feeding efficiency (Ali et al., 2024). Collectively, these findings indicate that microplastic contamination may induce bottom-up effects with cascading impacts on ecosystem structure and function.

Altered nutrient cycling

Microplastics can disrupt key biogeochemical cycles, including those of nitrogen, carbon, phosphorus and other micronutrients (De Silva et al., 2021; Bosker et al., 2019). Microplastics can cause imbalances in ecosystem nutrient dynamics by interfering with microbial processes responsible for nutrient remineralisation, (Oberbeckmann and Labrenz, 2020). For instance, their presence has been shown to alter soil microbial community composition, impair enzyme activity and disrupt nitrogen cycling (Brtnicky et al., 2025).

Similarly, microplastics can influence carbon cycling by modifying microbial activity, plant growth, litter decomposition and soil structure, ultimately affecting carbon storage and losses through respiration and leaching (Rillig et al., 2021).

Habitat alteration

The accumulation of microplastics in sediments and coastal zones can modify substrate composition, impacting benthic communities and essential ecological functions such as sediment stability and nutrient exchange (Horton et al., 2017).

Microplastics negatively affect habitats by diminishing floral and faunal biomass, reducing ecosystem productivity and disrupting key biogeochemical processes such as nitrogen cycling, oxygen production and carbon sequestration (Sridharan et al., 2021).

Disruptions in species interactions

Microplastic contamination can influence predator-prey relationships, alter foraging behaviours and reduce reproductive success in various aquatic species (Lu et al., 2021; Wright et al., 2013). In a study by Huang et al. (2020), the Lotka-Volterra model was used to theoretically investigate predator-prey population dynamics in relation to the toxicology response to microplastic particles. They found that microplastic particles reduce predator populations, leading to an increased prey abundance. This imbalance may result in ecosystem disruption (Huang et al., 2020).

Genetic and epigenetic effects

Microplastic exposure has been linked to DNA damage, altered gene expression and epigenetic modifications, which may influence population dynamics and species adaptation (Xu et al., 2021).

Studies have shown that microplastics can impair growth, reproduction and behaviour in organisms and can contribute to genotoxicity and stress (Wade et al., 2025). For example, Wade et al. (2025) reported that microplastic exposure induced heritable changes in gene regulation in fathead minnows (*Pimephales promelas*). They observed transgenerational effects, highlighting a mechanism in which parents can pass on the effects of microplastic exposure to their offspring. These findings highlight the potential for microplastics to cause long-term physiological and evolutionary impacts across species.

Microplastics act as vectors for persistent organic pollutants (POPs), heavy metals and invasive species

Plastics have large, hydrophobic surface areas which facilitates the adsorption of POPs and heavy metals from the surrounding environment. Because microplastics are persistent and buoyant adsorbed contaminants can be transported across ecosystems and, upon microplastic ingestion, organisms can bioaccumulate these contaminants and transfer across trophic levels (Farale et al., 2025; Gateuille and Naffrechoux, 2022; Sun et al., 2023).

These microplastic characteristics – large surface area, buoyant nature and ease of transport – also enable microplastics to act as dispersal vectors for both macro and microorganisms, including invasive species, which can colonise on plastic surfaces and spread across marine ecosystems, potentially altering endemic species composition (Agathokleous et al., 2021; García-Gómez et al., 2021; Gaylarde et al., 2023).

1.3.3 Microplastics in the NSW marine estate

The MDTARA identified microplastics as the highest-priority threat to the marine estate and highlighted the absence of spatial risk mapping as a major limitation in microplastic management.

Establishing comprehensive distribution and abundance datasets is crucial for identifying contamination hotspots and prioritising mitigation efforts. Given this, a broadscale microplastic assessment (this study) was undertaken in estuarine systems across the NSW marine estate.

Estuarine systems are crucial for microplastic monitoring as they are the receiving waters from upstream catchments and terrestrial sources. Estuaries act as sinks and temporarily retain microplastics before they are transported to the open ocean (Malli et al., 2022).

1.4 NSW estuaries

Monitoring estuarine ecosystems is important for understanding microplastic fluxes, identifying contamination sources and implementing targeted mitigation strategies to reduce the impact of microplastic pollution on marine biodiversity and water quality.

1.4.1 Introduction to NSW estuaries

Estuaries are coastal water bodies where freshwater runoff from the land meets the saltwater of the sea. They are places of transition from freshwater to saltwater environments and can be connected to the sea periodically or permanently. The salinity of estuaries is highly variable, being increased by oceanic influence and evaporation and diluted by freshwater from the catchments (Scanes et al., 2020).

Estuaries function as critical transition zones between terrestrial and marine environments, providing essential ecosystem services such as nutrient cycling, carbon sequestration, trophic transfer and support for both aquaculture and wild fisheries. These dynamic systems also serve as biodiversity hotspots, offering vital nursery habitats for commercially significant fish species (Scanes et al., 2020).

There are **184 estuaries** along the NSW coast:

- 55 in the northern region
- 40 in the central region
- 89 in the southern region.

1.4.2 Estuary types

NSW estuaries are dynamic systems and are classified into different groups or types according to their catchment characteristics, hydrodynamics, and connection to the sea.

The estuary typology classification is based upon the relative size of a system's catchment and receiving basin, degree of groundwater input and the propensity of the system to be closed or open to the ocean.

These typological characteristics impact a system's retention time and flushing rate and consequently its ability to concentrate or dilute inflowing contaminants. Based on this information, NSW estuaries are divided into: rivers, creeks, lakes, lagoons or back dune lagoons as outlined in Table 3.

Table 3 NSW Estuary types

Estuary type	Description	Entrance	Catchment	Examples
River (Drowned river valley)	Large and usually deep, formed by ocean flooding	Deep and wide and does not close	Large upland catchments and groundwater sources	Hawkesbury River Sydney Harbour
River Barrier river	Small to large rivers that are usually shallow	Affected by sand moving along the coast, some can close during periods of low freshwater	Large upland catchments and groundwater sources	Manning River Shoalhaven River
Creek	Small and narrow	Close frequently, but rapidly open in rainfall	Small floodplain catchments and local ground water	Tallow Creek
Lake	Moderate to large and tend to have a broad, open shape	Tend to be open, but are affected by sand moving along the coast and some can close	Small floodplain catchments and local ground water	Wallis Lake Lake Macquarie
Lagoon	Small to moderate in size with a broad, open shape and tend to be shallow	Often closed and will open after heavy rainfall in the catchment	Small floodplain catchments and local ground water	Narrabeen Lagoon Woolgoolga Lake
Back dune lagoon	Small to moderate in size with a broad, open shape and tend to be shallow	Often closed for a long time (years), but will open after heavy rainfall	Very small surface water catchments, predominantly local ground water	Dee Why Lagoon Nadgee Lake
Bay	Coastal oceanic embayment	Deep and wide	Large rivers	Jervis Bay

Lakes and rivers typically maintain an open connection to the ocean due to sufficient catchment inflows. Lagoons, creeks, and back dune lagoons are more prone to experience periodic closures during low-flow conditions (Hinwood et al., 2025). All estuary types are relatively shallow, allowing wind and tidal forces to maintain vertical mixing throughout the water column (Ralstonet al., 2010).

Intermittently open estuaries (lakes, lagoons, creeks, and back dune lagoons, known as Intermittently Closed and Open Lakes and Lagoons [ICOLL's]) experience periodic closures due to sandbar formation at their mouths (Photograph 4 and Figure 1). These systems alternate between open and closed states, significantly affecting dilution and flushing processes. When the estuary is open, tidal exchange allows for export of pollutants to the ocean.

During closed phases, contaminants are retained within estuarine waters and dilution is limited by the maximum potential volume of the receiving basin. Flushing efficiency is highly variable. When the estuary is open, strong tidal and riverine flows can effectively flush contaminants out to sea. When closed, pollutants accumulate leading to increased concentrations and potential environmental stress (Roper et al., 2011).

Photograph 4 Merrica River, Nadgee Wilderness, intermittently open estuarine system. Samantha Lynch/DCCEEW

Permanently open estuaries (predominately rivers) maintain a continuous connection to the ocean and continuous tidal exchange promotes better dilution as ocean water regularly mixes with estuarine waters, reducing contaminant concentrations (Figure 1). Additionally, higher flushing rates due to consistent tidal and riverine influences help transport pollutants out to the open ocean more efficiently (Roper et al., 2011).

However, even in well-flushed systems water quality can be compromised by sedimentation and contamination from sources such as stormwater runoff, bushfires, urbanisation, agriculture, industrial activities, floodplain drainage and sewage overflows. Pollutants can accumulate in sediments leading to ecological and human health risks, and opening estuaries does not necessarily mitigate contamination.

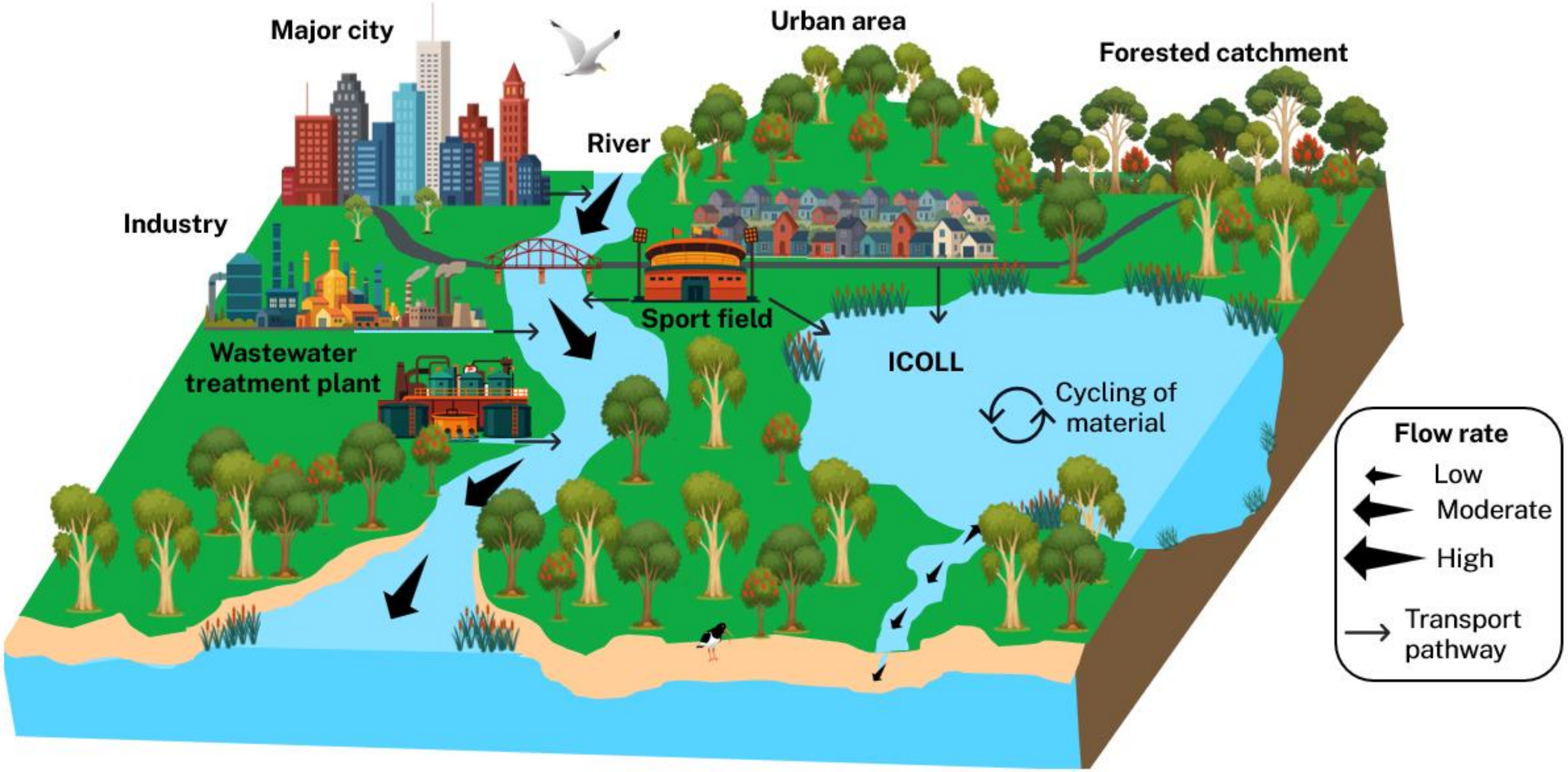


Figure 1 Conceptual diagram of open and closed systems. A permanently open system (River) on the left and an Intermittently Closed and Open Lake and Lagoon (ICOLL) on the right. ICOLL's experience limited flushing during closure, increasing the risk of pollutant accumulation. In contrast, permanently open systems facilitate greater dilution and flushing, decreasing the likelihood of pollutant retention. Diagram created by Tim Remaili

1.4.3 Catchment disturbance

Globally, estuaries are under increasing pressure from catchment disturbances which affect water quality and ecosystem health. In New South Wales, the most significant threats to environmental values from water pollution are urban stormwater discharge, agricultural diffuse-source runoff and solid waste such as marine debris and microplastics (Marine Estate Management Authority, 2017). The 184 estuaries in New South Wales have previously been categorised by the degree of disturbance in their catchments – from very high to very low.

Disturbance level is determined by a catchment land use assessment that uses the ratio of modelled total nitrogen loads for current land use to hypothetical pre-European settlement nitrogen loads (Roper et al., 2011). Monitoring estuaries of varying typologies across different disturbance levels allows us to monitor changes over time and understand factors impacting their resilience.

1.4.4 NSW Estuary Health Monitoring Program

Estuaries serve as vital ecosystems within the NSW marine estate, making them essential habitats for monitoring environmental changes[1].

Monitoring estuarine condition generally involves the routine or repeated measurement of physical, chemical and/or biological parameters to (i) quantify ecological status, (ii) detect and characterise human impacts, and (iii) evaluate ecosystem responses to management actions (Hirst, 2008).

It is important that monitoring outputs are reported in an appropriate manner (that is, grades [A-E]) rather than by simply supplying raw data as this allows the information to be better understood and utilised by managers, other stakeholders and the wider community (Hallett et al., 2016).

The Water Wetlands and Coastal Science (WWCS) team in the NSW Department of Climate Change, Energy, the Environment, and Water (DCCEEW), monitors, evaluates and reports on the health of NSW estuaries in order to assess the overall condition of estuarine ecosystems, understand where more research is needed and help inform management decisions. This program is called the NSW Estuary Health Monitoring Program (Hallett et al., 2016; OEH, 2016) and it monitors waterway health by measuring chlorophyll concentration, turbidity, nutrient concentrations and physical chemistry.

This program has been collecting data from NSW estuaries since 2007, using the sampling design that is set out in Roper et al. (2011). The data has been used to calculate an Estuary Health Index which grades estuaries ranging from A (very good) to E (very poor) (OEH (2016).

This long-term dataset has improved the understanding of the NSW estuarine water quality changes over time. Recent findings by Scanes et al. (2020) demonstrated that estuarine waters are warming at a rate exceeding that of both air and sea surface temperatures, with an average summer temperature increase of 2.16°C over the past decade (2010 to 2020).

Estuaries are increasingly subjected to anthropogenic pressures and play a critical role in assessing environmental impacts as they receive inputs from upstream and terrestrial sources. Estuaries function as temporary sinks, retaining pollutants before their eventual transport to the open ocean (Malli et al., 2022), highlighting the significance of estuaries as key monitoring sites for microplastic contamination.

1.5 Microplastic monitoring

Efforts to quantify microplastics in Australian coastal systems have been geographically limited and methodologically inconsistent. A comprehensive review of microplastic studies in Australian coastal environments identified 43 studies targeting sediment, 39 targeting biota and only 28 focused on microplastics in water (Wootton et al., 2024).

Of the limited number of studies targeting microplastics in aquatic environments only a few quantified concentrations across multiple sites using consistent methodologies. This highlights a significant knowledge gap in understanding the spatial distribution and abundance of microplastics within the Australian marine estate, including in New South Wales.

Considering this, and recognising the role of estuaries as contaminant sinks, water was chosen as the focus medium for this study. Additionally, water plays a key role in transporting microplastics from terrestrial to marine environments, particularly through estuarine systems where urban, industrial and catchment-based inputs converge. Therefore, water sampling provides a dynamic snapshot of microplastic load and mobility, capturing both localised discharges and cumulative upstream influences.

To ensure methodological rigour and comparability, a review of national and international microplastics monitoring practices was undertaken with a focus on coastal areas including estuarine environments.

Globally, surface trawling using neuston, plankton or manta nets is the most widely used approach (Gallagher et al., 2016; McEachern et al., 2019; Yonkos et al., 2014). These nets are typically designed with a rectangular mouth and dual floats, enabling the collection of large volumes of surface water. Surface tow nets with mesh sizes ranging from 200–333 µm are commonly used for sampling plastic debris from rivers, estuaries and marine environments, balancing particle capture efficiency with sampling feasibility.

On a national scale, Reisser et al. (2013) assessed plastic concentrations across Australian marine waters using surface net tows. While this study provided important baseline data, other Australian studies have employed varied sampling methods (e.g., manta, plankton and neuston nets), often with differing mesh sizes and sampling depths, reflecting the lack of method standardisation observed internationally. This is a recurring limitation across the literature and constrains data comparability and hinders regional or national syntheses (Wootton et al., 2024).

Among the methodological factors varying in the literature, the mesh size of the nets used to sample water remains a critical factor influencing microplastic detection rates and study comparability (Wootton et al., 2024).

Dris et al. (2018) demonstrated that nets with standard 330 µm mesh significantly underestimate microplastic concentrations compared to finer 80 µm mesh. However, a greater diversity of shape and types may be captured in larger mesh sizes. Furthermore, finer meshes are more prone to clogging, especially in turbid or organic-rich estuarine environments, leading to reduced effective sampling volumes (Dris et al., 2018).

In Australia, the Integrated Marine Observing System (IMOS) Marine Microplastics Sub-Facility, coordinated by the Australian Institute of Marine Science (AIMS), has adopted a neuston net approach (350 µm mesh) to monitor temporal and spatial variations of microplastics in coastal marine waters (Kroon et al., 2018).

To ensure consistency and enable comparison with national monitoring datasets, the current study aligned with AIMS methodologies, adapting their towed net design (Lynch et al., 2025). This methodology alignment supports the broader microplastic science community objective of establishing a consistent, scalable, microplastics monitoring framework across estuaries and coastal systems in New South Wales.

2. Methods

2.1 Sampling overview

A statewide survey encompassing 120 coastal waterways was undertaken by the department, between November 2021 and March 2024, to quantify microplastic concentrations and establish baseline conditions (Figure 2; Table 5).

The survey spanned 3 regions: North, Central, and South, to represent the geographical and climatic diversity of the NSW coastline (Figure 2). Sampling was carried out over 3 consecutive summers, with each region surveyed during a designated field season (Table 4):

- Northern region: November 2021 – January 2022
- Central region: January – March 2023
- Southern region: January – March 2024

A subset of 11 annual monitoring sites (marked with an * in Table 5) were resampled in each of the sampling years to support temporal analysis and comparison of systems and regions across years for grading.

Sampling in each region was designed to include replicate trips within the designated survey windows. A minimum interval of 3 weeks was maintained between replicate trips. Table 4 provides details of each sampling trip, including timing and region.

Table 4 Microplastic sampling trips.

	North	Central	South	Annual sites
Trip 1	November 2021	January 2023	January 2024	Every year
Trip 2	January 2022	March 2023	March 2024	Every year

Sampling sites were selected following the program design by Roper et al. (2011). Lakes, creeks, and lagoons, were sampled within designated central basin zones to ensure representative system coverage (Figure 3). River sites were selected based on salinity gradients (10–25 g/L [ppt]). A longitudinal transect of the mid-section of the river was conducted, with sampling zones selected within the appropriate salinity range (Figure 4).

The microplastic sample collection and processing method followed a workflow specifically designed for estuarine environments and was applied across all surveyed waterways (Lynch et al., 2025; Figure 5).

Figure 2 Microplastic sampling regions and waterways across New South Wales

Table 5 **List of sites surveyed in each of the sampling regions, north to south (*annual sites)**

North	Central	South
Terranora Creek	Tilligerry Creek	Minnamurra River
Tweed River	Port Stephens	Werri Lagoon
Cudgen Creek	Throsby Creek	Crooked River
Brunswick River	Hunter River	Shoalhaven River*
Belongil Creek	Glenrock Lagoon	Cararma Creek
Tallow Creek	Lake Macquarie	Currambene Creek
North Creek	Tuggerah Lake	Moona Moona Creek
Richmond River	Wamberal Lagoon	Jervis Bay
Lake Ainsworth	Terrigal Lagoon	St Georges Basin
Evans River	Avoca Lake	Swan Lake
Clarence River	Cockrone Lake	Conjola Lake
Oyster Channel	Brisbane Water	Ulladulla
Lake Arragan	Hawkesbury River	Burrill Lake
Sandon River	Cowan Creek	Durras Lake
Wooli Wooli River	Berowra Creek	Clyde River*
Station Creek	Pittwater	Batemans Bay
Corindi River	Broken Bay	Tomaga River
Darkum Creek	Narrabeen Lagoon	Moruya River
Woolgoolga Lake	Dee Why Lagoon	Congo Creek
Flat Top Point Creek	Manly Lagoon	Meringo Creek
Hearns Lake	Middle Harbour	Coila Lake
Moonee Creek	Lane Cove River	Tuross River
Coffs Creek	Toongabbie Creek	Lake Mummuga
Bellinger River	Parramatta River	Wagonga Inlet
Nambucca River	Duck River	Corunna Lake
Macleay River	Haslams Creek	Tilba Tilba Lake
South West Rocks Creek	Port Jackson	Wallaga Lake
Saltwater Creek (Frederickton)	Cooks River	Bermagui River
Maria River	Muddy Creek	Wapengo Lagoon
Hastings River	Georges River	Middle Lagoon

Cathie Creek	Botany Bay	Bega River
Camden Haven River	Port Hacking	Wallagoot Lake
Manning River*	Wattamolla Creek	Merimbula Lake
Khappinghat Creek*	Towradgi Creek	Pambula River
Wallis Lake*	Fairy Creek	Nullica River
Wallamba River*	Lake Illawarra	Towamba River
Wallamba Cove	–	Twofold Bay
Coolongolook River*	–	Wonboyn River
Smiths Lake*	–	Merrica River
Myall River	–	Nadgee River
Myall Lake*	–	Nadgee Lake
Myall Broadwater*	–	–
Karuah River*	–	–

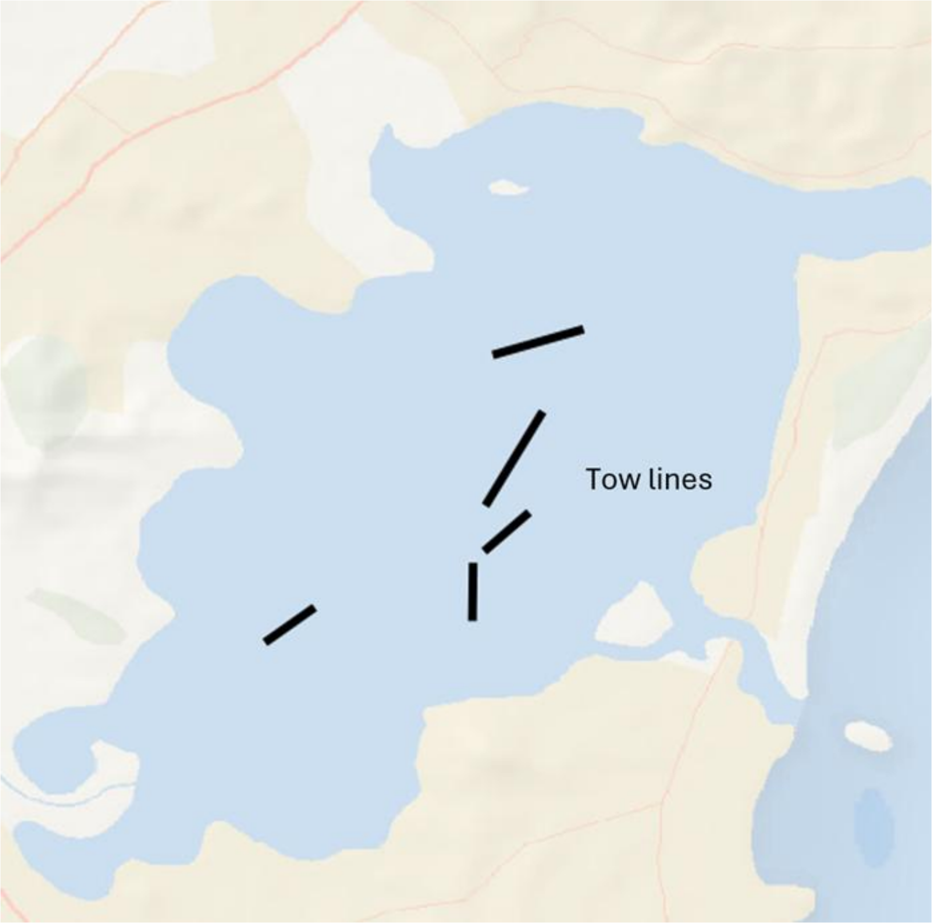


Figure 3 Lakes, creeks and lagoons sampling design

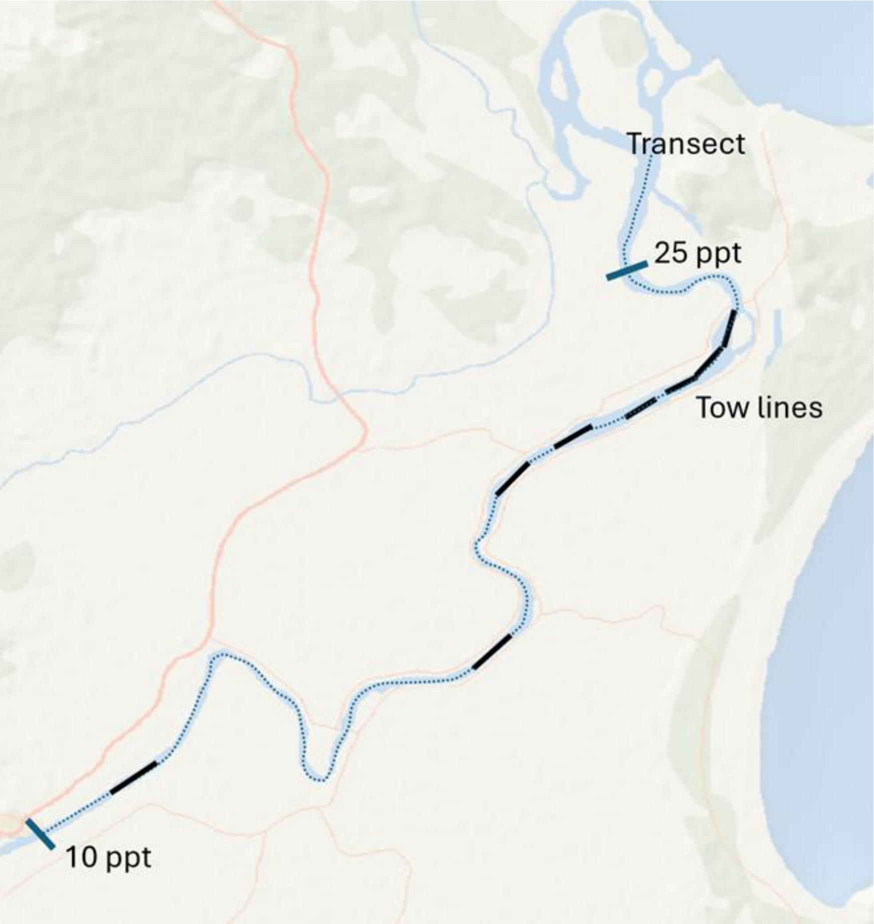


Figure 4 River sampling design

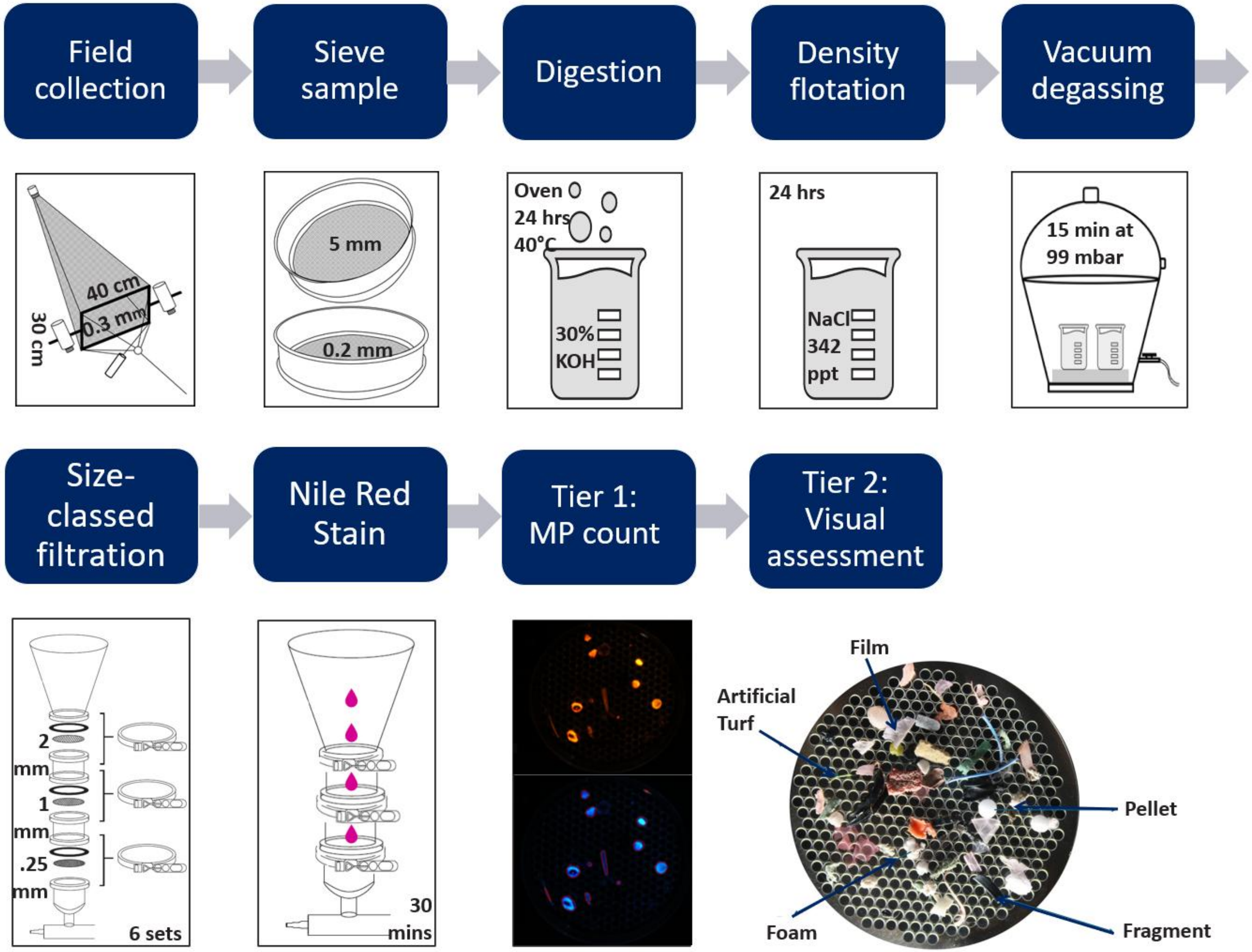


Figure 5 Microplastic field and sample analysis protocol from Lynch et al., 2025

A custom-designed manta net was used to sample the top 15 cm of the water column, fitted with a 300 µm mesh. The net was specifically adapted for use with a motorised canoe, enabling sampling in smaller and shallower systems (Lynch et al., 2025).

Surface water sampling for microplastics was conducted using different vessels depending on waterway depth. In large open systems (drowned river valleys and bays), a 4.5 m or 6.4 m vessel was used to tow the manta net (Figure 6), while in smaller, shallow systems, a 4 m motorised canoe was employed (Figure 7).

Figure 6 **Manta net being towed by 6.4-metre vessel. NSW EPA**

Figure 7 **Manta net being towed by 4-metre canoe rigged with a motor on Parramatta River. NSW EPA**

Using the protocol as set out in Lynch et al. (2025), each of the 120 waterways was sampled for microplastics using the manta net. Specifically, the manta net was deployed over the side of the vessel at each sampling site ensuring it towed outside the wake of the vessel and was only 50% submerged. GPS coordinates and initial flow meter readings were recorded at the start of each tow.

The net was towed for a period of 5 minutes at a speed of approximately 4 knots along a straight course. Water quality data and GPS location were simultaneously and continuously logged as the vessel moved along the waterway. Following the tow, the net was retrieved, and final GPS coordinates and flow meter readings were recorded.

The net was then rinsed using the ‘teabag method’ to transfer captured material into the codend (Lynch et al., 2025). The net contents were then transferred into a 500 mL ethanol-filled sample jar (total dilution 20% ethanol). Replicate tows were undertaken in each system. [2]

2.2 Sample processing

Microplastic samples were processed using a multi-step laboratory protocol tailored for complex estuarine surface waters as set out in Lynch et al. (2025). An overview of that process is explained in Figure 5.

The protocol used to process microplastic samples included 4 key stages:

1. 30% potassium hydroxide (KOH) digestion
2. saturated sodium chloride (NaCl) density separation
3. vacuum degassing
4. size-class filtration.

These steps were designed to clarify samples by removing organic matter and isolating buoyant synthetic particles for downstream analysis.

Size-class filtration was used to isolate microplastics into defined size ranges (Large >2 to <5 mm; Medium >1 to <2 mm; and Small >0.25 to <1 mm).

Nile Red (NR) staining was applied to enhance visualisation and enable automated image-based microplastic identification (Figure 5).

2.3 Sample analysis

2.3.1 Tier 1: The Rapid Count Method

Following filtration, all filter discs were dried and photographed in a dark room through an orange filter under blue light. These conditions cause the NR stained microplastics to fluoresce producing colours ranging from deep red to strong yellow gold, depending on the plastic type (Figure 8).

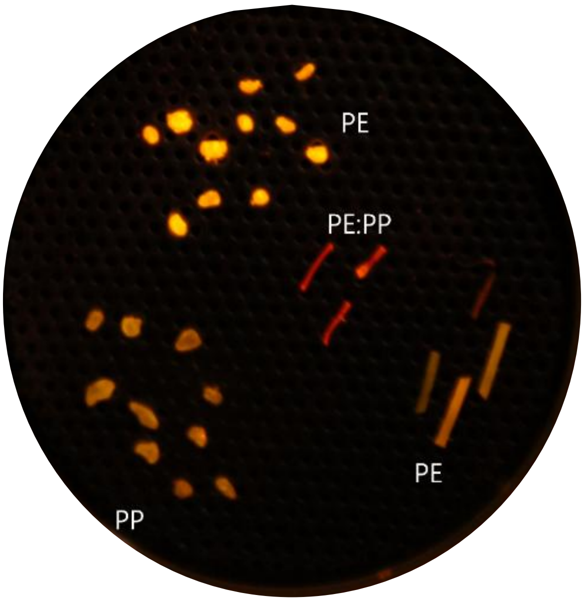


Figure 8 **NR stained microplastics photographed through an orange filter, in a dark room, and under blue light. Jaimie Loa-Kum-Cheung/DCCEEW**

Photographs were then sorted and processed through an automated image program 'Stat-on-pixel' (Lynch et al., 2025) (Figure 9). The python script reads the RAW image file (shown on the left), outlines the perimeter of each fluorescent particle and counts each individual particle (shown on the right). Each photo was then assigned a count.

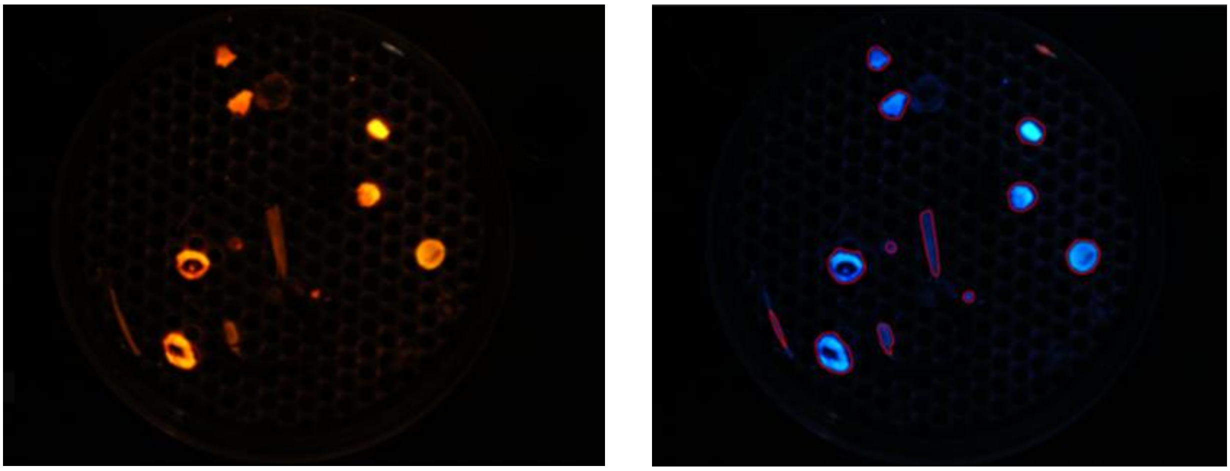
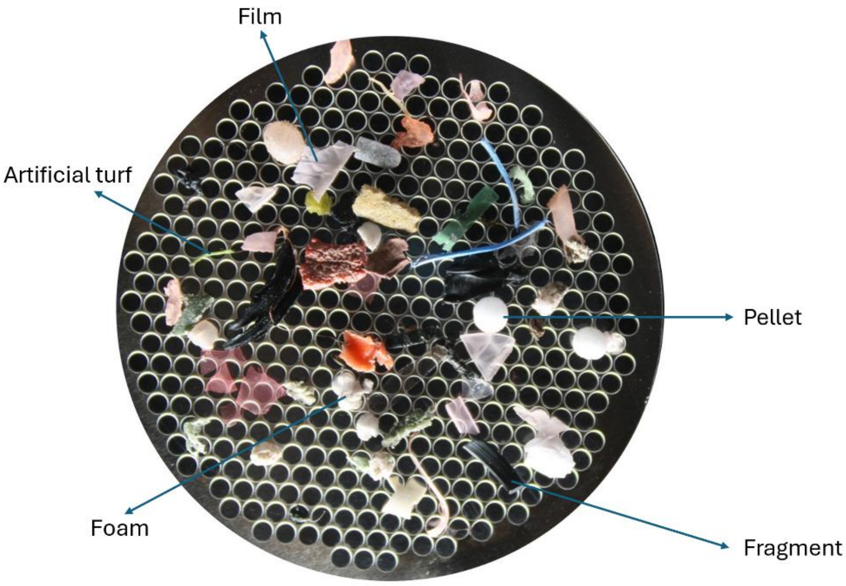


Figure 9 **Stat on pixels, automated image program that counts fluorescent particles. Jaimie Loa-Kum-Cheung and Shivanesh Rao/DCCEEW**

2.3.2 Tier 2: Physical characterisation

Microplastic morphology was assessed through visual inspection following the rapid characterisation method outlined in Lynch et al. (2025). Digital photographs of each sample were analysed using GNU Image Manipulation Program (GIMP), where large (>2 mm) microplastic particles were categorised by morphology (hard fragments, film, foam, artificial turf and pellets [Photograph 5]) using layered image annotation. The number of particles for each morphological category was tallied and recorded for every sample.



Photograph 5 **Microplastic physical characterisation by morphology. Samantha Lynch/DCCEEW**

2.4 Data analysis

2.4.1 Microplastic concentration calculations

Microplastic concentrations were determined by dividing the total number of particles identified in each sample by the volume of water filtered during the tow. The sampled volume was estimated by multiplying the cross-sectional area of the submerged portion of the manta net by the total tow distance recorded for that sample. Concentrations were expressed as the number of microplastic particles per cubic metre of water (MP/m^3), calculated using the ratio of particle count to estimated water volume (see Equation 1).

Equation 1
$$\frac{\text{Total number of microplastics } (MP)}{(\text{Flowmeter distance } x \text{ } 0.5 \text{ net interface})} = MP/m^3$$

2.4.2 Microplastic contamination grading

Microplastic contamination grades were assigned using a percentile-based approach to compare each system's relative position within the statewide dataset rather than relying on absolute concentration values. This method accounts for the highly skewed distribution of microplastic concentrations, ensuring balanced representation across quantile ranges and reducing the influence of extreme outliers.

Percentiles were calculated from the complete dataset of 594 analysed water samples (tow replicates), and these values were used to define a five-tier grading system for categorising contamination levels:

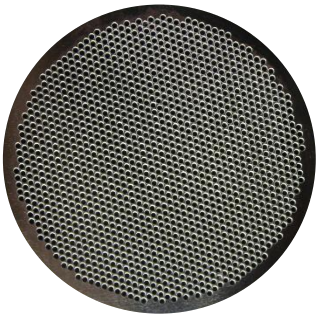
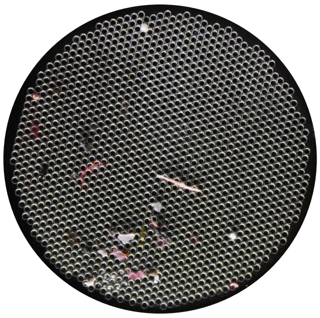
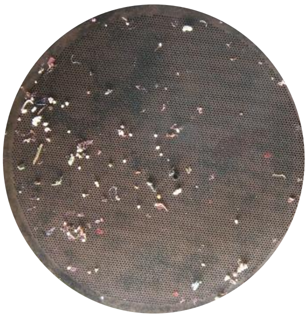
- 0–20th percentile (Very low)
- 20th–40th percentile (Low)
- 40th–60th percentile (Moderate)
- 60th–80th percentile (High)
- 80th–100th percentile (Very high)

Each of the categories was assigned a numerical score from 1 (Very low) to 5 (Very high). Individual sampling events were then assigned a grade score (1 to 5), calculated from the microplastic concentration within the sample (Table 6). Grade scores were then averaged across all samples within each waterway to determine an overall system grade (see Tables 6 and 7).

Table 6 Grade boundaries for system grades

Average grade scores	System grade
<1.5	A
1.5≥ to <2.5	B
2.5≥ to <3.5	C
3.5≥ to <4.5	D
≥4.5	E

Table 7 Microplastic contamination grade scoring

Grade score and category	Microplastic concentration (MP/m^3)	Percentile	What that looks like
1 Very low	< 0.1	Less than ~20th percentile	
2 Low	0.1 – < 0.3	~20th percentile to ~40th percentile	
3 Moderate	0.3 – < 0.5	~40th percentile to ~60th percentile	
4 High	0.5 – < 1.3	~60th percentile to ~80th percentile	
5 Very high	> 1.3	Greater than ~80th percentile	

2.4.3 Spatial mapping

Existing estuarine spatial layers were imported into QGIS and symbolised according to their assigned contamination grade using a standardised traffic-light colour scheme (Tables 6 and 7). This visualisation represented grades from very low to very high microplastic contamination and highlighted contamination hotspots.

Statewide and regional risk maps were then generated to support spatial interpretation and comparative assessment.

2.4.4 Waterway ranking

Waterways were ranked using a dual-metric approach that considered both the average grade score and the median microplastic concentration for each system. This method provided a relative index of microplastic contamination across all 120 NSW waterways included in the study.

Rankings were presented in descending order, from the most contaminated (Rank 120) to the least contaminated (Rank 1), as shown in Table 8. Regions were ranked using the same methodology (Table 9).

2.4.5 Microplastic concentration data analysis

All microplastic samples were plotted into a histogram to assess data distribution. Descriptive statistics were calculated for each waterway, including mean, minimum, maximum, and median microplastic concentration, and standard deviation (Appendix Table 1).

These metrics were then compared within each region and across regions to assess spatial variability in microplastic contamination and visualised using box-and-whisker and bar plots, with grade reference thresholds overlaid.

2.4.6 Microplastic size and morphology data analysis

Microplastic size distribution was assessed by tallying the total number of particles in each size class (small: 0.25–1 mm, medium: 1–2 mm, large: 2–5 mm) as determined by the automated image analysis script. The number of particles in each size class was recorded and the relative proportion of each was calculated for each waterway.

Microplastic morphology distribution was assessed by counting the total number of particles within each category (fragments, film, foam, artificial turf and pellets). These total counts were then used to calculate the relative proportion of each morphology type for each region.

To visualise the data, pie charts displayed results at both a state and region scale.

2.4.7 Annual site data analysis

A subset of 11 waterways, designated as annual monitoring sites, were sampled repeatedly across the years (2021 to 2024) to assess temporal trends and validate the microplastic grading framework.

For each site, descriptive statistics were calculated for microplastic concentrations. These results were visualised using scatter plots to illustrate temporal patterns. Intra-site variability and consistency of microplastic concentrations over time (2021 to 2024) were also evaluated.

2.4.8 Estuary type and disturbance rating data analysis

The distribution of grades across estuary types and catchment disturbance were calculated and proportions visualised using multi series bar plots.

3. Results

3.1 Statewide results

3.1.1 Microplastic concentration data distribution

A total of 594 surface water tow samples were collected across 120 NSW coastal waterways between 2021 and 2024. Microplastic concentrations for all samples were plotted into a histogram to visualise the data distribution (Figure 10). The sample distribution is log-normal distributed (see Figure 10) because many samples had low concentrations of microplastics. The few samples with very high microplastic contamination levels are identified as outliers.

This data distribution is normal in environmental contaminant data, where inputs are uneven and often driven by localised sources. For this reason, percentile-based grading is particularly appropriate here, as it compares relative positions rather than relying on raw concentrations distorted by skewed data. Further to this, arithmetic means are misleading as they are inflated by outliers, with median values being more representative for each of the systems. However, means are still used to harmonise with published data for comparison.

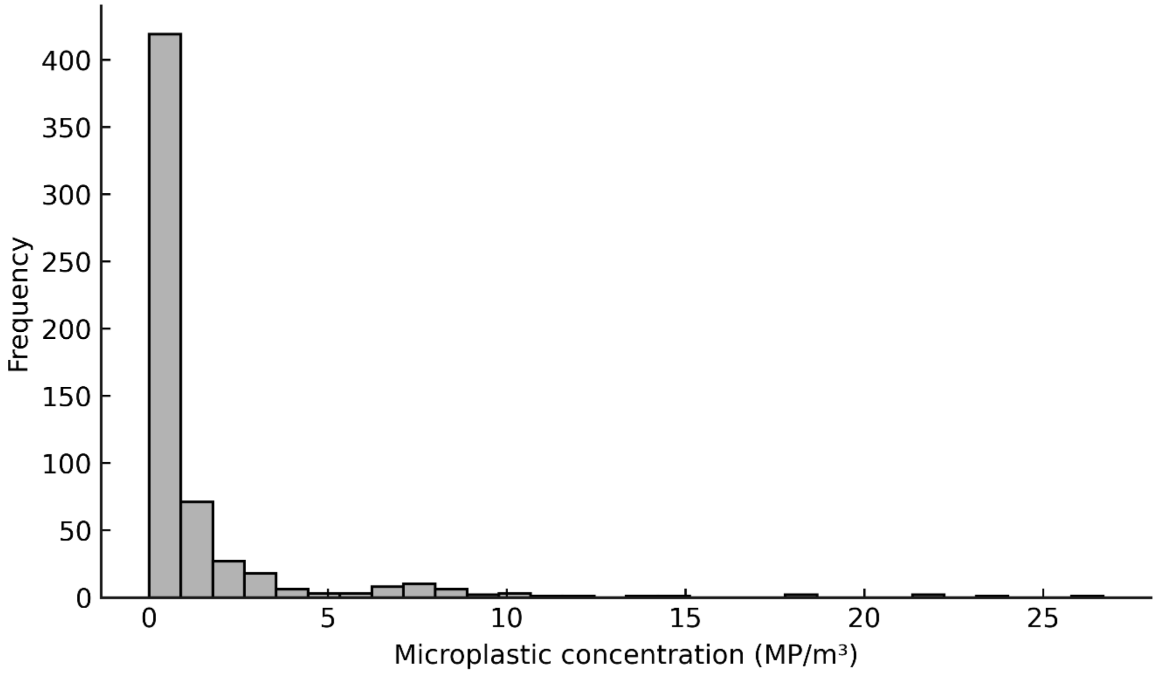


Figure 10 **Frequency distribution of microplastic concentrations (MP/m^3) across all samples. Values exceeding 30 MP/m^3 were excluded from the plot to enhance visual interpretation**

3.1.2 Microplastic contamination grades

Each of the 594 samples were analysed for microplastic concentration (particles per cubic metre [MP/m^3]), particle size distribution, and particle morphology (for MP >2 mm). Each sample was assigned a grade score (as per Table 6), then all grade scores for each system were averaged to determine the final grade for each waterway (as per Table 7).

Microplastic contamination grades were defined by 20th-percentile intervals to ensure an even distribution across categories. The grading scale ranged from A to E, where grade A indicates very low microplastic contamination (<0.1 MP/m^3) and grade E indicates very high microplastic contamination (>1.3 MP/m^3) (Table's 6 and 7).

Overall, only 4 waterways were categorised as having very low microplastic contamination (Grade A; <0.1 MP/m^3), while 32 waterways were classified as having low contamination (Grade B; 0.1 – <0.3 MP/m^3). Most waterways (38) had moderate contamination (Grade C; 0.3 – <0.5 MP/m^3); 23 waterways had high contamination (Grade D; 0.5 – <1.3 MP/m^3); and 23 waterways exhibited very high microplastic contamination levels (Grade E; >1.3 MP/m^3) – see Figure 11.

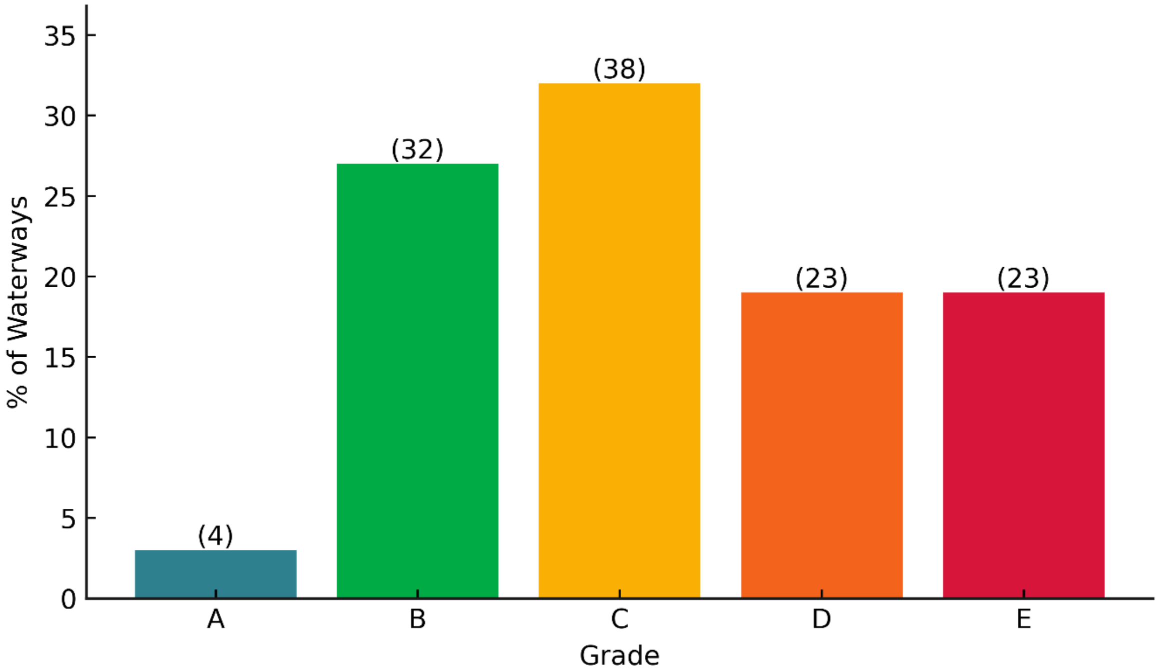


Figure 11 **Distribution of NSW coastal waterways across microplastic contamination grades (A–E). Bars represent the proportion of waterways within each grade category, colour-coded using a traffic-light scheme from very low (Grade A) to very high (Grade E) contamination. Sample counts are in brackets above bars**

All 120 coastal waterways were then ranked from least contaminated to most contaminated (Table 8), based first on their average grade score and then on the median microplastic concentration across all samples. This approach ensured that systems with consistently high microplastic contamination levels were ranked above those with more variable contamination levels.

Table 8 Ranked summary of microplastic contamination across 120 coastal waterways in New South Wales. Table includes contamination rank, waterway name, and average grade, listed from highest microplastic concentration to lowest concentration

Rank	Estuary	Grade
120	Cooks River	E
119	Dee Why Lagoon	E
118	Muddy Creek	E
117	Toongabbie Creek	E
116	Throsby Creek	E
115	Coffs Creek	E
114	South West Rocks Creek	E
113	Manly Lagoon	E
112	Parramatta River	E
111	Middle Harbour Creek	E
110	Haslams Creek	E
109	Cararma Creek	E
108	Ulladulla	E
107	Georges River	E
106	Moona Moona Creek	E
105	Fairy Creek	E
104	Terrigal Lagoon	E
103	Duck River	E
102	Towradgi Creek	E
101	Lake Ainsworth	E
100	Belongil Creek	E
99	Minnamurra River	E
98	Darkum Creek	E
97	Lane Cove River	D
96	Narrabeen Lagoon	D
95	Moonee Creek	D
94	Merimbula Lake	D
93	Cudgen Creek	E
92	Evans River	D

Rank	Estuary	Grade
91	Tallow Creek	D
90	Wattamolla Creek	D
89	Tomaga River	D
88	Glenrock Lagoon	D
87	Port Jackson	D
86	Saltwater Creek (Frederickton)	D
85	Bermagui River	D
84	Werri Lagoon	D
83	Twofold Bay	D
82	Avoca Lake	D
81	Brunswick River	D
80	Jervis Bay	D
79	Congo Creek	D
78	Currambene Creek	D
77	Botany Bay	D
76	Cathie Creek	D
75	Crooked River	D
74	Hawkesbury River	C
73	Flat Top Point Creek	C
72	Port Stephens	C
71	Bellinger River	C
70	Pambula River	C
69	Cowan Creek	C
68	Hearns Lake	C
67	Lake Arragan	C
66	Nullica River	C
65	Pittwater	C
64	Oyster Channel	C
63	Nambucca River	C
62	Cockrone Lake	C
61	Brisbane Water	C
60	Lake Mummuga	C

Rank	Estuary	Grade
59	Camden Haven River	C
58	Port Hacking	C
57	Maria River	C
56	Corunna Lake	C
55	Burrill Lake	C
54	Macleay River	C
53	North Creek	C
52	Wallagoot Lake	C
51	Wallamba Cove	C
50	Hastings River	C
49	Terranora Creek	C
48	Berowra Creek	C
47	Bega River	C
46	Batemans Bay	C
45	Durras Lake	C
44	Tuross River	C
43	Wamberal Lagoon	C
42	Sandon River	C
41	Station Creek	C
40	Woolgoolga Lake	C
39	Meringo Creek	C
38	Corindi River	C
37	Wapengo Lagoon	C
36	Karuah River	B
35	Hunter River	B
34	Tuggerah Lakes	B
33	Towamba River	B
32	Wagonga Inlet	B
31	Tweed River	B
30	Coolongolook River	B
29	Wonboyn River	B
28	St Georges Basin	B

Rank	Estuary	Grade
27	Wallamba River	B
26	Wallis Lake	B
25	Manning River	B
24	Clyde River	B
23	Lake Macquarie	B
22	Conjola Lake	B
21	Broken Bay	B
20	Moruya River	B
19	Swan Lake	B
18	Wooli Wooli River	B
17	Tilligerry Creek	B
16	Clarence River	B
15	Nadgee River	B
14	Tilba Tilba Lake	B
13	Lake Illawarra	B
12	Richmond River	B
11	Myall River	B
10	Coila Lake	B
9	Shoalhaven River	B
8	Merrica River	B
7	Khappinghat Creek	B
6	Smiths Lake	B
5	Wallaga Lake	B
4	Myall Broadwater	A
3	Middle Lagoon	A
2	Nadgee Lake	A
1	Myall Lake	A

3.1.3 NSW coastal waterways microplastic summary statistics

The data reveals that microplastic concentrations across NSW coastal waterways surveyed varied substantially among waterways. Median concentrations ranged from 0.01 MP/m^3 to 24.70 MP/m^3, while mean concentrations ranged from 0.02 MP/m^3 to 34.80 MP/m^3.

Across all 594 samples, the overall median concentration was 0.38 MP/m^3, with a mean of 2.15 MP/m^3 and a standard deviation (SD) of 7.96 MP/m^3 (Appendix Table 1), indicating high variability and the presence of extreme values within certain systems.

The highest median microplastic concentrations were recorded in urban catchments, including Duck River (24.70 MP/m^3), Cooks River (14.43 MP/m^3), and Dee Why Lagoon (9.98 MP/m^3).

Similarly, the highest mean concentrations were observed in these same systems; Duck River (34.80 MP/m^3 ± 42.29 SD), Dee Why Lagoon (22.45 MP/m^3 ± 28.49 SD), and Cooks River (19.89 MP/m^3 ± 19.69 SD) (Figure 12).

The Cooks River was ranked as having the highest microplastic contamination level in New South Wales, due to its consistently elevated concentrations recorded throughout the study period.

This system was followed closely by Dee Why Lagoon, Muddy Creek (a tributary of the Cooks River), Toongabbie Creek (upper Parramatta River), and Throsby Creek (Table 8). All these waterways are located within highly urbanised catchments.

The least contaminated systems were in less disturbed catchments, where minimal anthropogenic influence is evident. These included Myall Lake (median = 0.01 MP/m^3; mean = 0.02 MP/m^3 ± 0.03 SD), Nadgee Lake (median = 0.08 MP/m^3; mean = 0.08 MP/m^3 ± 0.01 SD), Middle Lagoon (median = 0.02 MP/m^3; mean = 0.04 MP/m^3 ± 0.05 SD), Myall Broadwater (median = 0.05 MP/m^3; mean = 0.07 MP/m^3 ± 0.06 SD), and Wallaga Lake (median = 0.08 MP/m^3; mean = 0.09 MP/m^3 ± 0.01 SD) (Figure 12).

These waterways are situated in low-population coastal environments with limited urban or industrial inputs, possibly reflecting background concentrations of microplastics in the absence of significant catchment pressures.

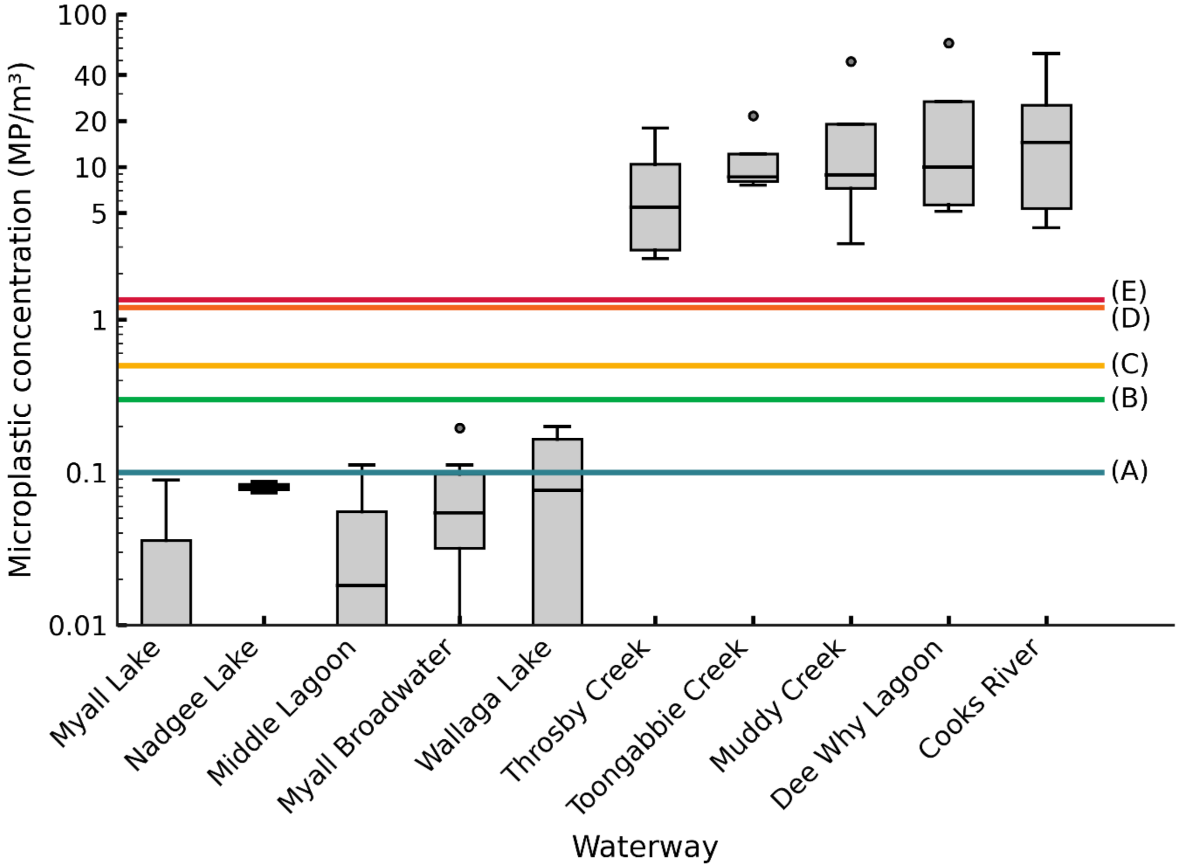


Figure 12 **A box-and-whisker plot of the 5 waterways with the least microplastic contamination (MP/m^3) and the 5 waterways with the highest microplastic contamination. Box-and-whisker plots show median, interquartile range, and outliers. The y-axis is log-scaled and refined to 100 MP/m^3. Grade references are represented by coloured lines and labelled accordingly**

3.1.4 Microplastic size and morphology across NSW coastal waters

There was an estimated 31,966 microplastics counted across all samples. From this total, smaller sized particles (>0.25 – <1 mm) were far more abundant (21,795), accounting for 68% of all particles. Medium sized particles (1 – <2 mm) accounted for 18% of all particles (5,734), and large particles (2 – <5 mm) accounted for only 14% of all particles found (4,437) (Figure 13).

Only large particles (>2 mm) were visually examined to determine their plastic morphology (artificial turf, foam, pellet, fragment, and film; fibres were excluded from this analysis). Overall, fragments and foam were the most abundant, each accounting for 37% of all large particles surveyed, film accounted for 19%, artificial turf 5%, and pellets 2% (Figure 14).

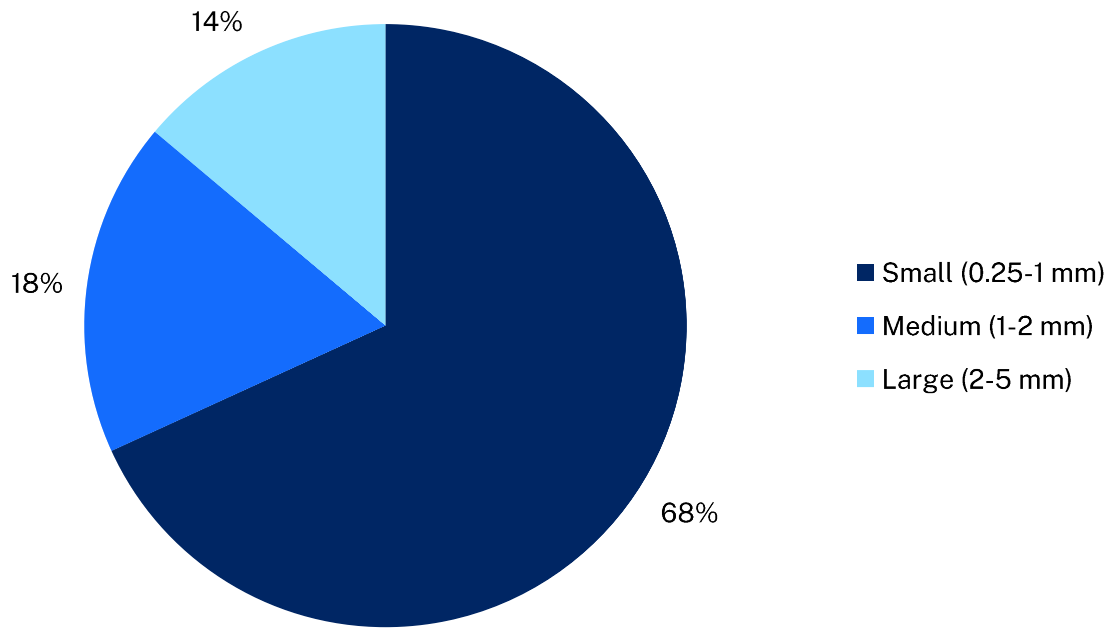


Figure 13 Proportion of microplastic particles by size class across all samples

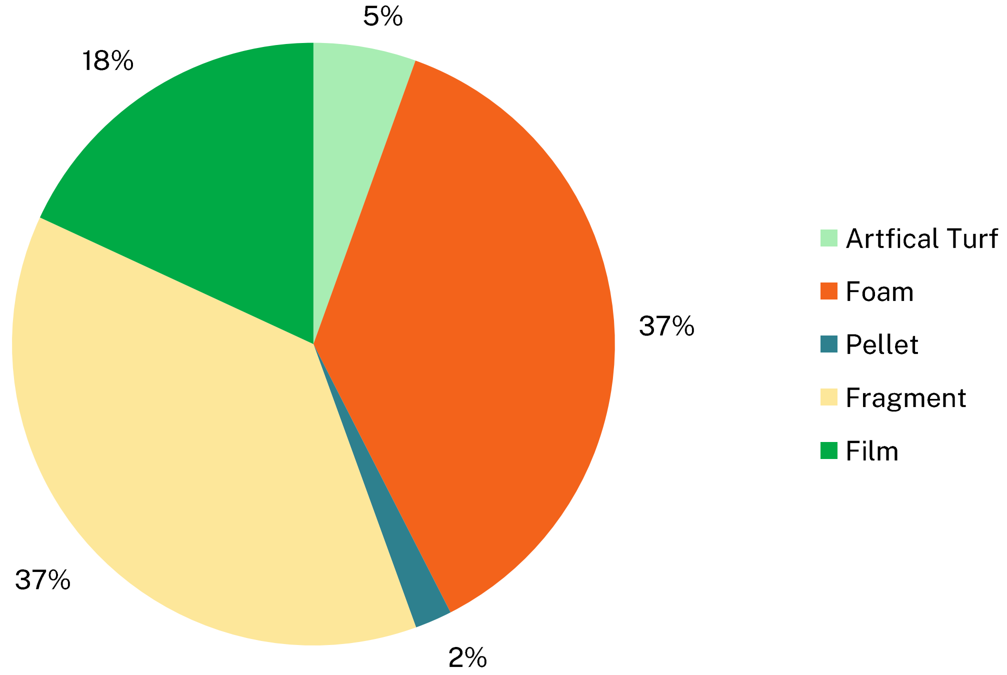


Figure 14 Proportion of microplastic particles by morphology across the state

3.2 Regional results

Due to the geographic scale of New South Wales and the large number of waterways surveyed (n=120) the state was subdivided into 8 regions (Figure 15) to simplify data interpretation and visualisation. The regions are divided accordingly:

- **Northern Rivers** encompassing the waters from the Tweed River in the north to Wooli River in the south
- **North Coast** encompassing the waters from Station Creek in the north to Camden Haven in the south
- **Mid North Coast** encompassing the waters from Manning River in the north to Karuah River in the south
- **Hunter–Central Coast** encompassing the waters from Tilligerry Creek in the north to Brisbane Waters in the south
- **Hawkesbury–Sydney** encompassing the waters from Hawkesbury River in the north to Wattamolla Creek in the south
- **Illawarra–Shoalhaven** encompassing the waters from Towradgi Creek in the north to Burrill Lake in the south
- **Eurobodalla** encompassing the waters from Durras Lake in the north to Tilba Tilba Lake in the south
- **Bega** encompassing the waters from Wallaga Lake in the north to Nadgee Lake in the south.

Grades were visualised using a traffic-light colour scheme, ranging from teal (very low contamination) to red (very high contamination). This colour scheme was used to produce a spatial heatmap for each region, clearly identifying locations where the highest and lowest microplastic contamination had occurred (Figure 15).

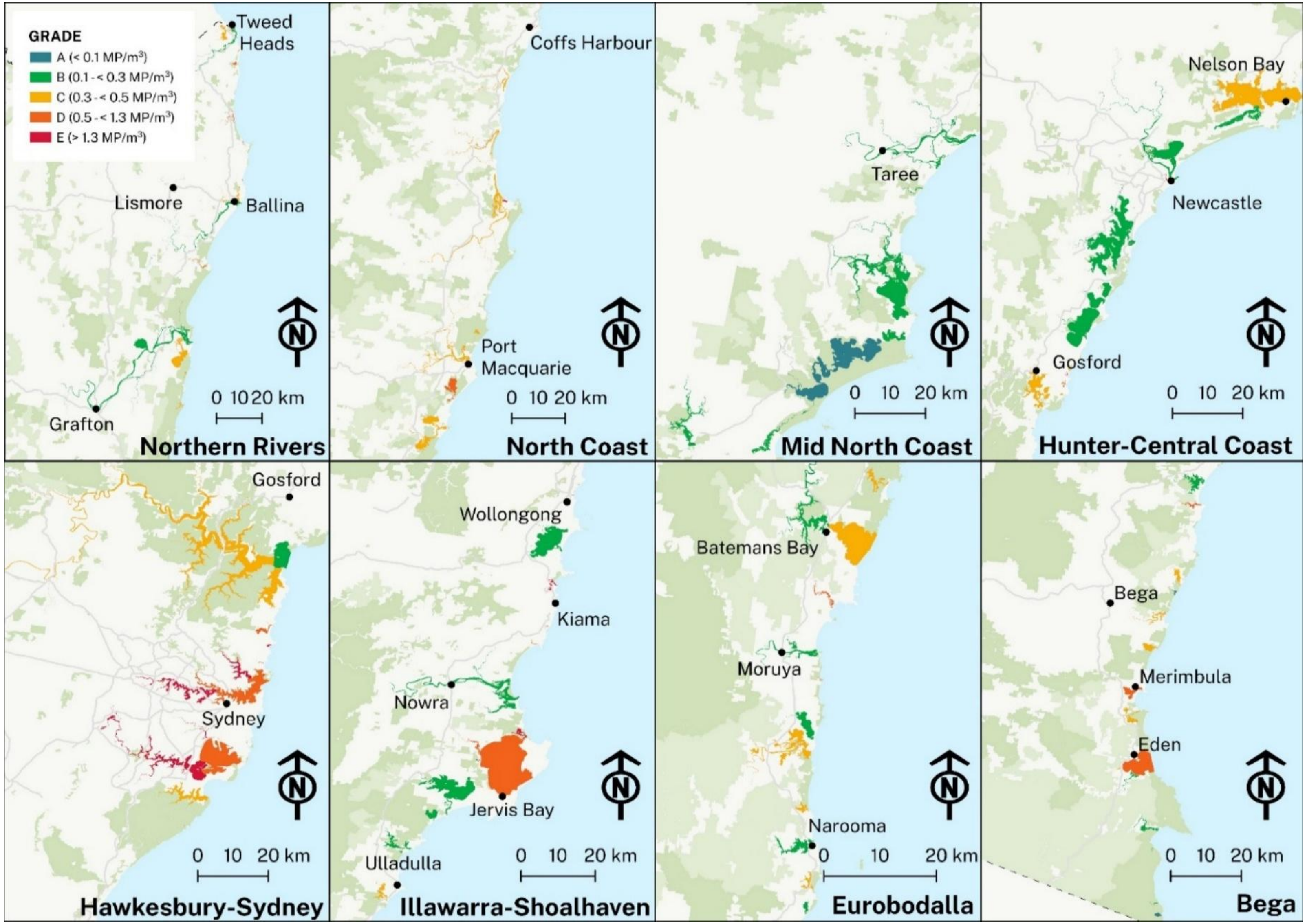


Figure 15 Spatial assessment of microplastic contamination across 120 sampled NSW coastal waterways. Created by Neda Sharifi Soltani

The mean grade score for each region, derived from all samples collected within that region was calculated to provide a comparative measure of overall microplastic contamination status (Table 9).

Regional mean grades represent the aggregated contamination level of each region's waterways (Figure 16). Among the 8 regions assessed, the Mid North Coast exhibited on average the lowest microplastic contamination levels, corresponding to an aggregated grade of B, while the Hawkesbury–Sydney region showed the highest contamination, with an aggregated grade of D (Figure 17).

Table 9 Aggregated broadscale microplastic assessment regional results

Estuary	Mean grade score	Grade	Median MP/m^3	Regional rank
Mid North Coast	1.94	B	0.13	1
Eurobodalla	2.52	C	0.18	2
Bega	2.59	C	0.21	3
Hunter–Central Coast	2.62	C	0.25	4
Northern Rivers	3.10	C	0.47	5
Illawarra–Shoalhaven	3.21	C	0.47	6
North Coast	3.36	C	0.57	7
Hawkesbury–Sydney	4.17	D	1.86	8

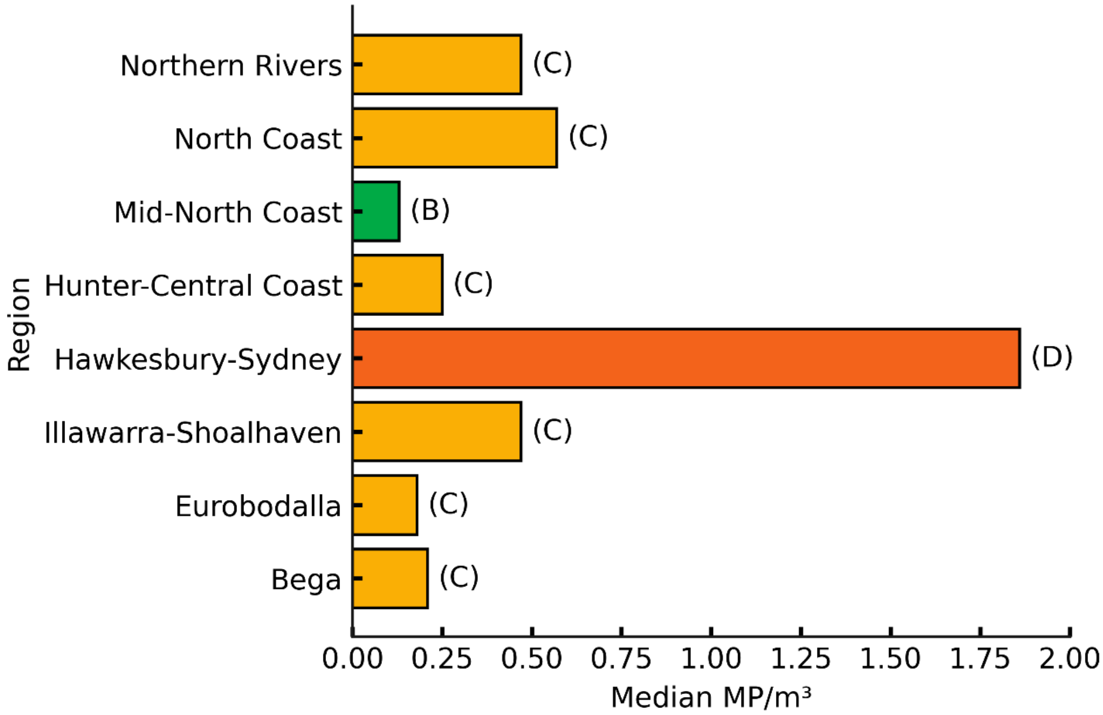


Figure 16 Median microplastic concentrations (MP/m^3) by region, coloured by grade and grades are indicated in brackets after each bar. Axis range is 0–2 MP/m^3

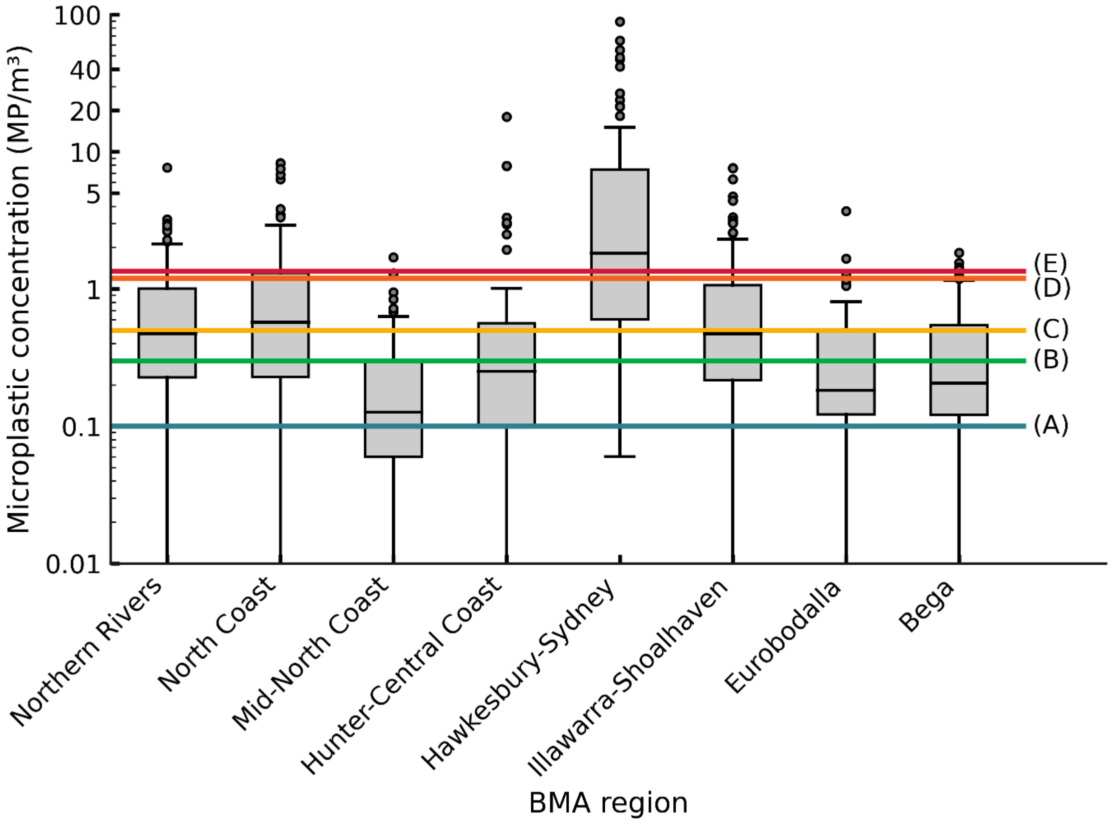


Figure 17 A box-and-whisker plot of the 8 broadscale microplastic assessment regions

3.2.1 Northern Rivers

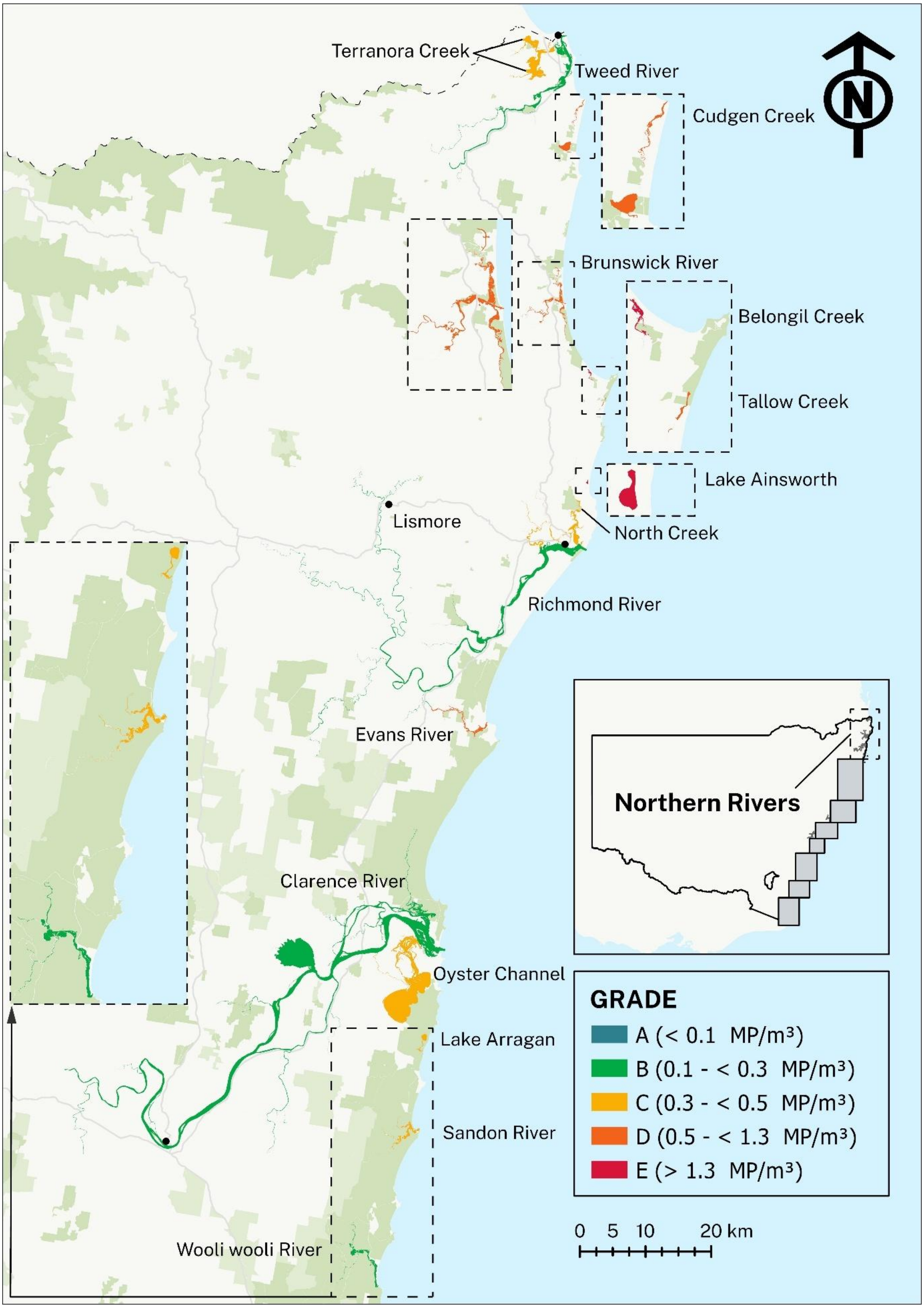


Figure 18 Coastal waterways within the Northern Rivers region colour-coded according to microplastic contamination grade. Map created by Neda Sharifi Soltani

In the Northern Rivers region (Figure 18), 58 samples were collected across 15 waterways. Microplastic concentrations varied among systems but were generally within the low-to-moderate contamination range.

Four waterways were graded B (0.1–<0.3 MP/m^3), 5 were graded C (0.3–<0.5 MP/m^3), 4 were graded D (0.5–<1.3 MP/m^3), and 2 were graded E (>1.3 MP/m^3) (Figure 19).

Within the statewide comparison, the Northern Rivers region ranked fifth out of the 8 regions for microplastic contamination (Table 9).

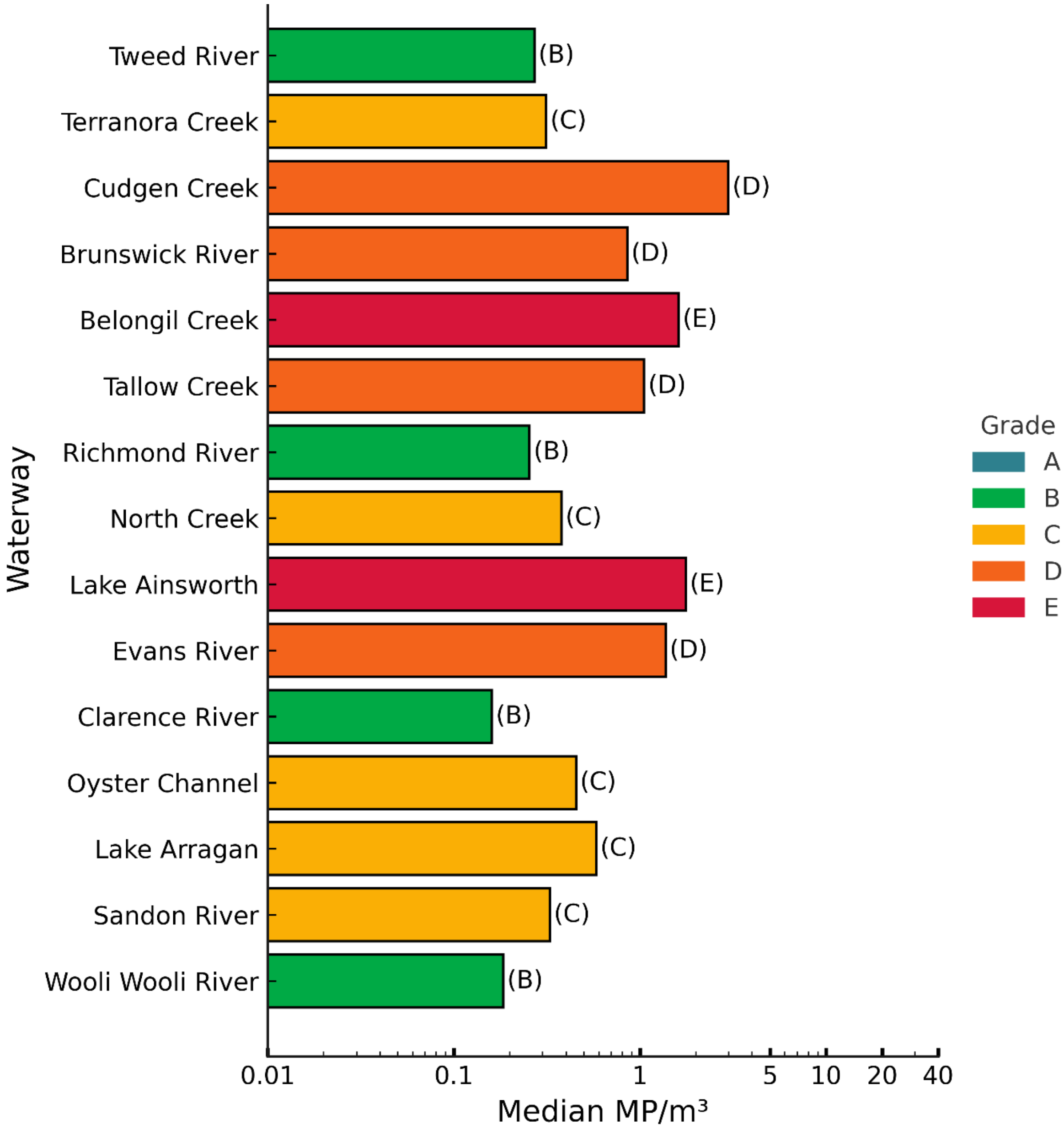


Figure 19 **The median microplastic concentration (MP/m^3) of each waterway in the Northern Rivers region, colour-coded according to average grade. Median MP/m^3 (x-axis) is on a logarithmic scale**

Across all samples, the median microplastic concentration was 0.47 MP/m^3, with a mean of 0.94 MP/m^3 and a SD of 1.27 MP/m^3. The highest recorded concentration (7.67 MP/m^3) occurred at Cudgen Creek, while Wooli River contained instances where no microplastics were detected (0 MP/m^3) (Figure 19).

Several sites, including Cudgen Creek, Belongil Creek, Lake Ainsworth, and Evans River, had median concentrations exceeding 1.3 MP/m^3 (Grade E), indicating localised contamination events.

Conversely, systems such as Terranora Creek, Cudgen Creek, Sandon River, and Wooli River showed high temporal variability, with both zero detections and elevated values detected across samples (Figure 20).

Overall, the large rivers (Tweed River, Richmond River, Clarence River, and Wooli River) exhibited low levels of microplastic contamination (median 0.27 MP/m^3, 0.26 MP/m^3, 0.16 MP/m^3, and 0.18 MP/m^3, respectively; Grade B) (Figure 19).

The 2 largest rivers, the Richmond and the Clarance had on average the lowest microplastic contamination levels in the Northern Rivers region, ranking 12th and 16th in the state, respectively. Whereas, in the smaller systems (lagoons), Lake Ainsworth and Belongil Creek, had on average the highest microplastic contamination levels in the Northern Rivers region, ranking 101 and 100 out of 120 in the state.

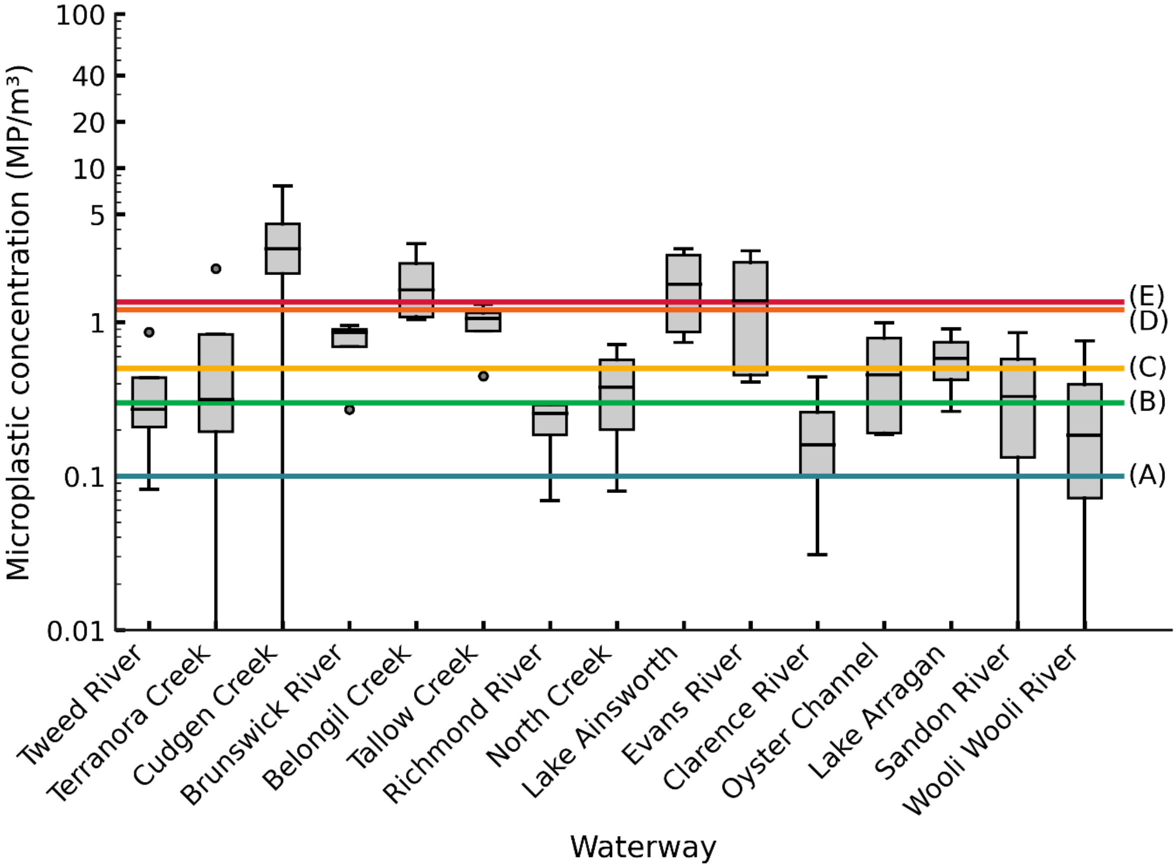


Figure 20 **Box-and-whisker plot of microplastic concentration (MP/m^3) across waterways in the Northern Rivers region. The y-axis is log-scaled. Grade references are represented by coloured lines**

Overall, the Northern Rivers region represents moderate microplastic contamination relative to other NSW coastal regions, with concentrations typically within Grades B–C and few instances exceeding Grade D–E thresholds (Figure 20).

There were an estimated 1,157 particles counted across the region (4% of the states total particles). Smaller sized particles (>0.25 – <1 mm) were far more abundant (812), accounting for 70% of all particles found in the region.

Medium sized particles (1 – <2 mm) accounted for 17% of all particles found (199), and large particles (2 – <5 mm) accounted for 13% of all particles found (146) (Figure 21). Of the larger particles characterised, hard fragment was the most abundant morphology, accounting for 48%, followed by foam 27%, film 23%, artificial turf 2%, and pellets 1% (Figure 22).

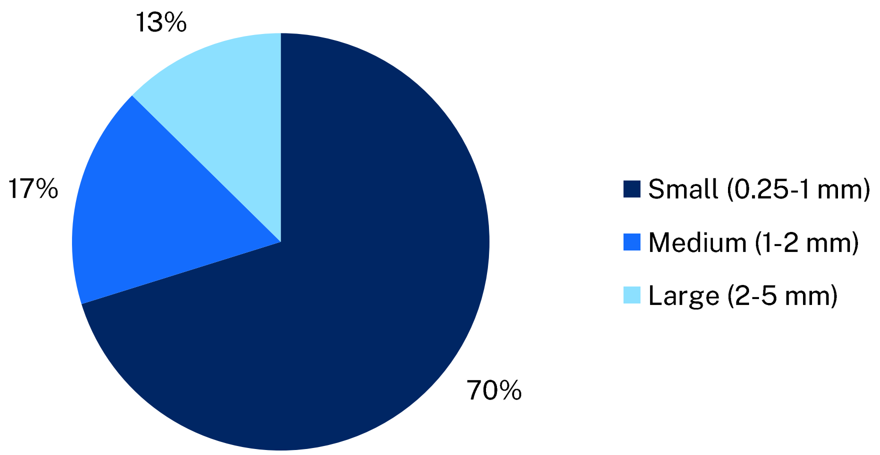


Figure 21 **Proportion of microplastic particles by size class across Northern Rivers region**

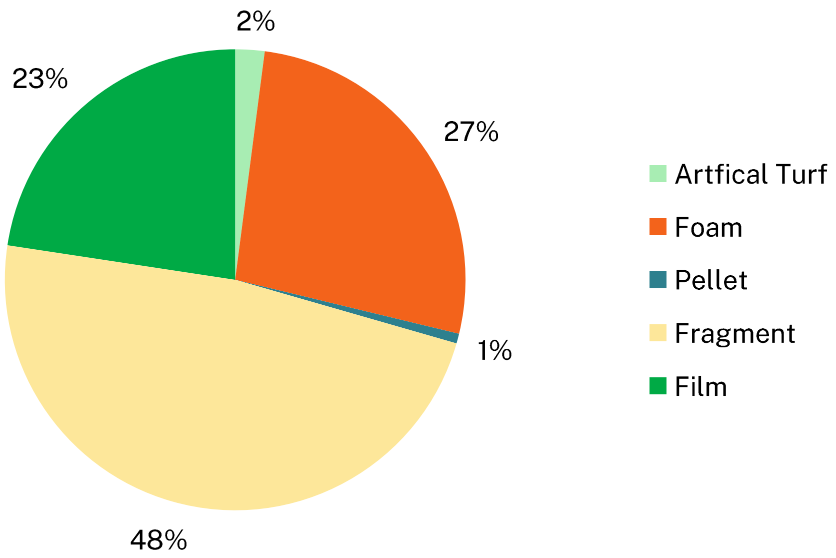


Figure 22 **Proportion of microplastic particles by morphology across Northern Rivers region**

3.2.2 North Coast

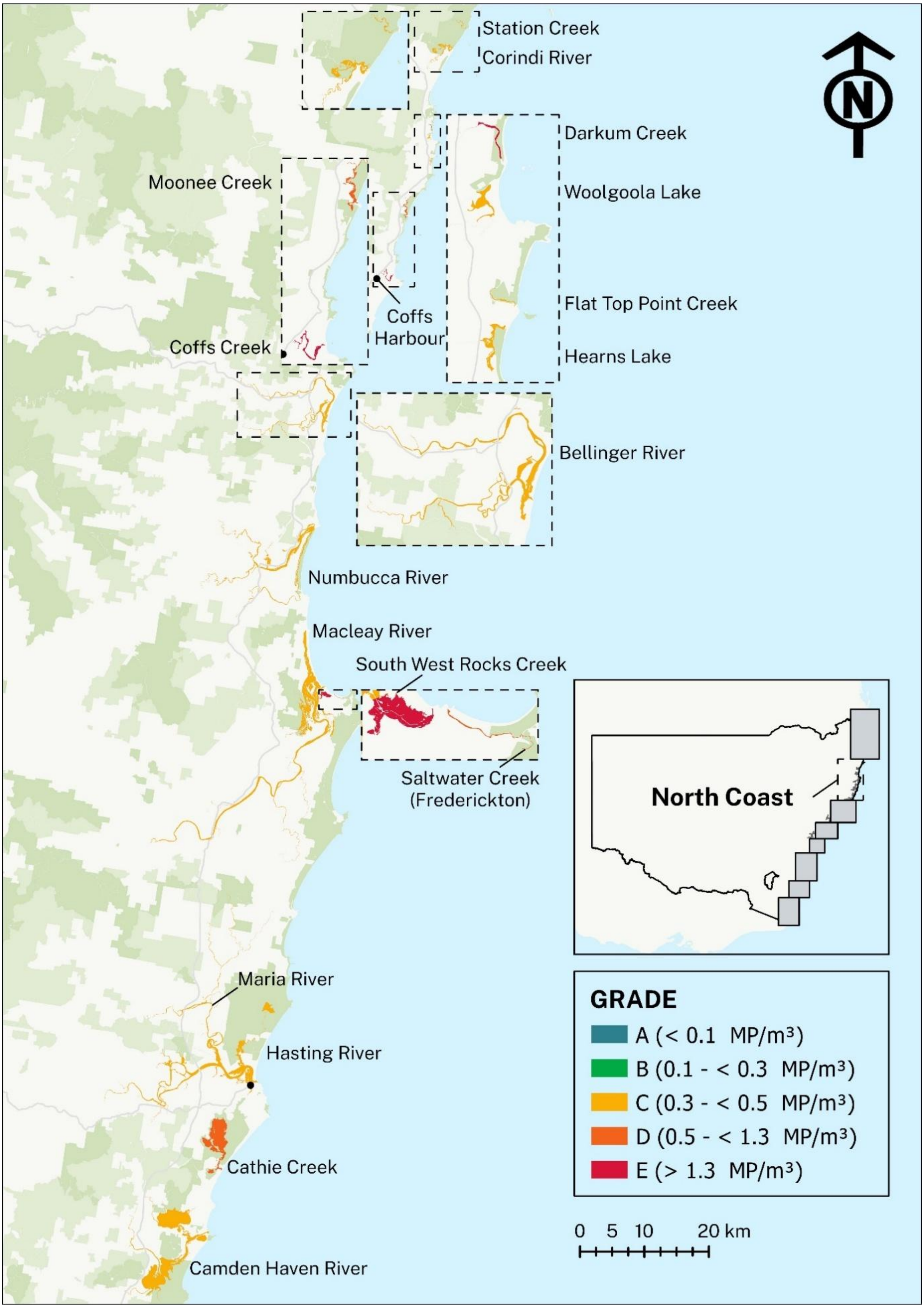


Figure 23 **Coastal waterways within the North Coast region colour-coded according to microplastic contamination grade. Map created by Neda Sharifi Soltani**

In the North Coast region (Figure 23), 67 samples were collected across 17 waterways. Microplastic concentrations varied among systems but were generally within the moderate contamination range.

No waterways were graded as an A or B, 11 were graded C (0.3–<0.5 MP/m^3), 3 were graded D (0.5–<1.3 MP/m^3), and 3 were graded E (>1.3 MP/m^3) (Figure 24). Within the region statewide comparison, the North Coast region ranked seventh out of the 8 regions for overall microplastic contamination (Table 9).

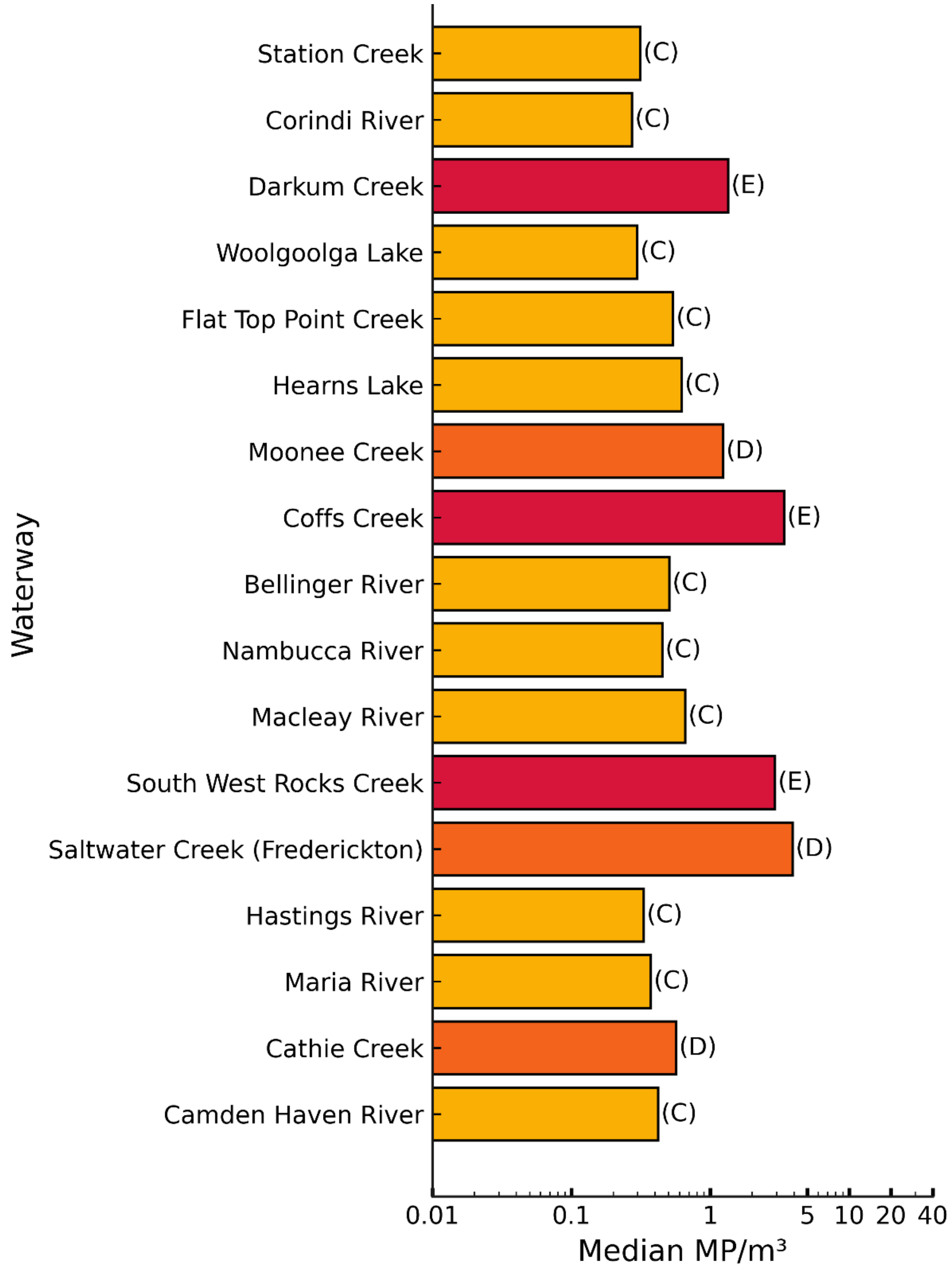


Figure 24 **The median microplastic concentration (MP/m^3) of each waterway in the North Coast region, colour-coded according to grade. Median MP/m^3 (x-axis) is on a logarithmic scale**

Across all samples, the median microplastic concentration was 0.57 MP/m^3, with a mean of 1.38 MP/m^3 and a SD of 1.97 MP/m^3. The highest recorded concentration (8.28 MP/m^3) occurred at Coffs Creek, while Station Creek had instances where no microplastics were detected (0 MP/m^3) (Figure 25).

Several sites, including Darkum Creek, Coffs Creek, South West Rocks Creek, and Saltwater Creek had median concentrations exceeding 1.3 MP/m^3 (Grade E), indicating localised contamination.

Systems such as Station Creek, Woolgoolga Lake, Macleay River, and Saltwater Creek showed high temporal variability, with Station Creek and Woolgoolga having instances with zero detections (Figure 25).

Overall, Darkum Creek, Coffs Creek, and South West Rocks Creek had the highest microplastic contamination levels in the North Coast region, ranking 98th, 115th and 114th out of 120 in the state (median 1.34 MP/m^3, 3.40 MP/m^3, and 2.92 MP/m^3, respectively; Grade E) (Figure 24). These systems all have highly disturbed catchments.

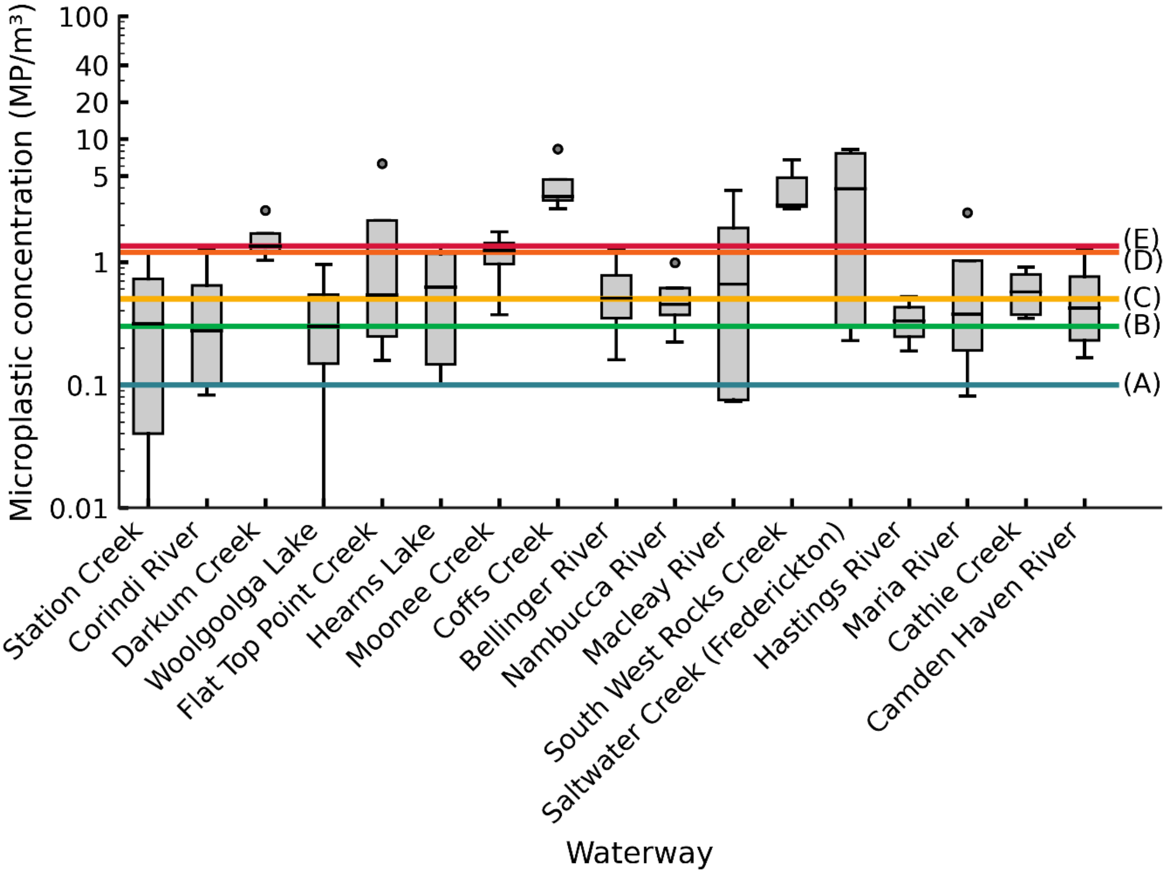


Figure 25 **Microplastic concentration (MP/m^3) across waterways in the North Coast region. The y-axis is log-scaled. Grade references are represented by coloured lines**

The North Coast region represents moderate to high microplastic contamination relative to other NSW coastal regions, with concentrations typically within Grades C and few instances exceeding Grade D–E thresholds (Figure 25).

There were an estimated 1,724 particles counted across the region (5% of the states total particles). Smaller sized particles (>0.25 – <1 mm) were far more abundant (1,164), accounting for 68% of all particles found in the region. Medium sized particles (1 – <2 mm) accounted for 20% of all particles found (346), and large particles (2 – <5 mm) accounted for 12% of all particles found (214) (Figure 26). Of the larger particles characterised, hard fragment was the most abundant morphology, accounting for 53%, followed by foam 25%, film 21%, and pellets 1%, no artificial turf was found (Figure 27).

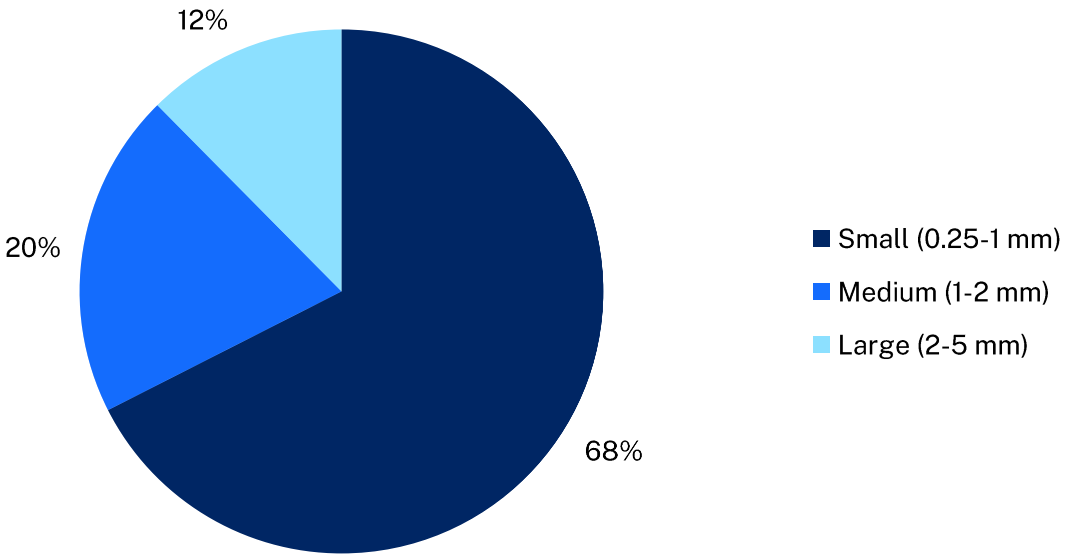


Figure 26 **Proportion of microplastic particles by size class across the North Coast region**

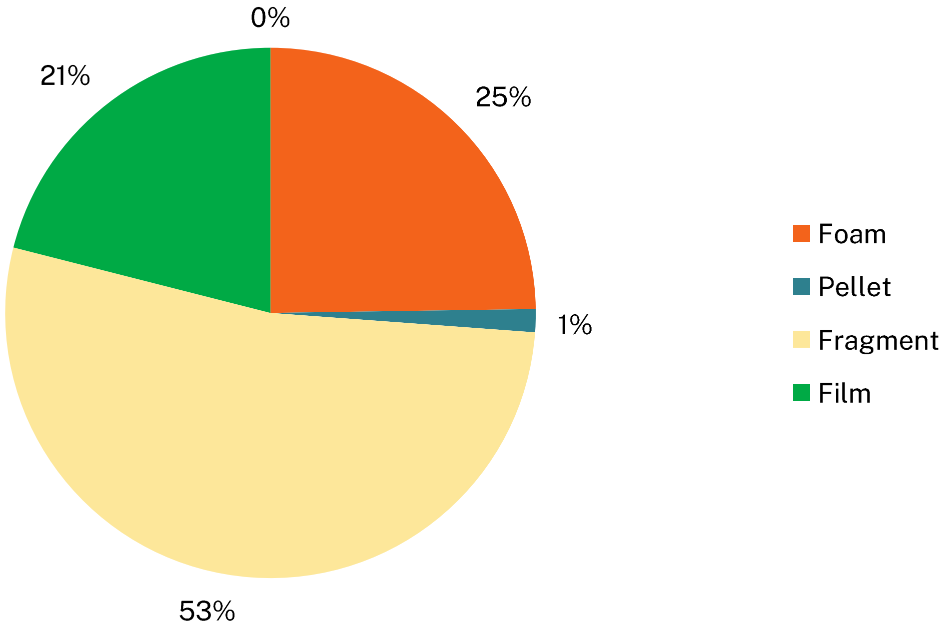


Figure 27 **Proportion of microplastic particles by morphology across North Coast region**

3.2.3 Mid North Coast region

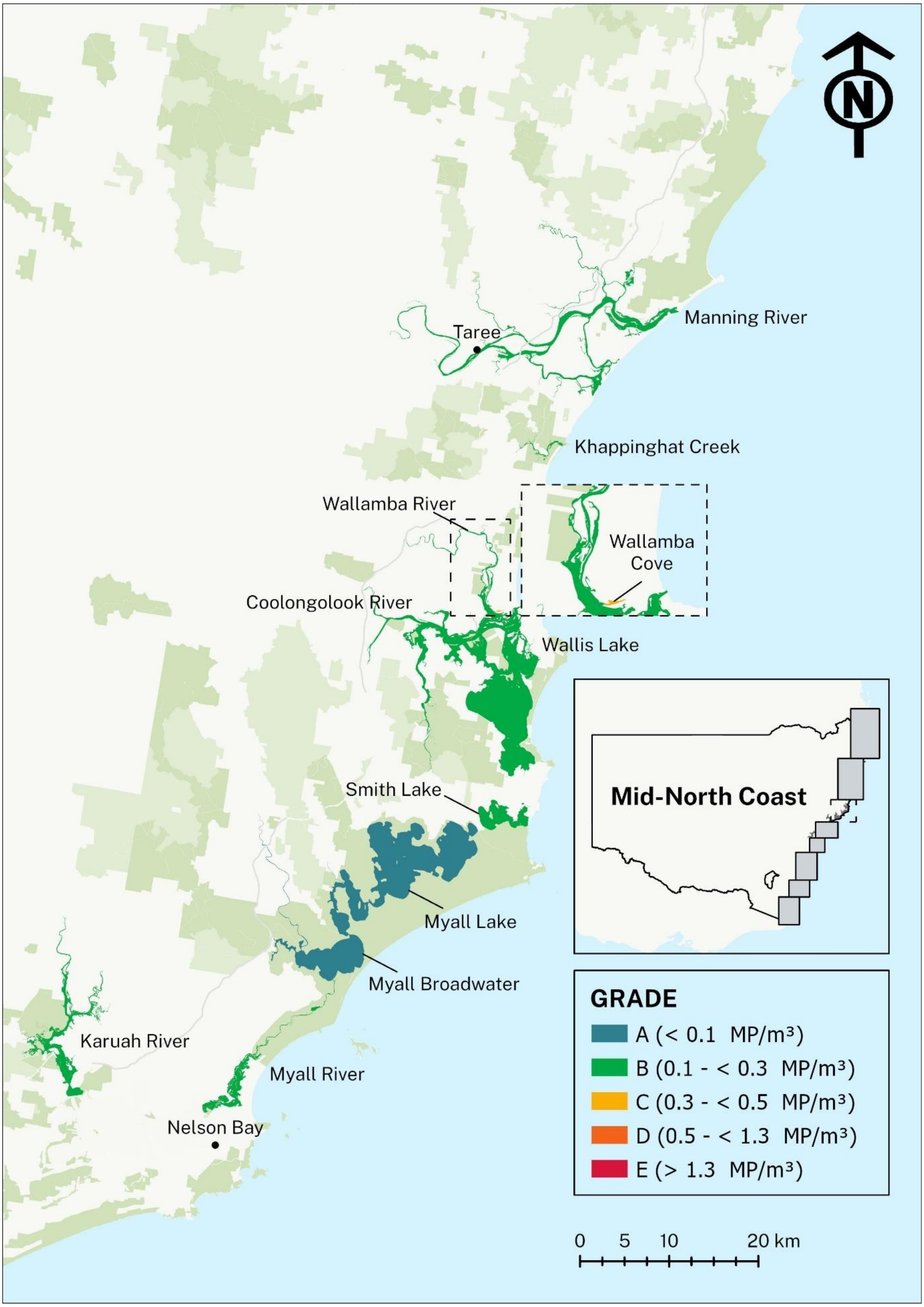


Figure 28 **Coastal waterways within the Mid North Coast region colour-coded according to microplastic contamination grade. Map created by Neda Sharifi Soltani**

In the Mid North Coast region (Figure 28), 96 samples were collected across 11 waterways. Microplastic concentrations varied among systems but were generally within the low contamination range (Figure 29).

Two waterways were graded as an A (<0.1 MP/m^3), 8 as a B (0.1–<0.3 MP/m^3), one as a C (0.3–<0.5 MP/m^3), and no waterways were graded as a D (0.5–<1.3 MP/m^3), or E (>1.3 MP/m^3) (Figure 29).

Within the statewide comparison, the Mid North Coast region ranked first out of the 8 regions for overall microplastic contamination, having the least amount of microplastic contamination on average (Table 9).

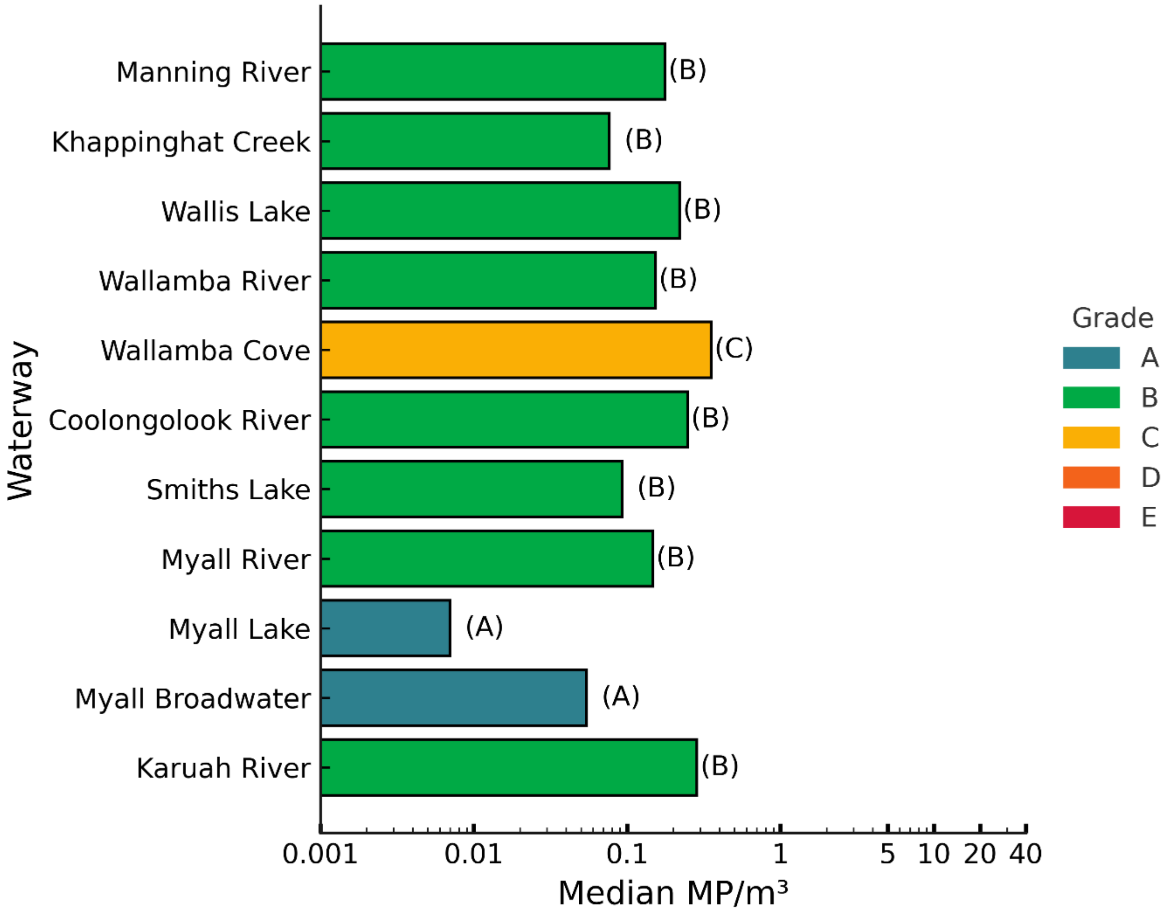


Figure 29 **The median microplastic concentration (MP/m^3) of each waterway in the Mid North Coast region, colour-coded according to average grade. Median MP/m^3 (x-axis) is on a logarithmic scale**

Across all samples, the median microplastic concentration was 0.13 MP/m^3, with a mean of 0.23 MP/m^3 and a SD of 0.29 MP/m^3. The highest recorded concentration (1.70 MP/m^3) occurred at Manning River (upstream), while Manning River (downstream), and Myall Lake contained instances where no microplastics were detected (0 MP/m^3) (Figure 30).

No sites had median microplastic concentrations exceeding 0.5 MP/m^3 (Grade C), with most sites recording a median microplastic concentration between 0.1 and 0.3 MP/m^3

indicating low microplastic contamination in the region. Wallamba Cove was the only waterway in the region to receive a C grade, likely driven by localised sources.

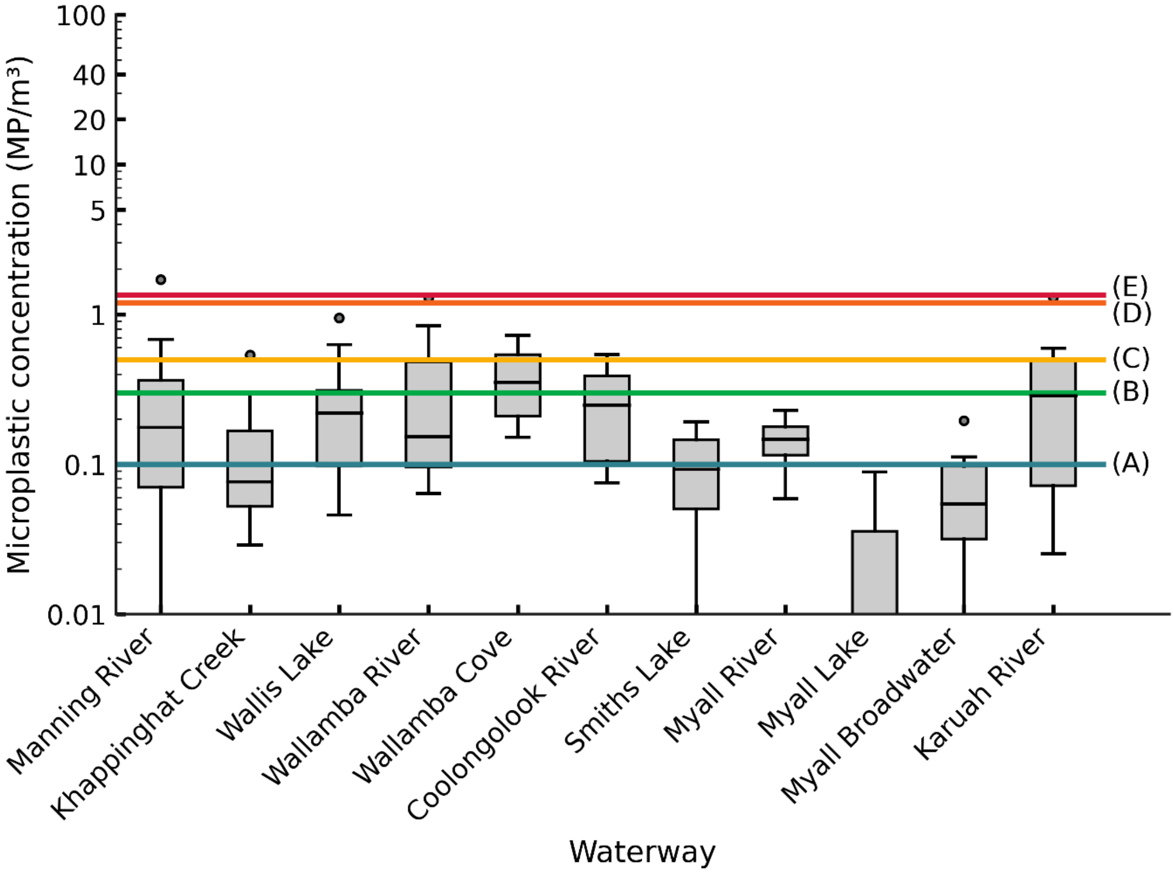


Figure 30 Box-and-whisker plot of microplastic concentration (MP/m^3) across waterways in the Mid North Coast region. The y-axis is log-scaled. Grade references are represented by coloured lines

Overall, the Mid North Coast region had the lowest microplastic contamination levels in the state with Myall Lake also being ranked first out of 120 assessed waterways for microplastic contamination (Median 0.01 MP/m^3; Grade A) (Figure 29). This system has a small and minimally disturbed catchment.

There were an estimated 883 particles counted across the region (3% of the states total particles). Smaller sized particles (>0.25 – <1 mm) were far more abundant (680), accounting for 77% of all particles found in the region.

Medium sized particles (1 – <2 mm) accounted for 18% of all particles found (160), and large particles (2 – <5 mm) accounted for 5% of all particles found (43) (Figure 31). Of the larger particles characterised, film was the most abundant morphology, accounting for 53%, followed by fragment 30%, then foam 16%, no artificial turf or pellets were recorded in the Mid North Coast region (Figure 32).

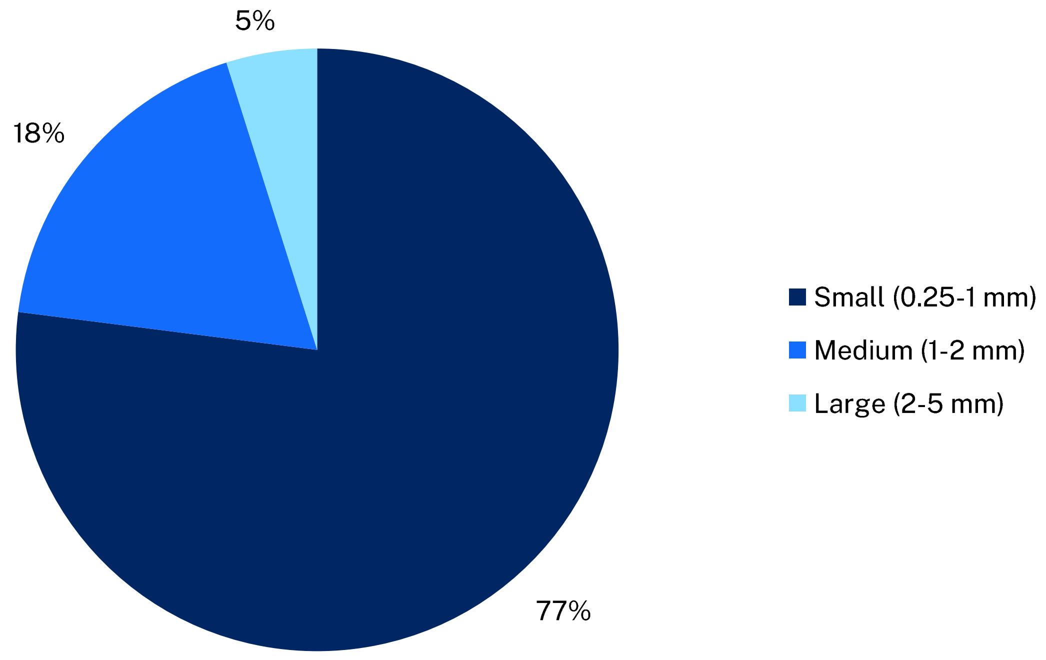


Figure 31 Proportion of microplastic particles by size class across Mid North Coast region

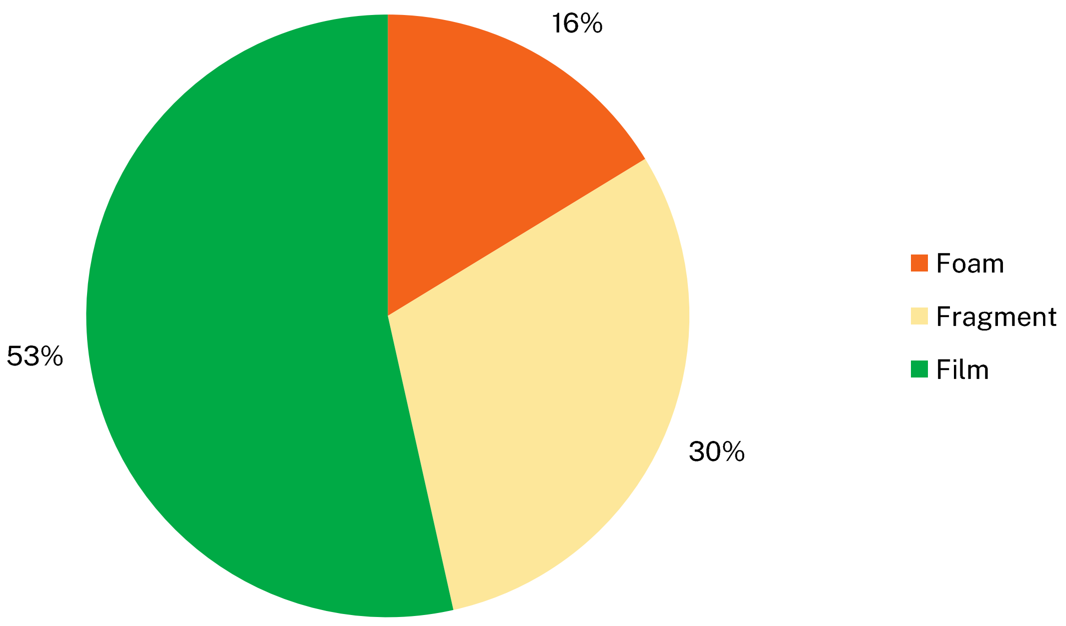


Figure 32 Proportion of microplastic particles by morphology across Mid North Coast region

3.2.4 Hunter–Central Coast region

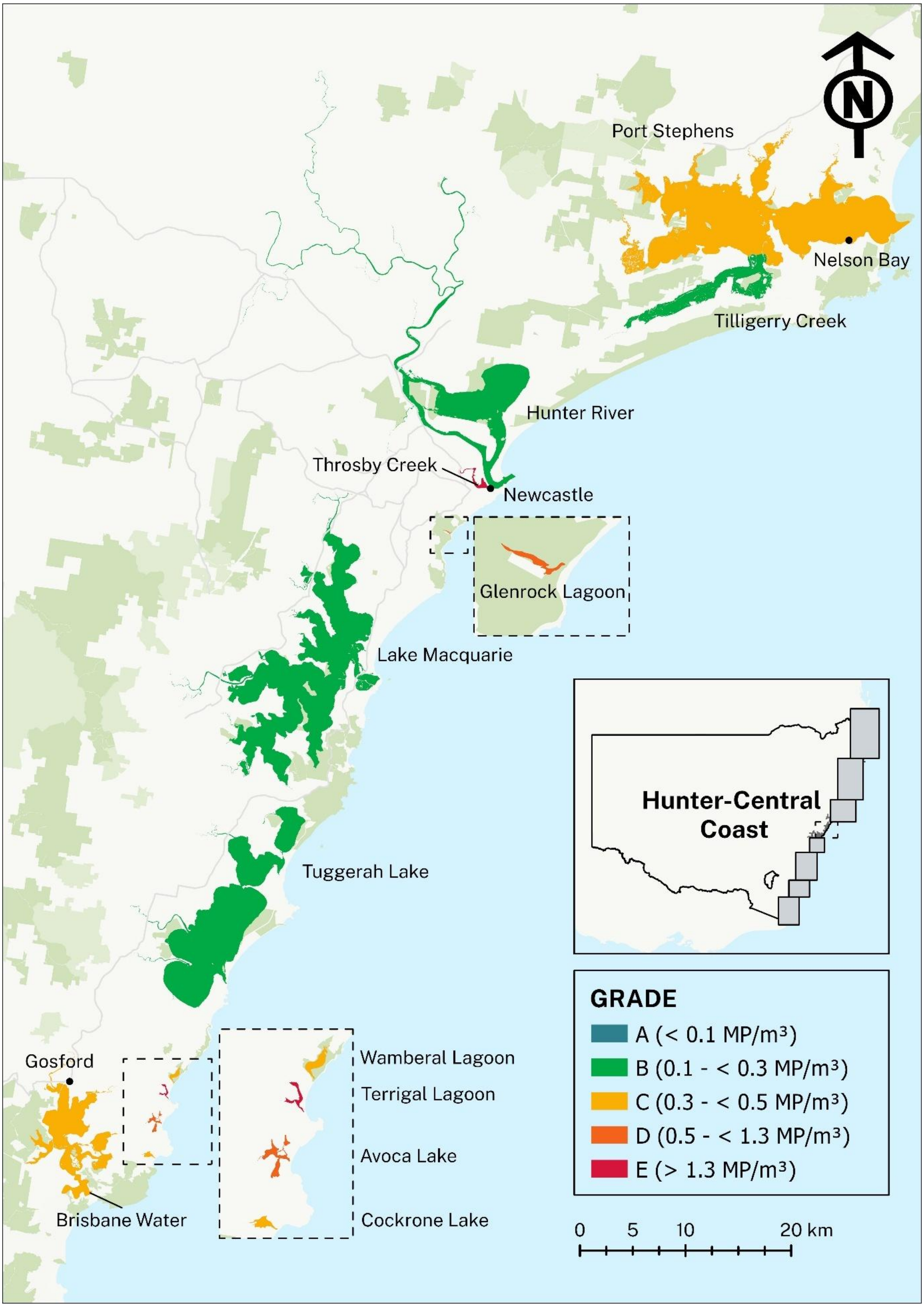


Figure 33 Hunter–Central Coast waterways spatial assessment of microplastic contamination. Map created by Neda Sharifi Soltani

In the Hunter–Central Coast region (Figure 33), 74 samples were collected across 12 waterways. Microplastic concentrations varied among systems but were generally within the low-to-moderate contamination range.

Four waterways were graded as a B (0.1–<0.3 MP/m^3), 4 were graded C (0.3–<0.5 MP/m^3), 2 were graded D (0.5–<1.3 MP/m^3), and 2 were graded as an E (>1.3 MP/m^3) (Figure 34). Within the statewide comparison, the Hunter–Central Coast region ranked fourth out of the 8 regions for overall microplastic contamination (Table 9).

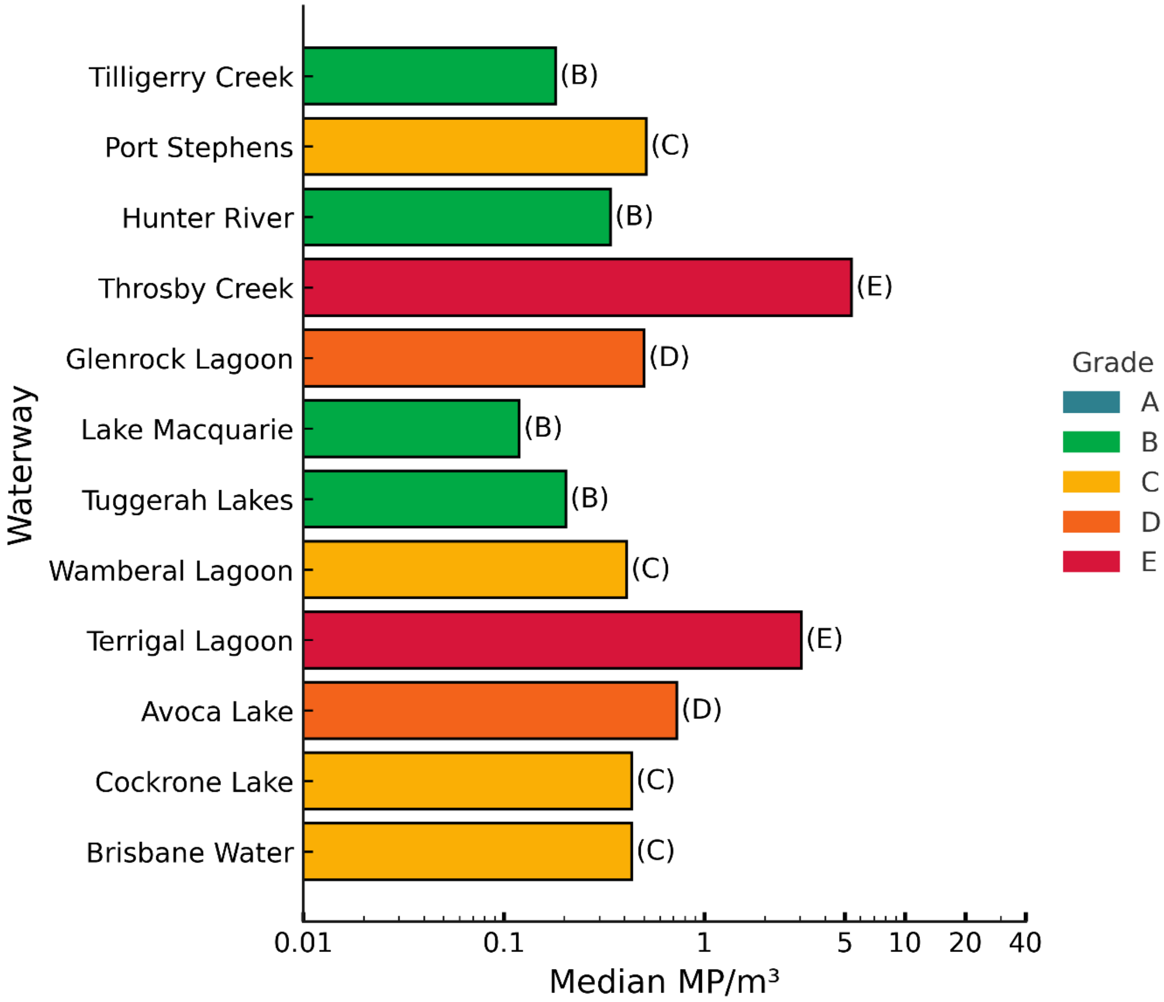


Figure 34 **The median microplastic concentration (MP/m^3) of each waterway in the Hunter–Central Coast region, colour-coded according to average grade. Median MP/m^3 (x-axis) is on a logarithmic scale**

Across all samples in the region, the median microplastic concentration was 0.25 MP/m^3, with a mean of 0.91 MP/m^3 and a SD of 2.44 MP/m^3. The highest concentration recorded was 17.96 MP/m^3 at Throsby Creek, whereas Lake Macquarie occasionally had no detectable microplastics (0 MP/m^3) (Figure 35).

Despite the region's low median (0.25 MP/m^3), several high-concentration outliers (Figure 35) indicate localised contamination in urban tributaries and lagoons. Throsby Creek and Terrigal Lagoon exhibited median concentrations well above the Grade E threshold (>1.3 MP/m^3), with medians of 5.42 MP/m^3 and 3.04 MP/m^3, respectively, indicating localised contamination (Figure 34).

Throsby Creek consistently exceeded the Grade E threshold for microplastic contamination (>1.3 MP/m^3) (Figure 35)and ranked among the most contaminated waterways in New South Wales (116th of 120) (Table 8). This identifies Throsby Creek as a high-priority site for targeted monitoring and management interventions. In contrast, larger systems such as Tilligerry Creek, Lake Macquarie, and Tuggerah Lakes generally recorded concentrations below 0.3 MP/m^3 (Grade B).

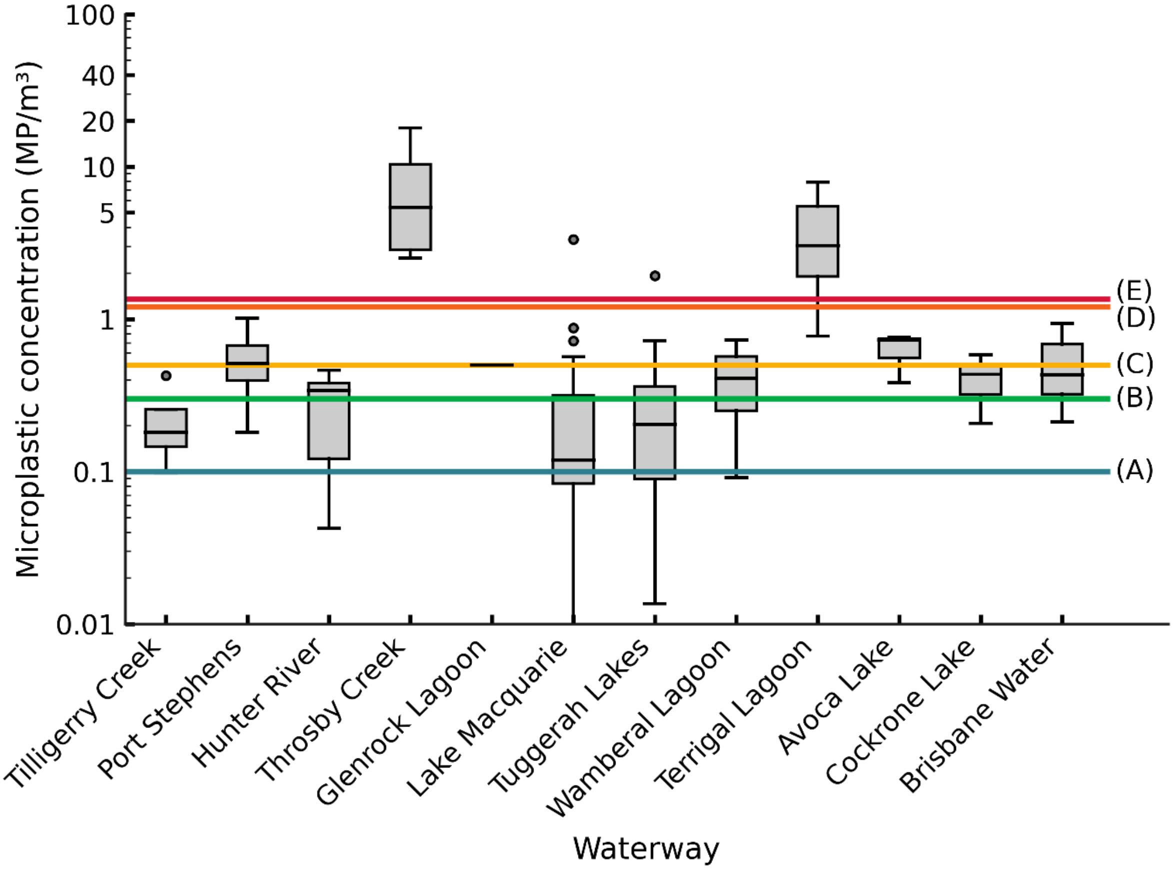


Figure 35 Box-and-whisker plot of microplastic concentration (MP/m^3) across waterways in the Hunter–Central Coast region. The y-axis is log-scaled. Grade references are represented by coloured lines

Overall, the Hunter–Central Coast region represents moderate microplastic contamination relative to other NSW coastal regions, with concentrations typically within Grades B–C and few instances exceeding Grade D–E thresholds (Figure 34).

There were an estimated 2,028 particles counted across the region (5% of the states total particles). Smaller sized particles (>0.25 – <1 mm) were far more abundant (1,388), accounting for 68% of all particles found in the region.

Medium sized particles (1 – <2 mm) accounted for 23% of all particles found (475), and large particles (2 – <5 mm) accounted for 8% of all particles found (165) (Figure 36). Throsby Creek was responsible for 50% of those large particles (82).

Of all the larger particles characterised (165), hard fragment was the most abundant morphology, accounting for 52%, followed by film 35%, foam 10%, and artificial turf 3%, and no pellets (Figure 37).

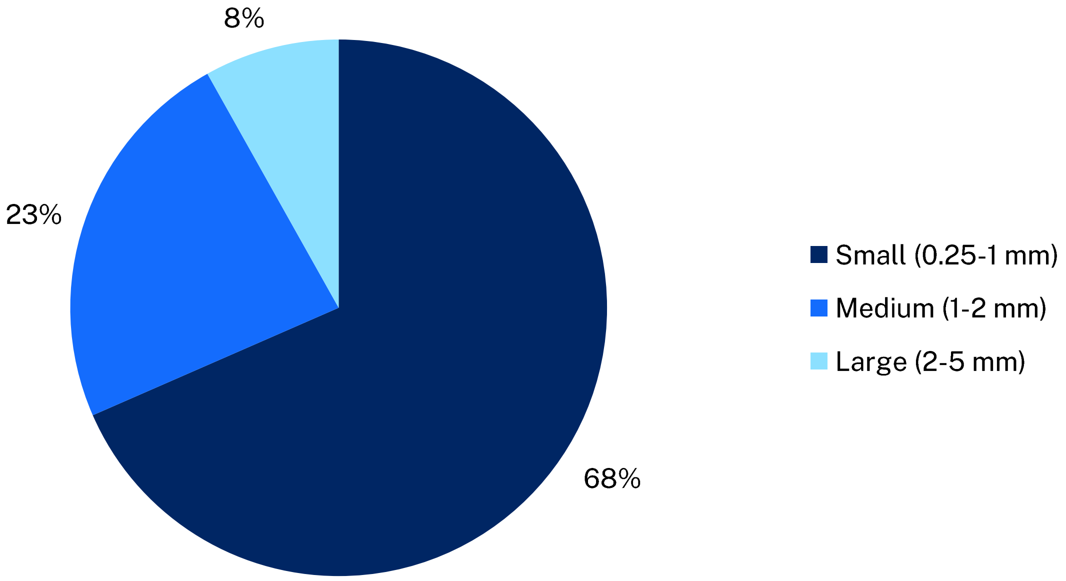


Figure 36 **Proportion of microplastic particles by size class across Hunter–Central Coast region**

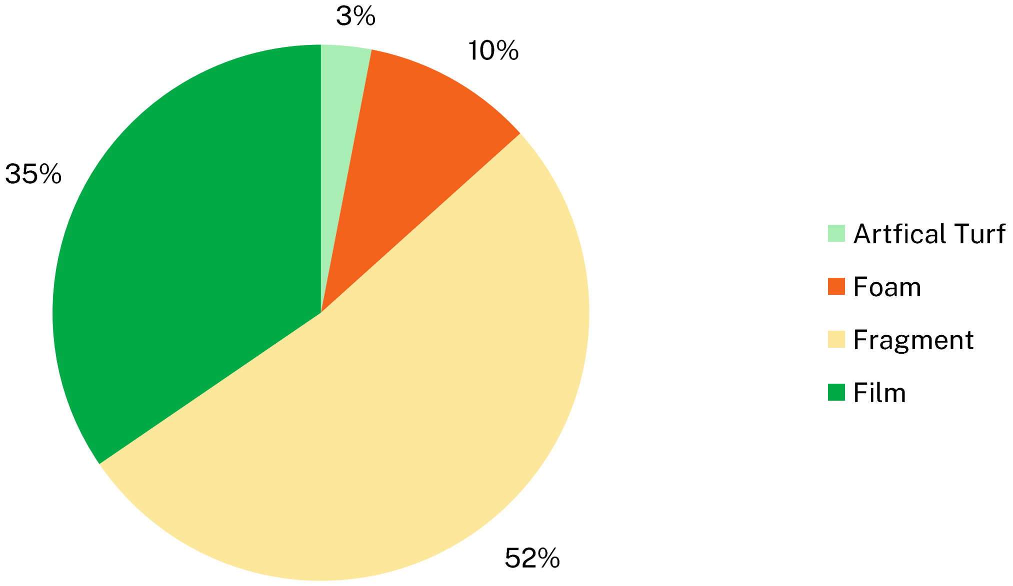


Figure 37 **Proportion of microplastic particles by morphology across Hunter–Central Coast region**

3.2.5 Hawkesbury–Sydney region

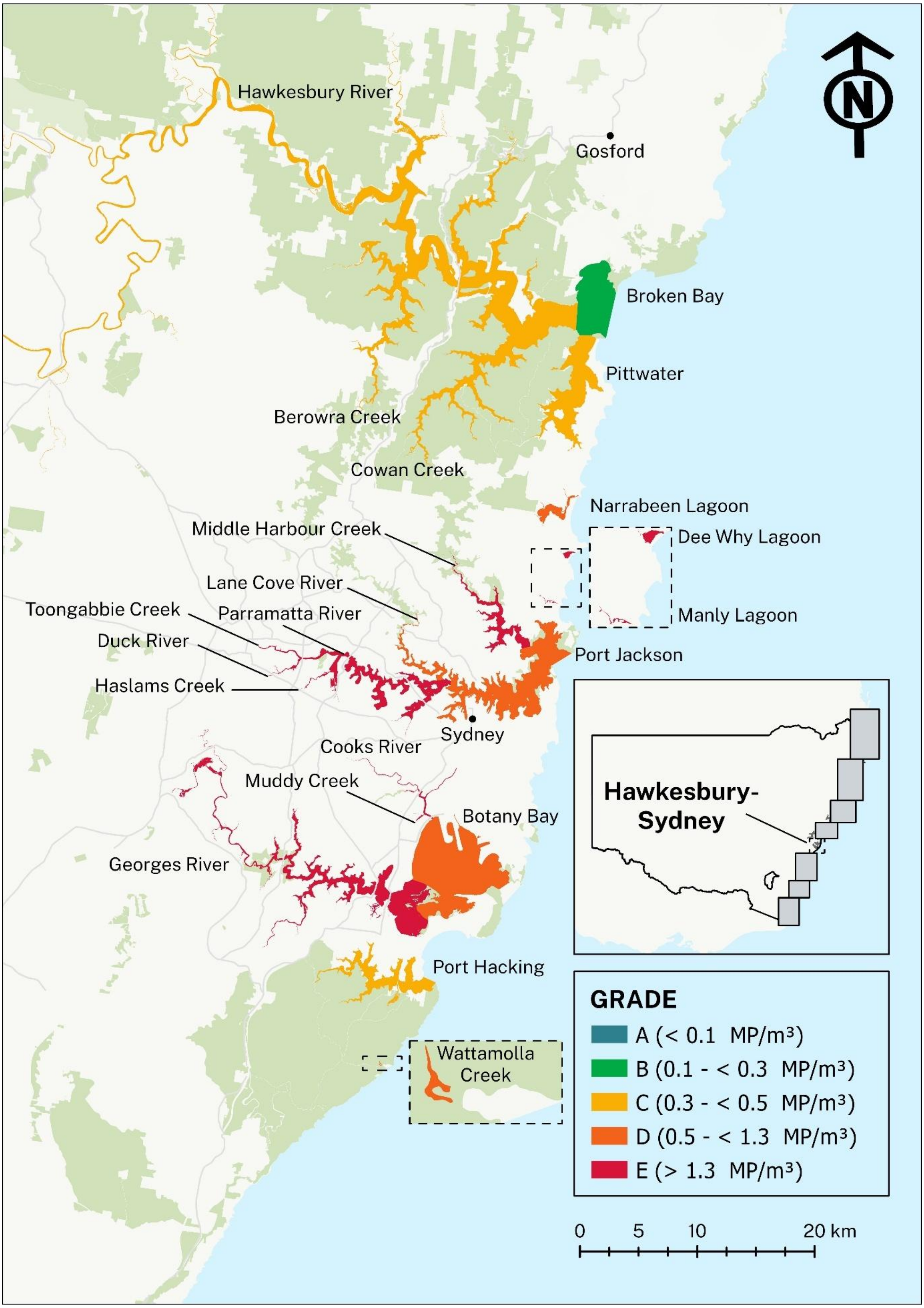


Figure 38 **Spatial distribution of microplastic contamination grades (A–E) across waterways in the Hawkesbury–Sydney region. Created by Neda Sharifi Soltani**

In the Hawkesbury–Sydney region (Figure 38), 111 samples were collected across 21 waterways. Microplastic concentrations varied among systems but were generally within the high-to-very high contamination range. One waterway was graded as a B (0.1–<0.3 MP/m^3), 5 were graded C (0.3–<0.5 MP/m^3), 5 were graded D (0.5–<1.3 MP/m^3), and 10 were graded as an E (>1.3 MP/m^3) (Figure 39).

The Hawkesbury–Sydney region ranked last (8th of 8) in the statewide regional comparison, indicating it had the highest overall microplastic contamination among all regions (Table 9).

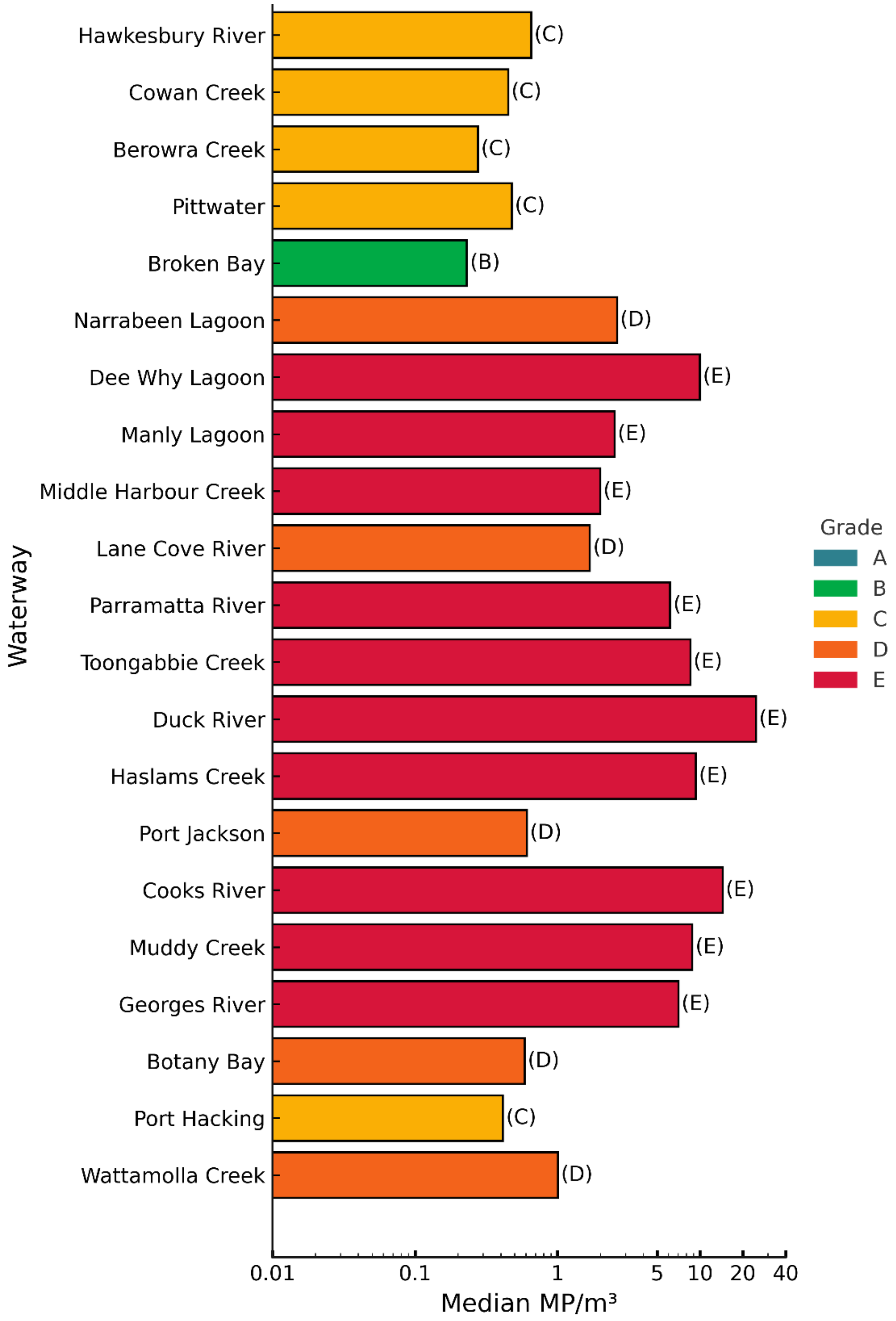


Figure 39 **The median microplastic concentration (MP/m^3) and microplastic contamination grade of each waterway in the Hawkesbury–Sydney region**

Across all samples in the region, the median microplastic concentration was 1.86 MP/m^3, with a mean of 8.20 MP/m^3 and a SD of 16.93 MP/m^3. The highest concentration (102.04 MP/m^3) was recorded in Parramatta River, while Broken Bay had the lowest recorded microplastic concentration (0.06 MP/m^3) (Figure 40).

Most sites in the Hawkesbury–Sydney region recorded median microplastic concentrations above the Grade E threshold (>1.3 MP/m^3), including Lane Cove River, Middle Harbour Creek, Manly Lagoon, Narrabeen Lagoon, Parramatta River, Georges River, Toongabbie Creek, Muddy Creek, Haslams Creek, Dee Why Lagoon, Cooks River, and Duck River, regardless of estuary size or type (Figure 39). Broken Bay was the only site in the region classified as having low microplastic contamination (Grade B), reflecting its status as an oceanic bay with greater tidal flushing.

Overall, the Hawkesbury–Sydney region exhibited the highest microplastic contamination of all NSW coastal regions, with concentrations predominantly within Grade E (Figure 39). Eight of the most contaminated waterways statewide are in this region: Haslams Creek (ranked 110/120), Middle Harbour Creek (111/120), Parramatta River (112/120), Manly Lagoon (113/120), Toongabbie Creek (117/120), Muddy Creek (118/120), Dee Why Lagoon (119/120), and Cooks River (120/120).

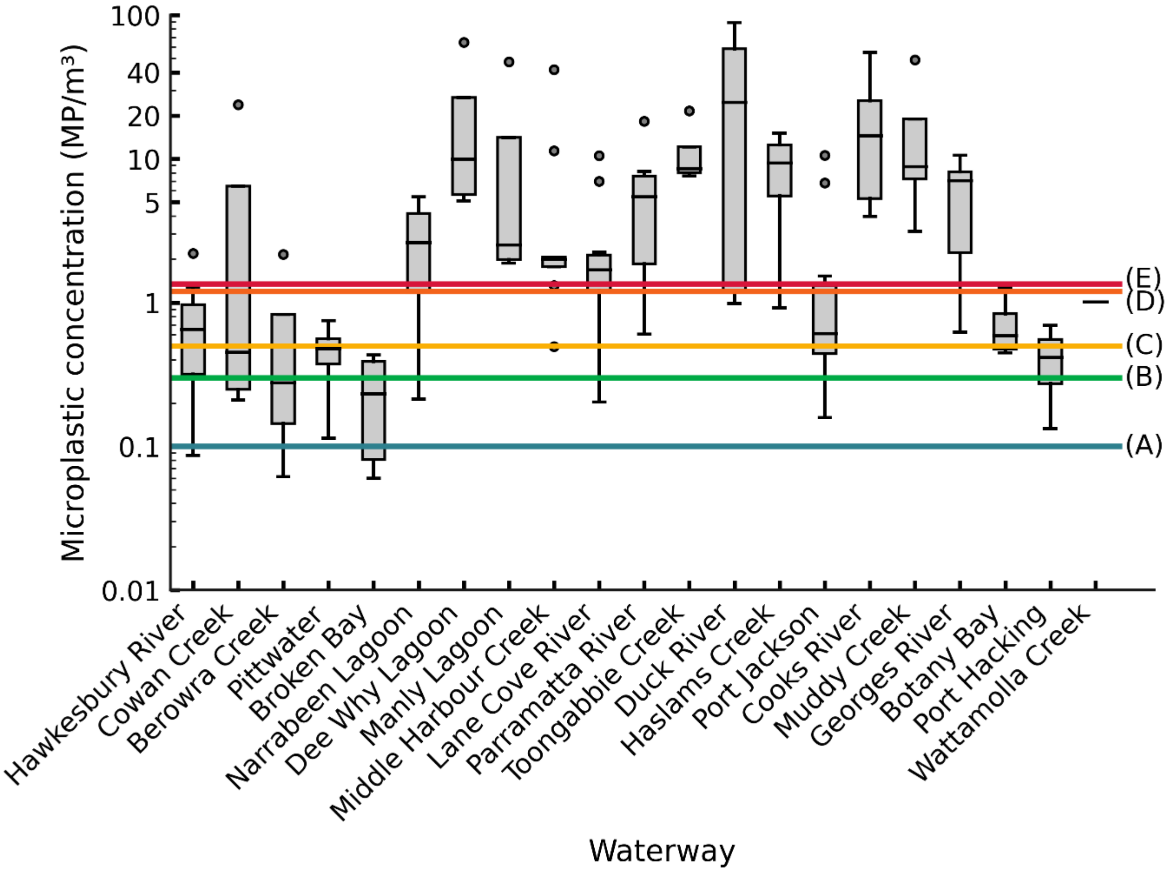


Figure 40 Box-and-whisker plot of microplastic concentration (MP/m^3) across waterways in the Hawkesbury–Sydney region

There were an estimated 23,184 particles counted across the region (73% of the states total particles). Smaller sized particles (>0.25 – <1 mm) were far more abundant (15,400), accounting for 66% of all particles found in the region. Medium sized particles (1 – <2 mm) accounted for 18% of all particles found (4,113), and large particles (2 – <5 mm) accounted for 16% of all particles found (3,671) (Figure 41). Of the larger particles characterised, foam was the most abundant morphology, accounting for 41%, followed by fragment 34%, film 16%, artificial turf 6%, and pellets 2% (Figure 42).

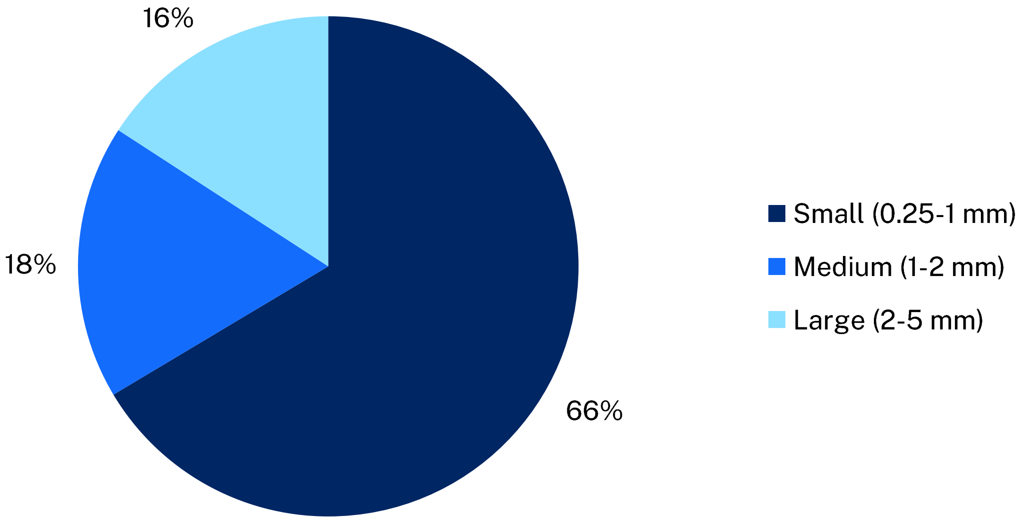


Figure 41 Proportion of microplastic particles by size class across the Hawkesbury–Sydney region

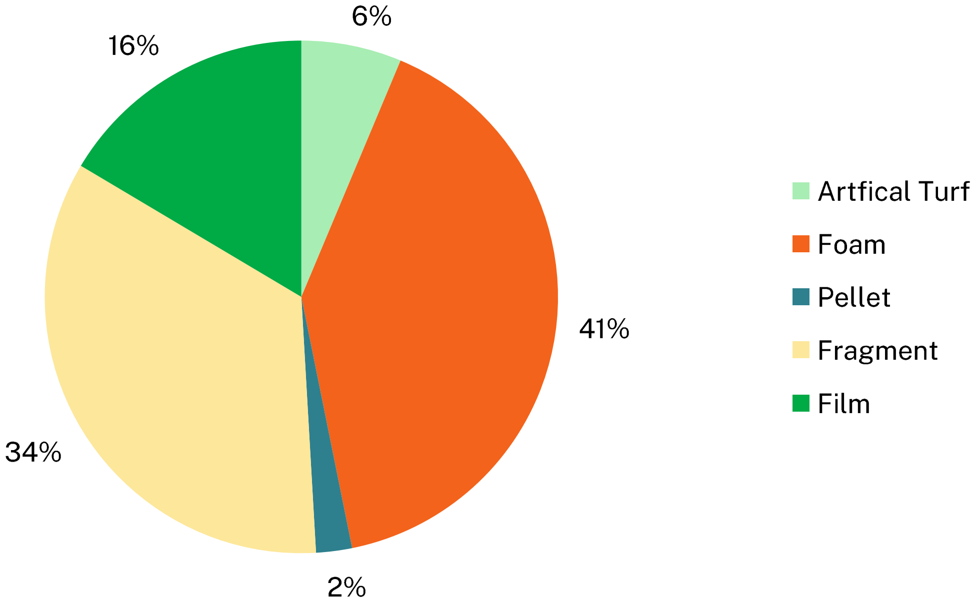


Figure 42 Proportion of microplastic particles by morphology across the Hawkesbury–Sydney region

3.2.6 Illawarra–Shoalhaven

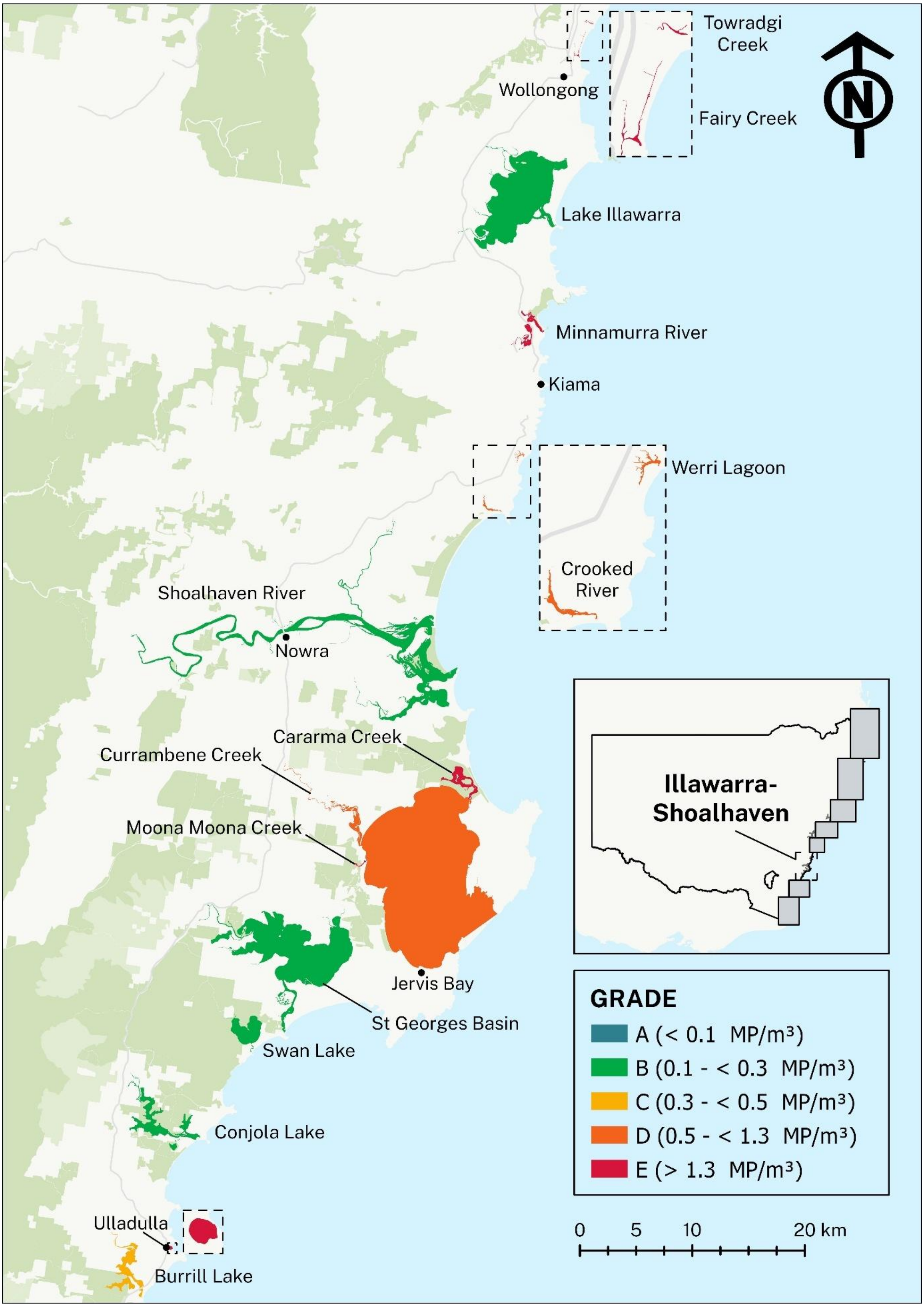


Figure 43 Spatial distribution of microplastic contamination grades (A–E) across coastal waterways in Illawarra–Shoalhaven region. Created by Neda Sharifi Soltani

In the Illawarra–Shoalhaven region (Figure 43), 72 samples were collected across 16 waterways. Microplastic concentrations varied among systems but were generally within the moderate to high contamination range. Five waterways were graded as a B (0.1–<0.3 MP/m^3), one was graded C (0.3–<0.5 MP/m^3), 4 were graded D (0.5–<1.3 MP/m^3), and 6 were graded E (>1.3 MP/m^3) (Figure 44). Within the statewide comparison, the Illawarra–Shoalhaven region ranked sixth out of the 8 regions for overall microplastic contamination (Table 9).

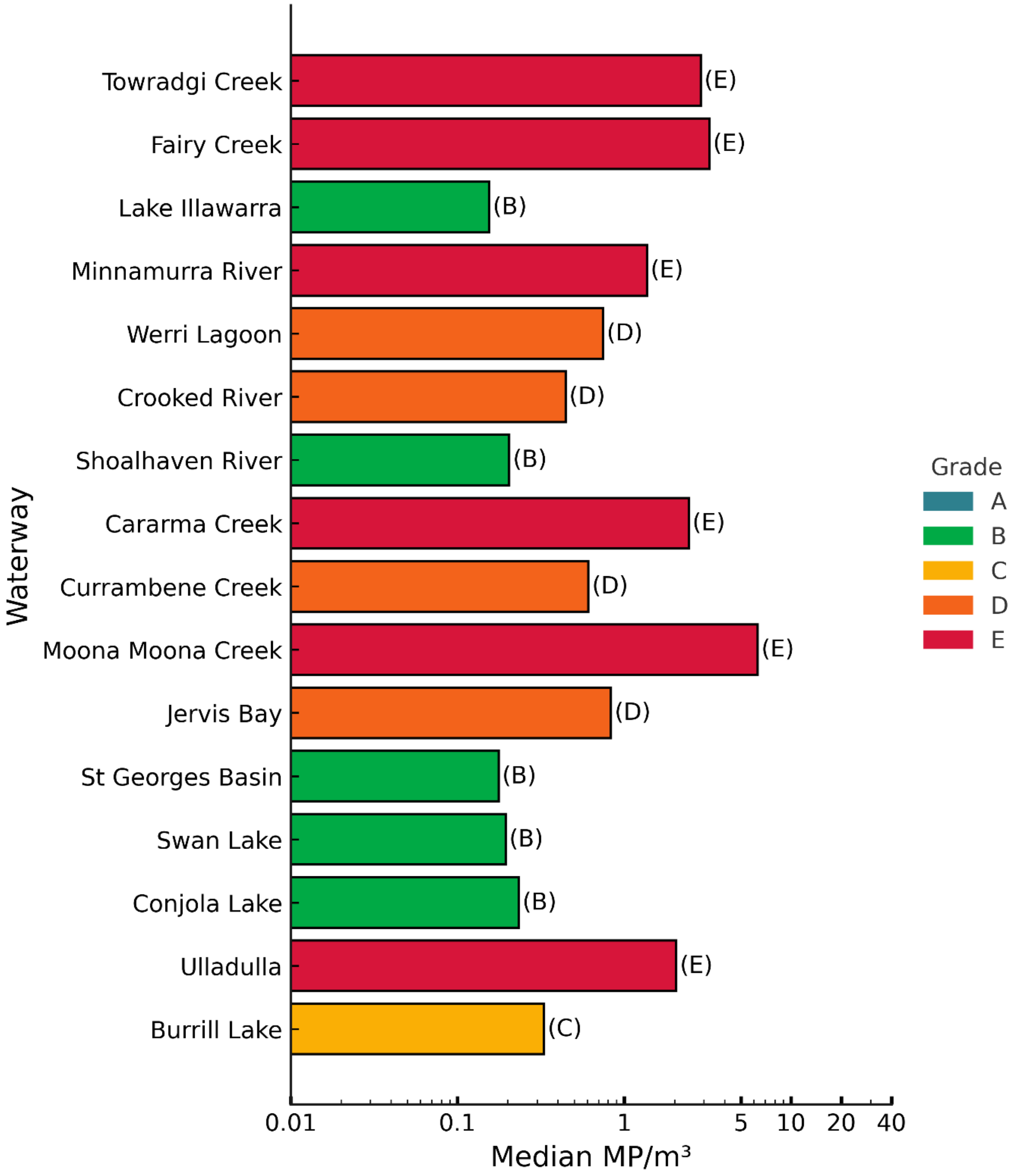


Figure 44 **The median microplastic concentration (MP/m^3) and microplastic contamination grade of each waterway in the Illawarra–Shoalhaven region**

Across all samples, the median microplastic concentration was 0.47 MP/m^3, with a mean of 1.15 MP/m^3 and a SD of 1.68 MP/m^3. The highest recorded concentration (7.64 MP/m^3) occurred at Fairy Creek, while Lake Illawarra had instances where no microplastics were detected (0 MP/m^3) (Figure 45).

Several sites, including Towradgi Creek, Fairy Creek, Minnamurra River, Cararma Creek, Moona Moona Creek and Ulladulla, had median concentrations exceeding 1.3 MP/m^3 (Grade E), indicating localised contamination. Moona Moona Creek and Fairy Creek recorded the highest median microplastic concentrations in the region (3.24 MP/m^3 and 6.30 MP/m^3), ranking 105th and 106th in the state, respectively (Table 8).

Conversely, Lake Illawarra, Shoalhaven River, St Georges Basin, Swan Lake, and Conjola Lake, had low median microplastic concentrations of less than 0.3 MP/m^3 (Grade B). These high-level results suggest that both estuary type and catchment disturbance may influence microplastic concentration in surface waters.

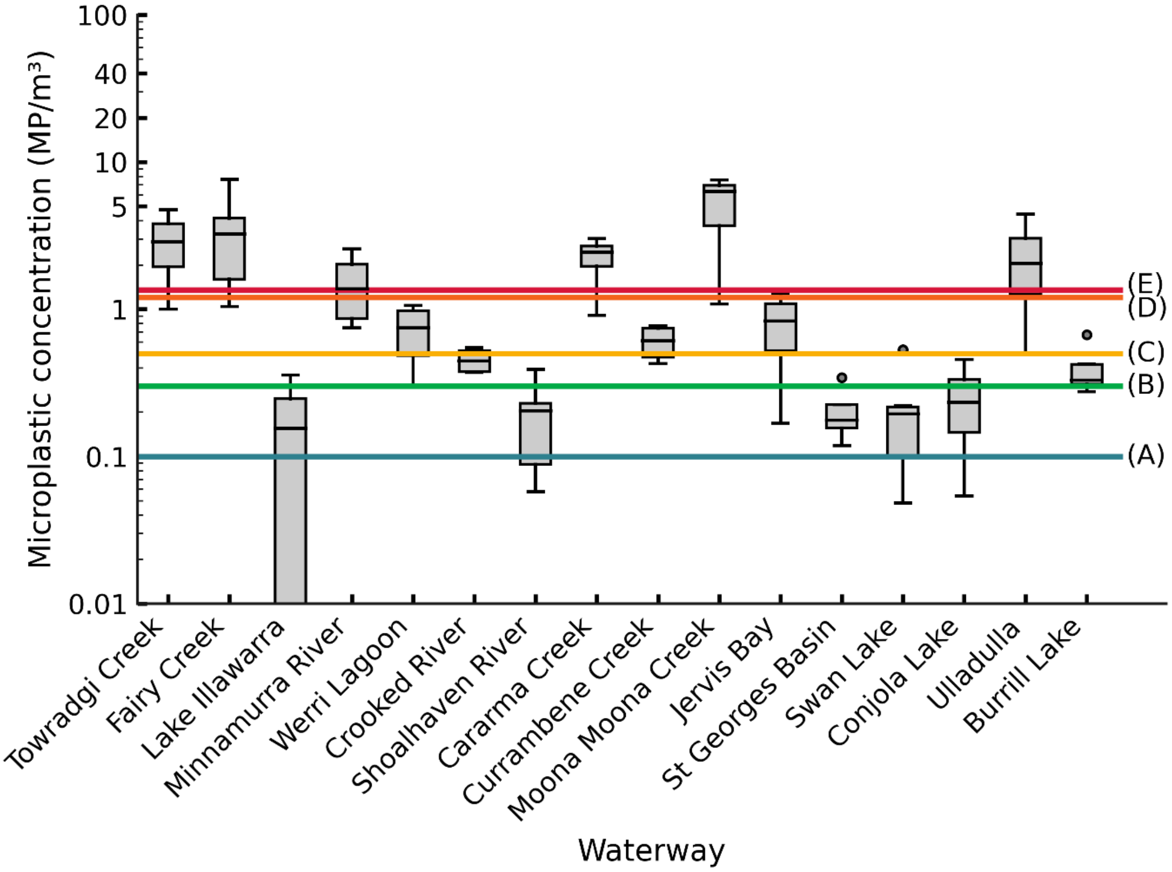


Figure 45 Box-and-whisker plot of microplastic concentration (MP/m^3) across waterways in the Illawarra–Shoalhaven region

Overall, the Illawarra–Shoalhaven region exhibits moderate to high microplastic contamination compared to other NSW regions. Although the regional median corresponds to Grade C, with 10 of 16 systems with Grades D-E, only one system (Burrill Lake) was graded ‘C’ and remaining systems all received Grade B (Figure 44). The variability observed across this region highlights the interaction between land use and hydrodynamic conditions, with higher loads generally associated with smaller waterways.

There were an estimated 1,720 particles recorded across the region (5% of the states total particles). Smaller sized particles (>0.25 – <1 mm) were far more abundant (1,319), accounting for 77% of all particles found in the region. Medium sized particles (1 – <2 mm) accounted for 16% of all particles found (271), and large particles (2 – <5 mm) accounted for only 8% of all particles found (130) (Figure 46). Of the larger particles characterised, fragment was the most abundant morphology, accounting for 55%, followed by foam 21%, film 20%, artificial turf 3%, and pellets 1% (Figure 47).

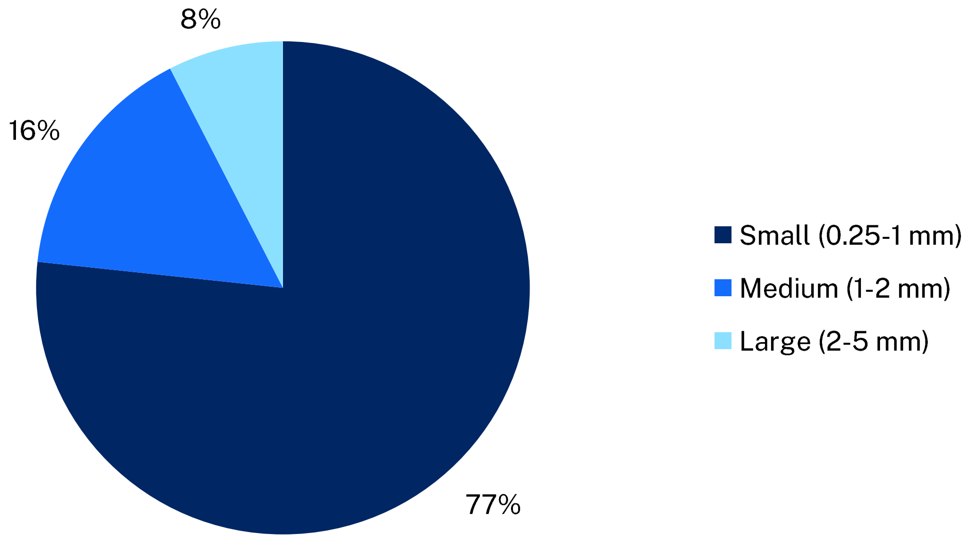


Figure 46 Proportion of microplastic particles by size across Illawarra–Shoalhaven region

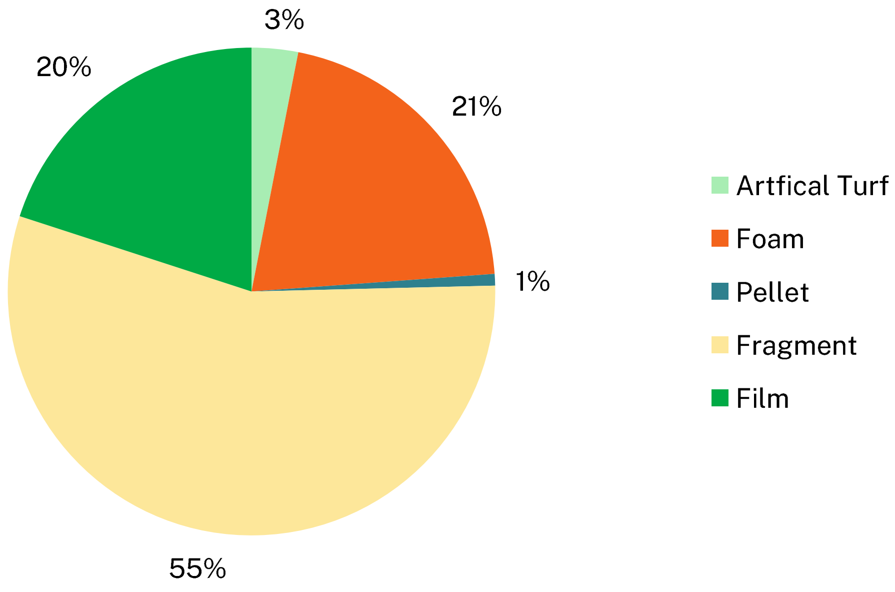


Figure 47 Proportion of microplastic particles by morphology across Illawarra–Shoalhaven region

3.2.7 Eurobodalla region

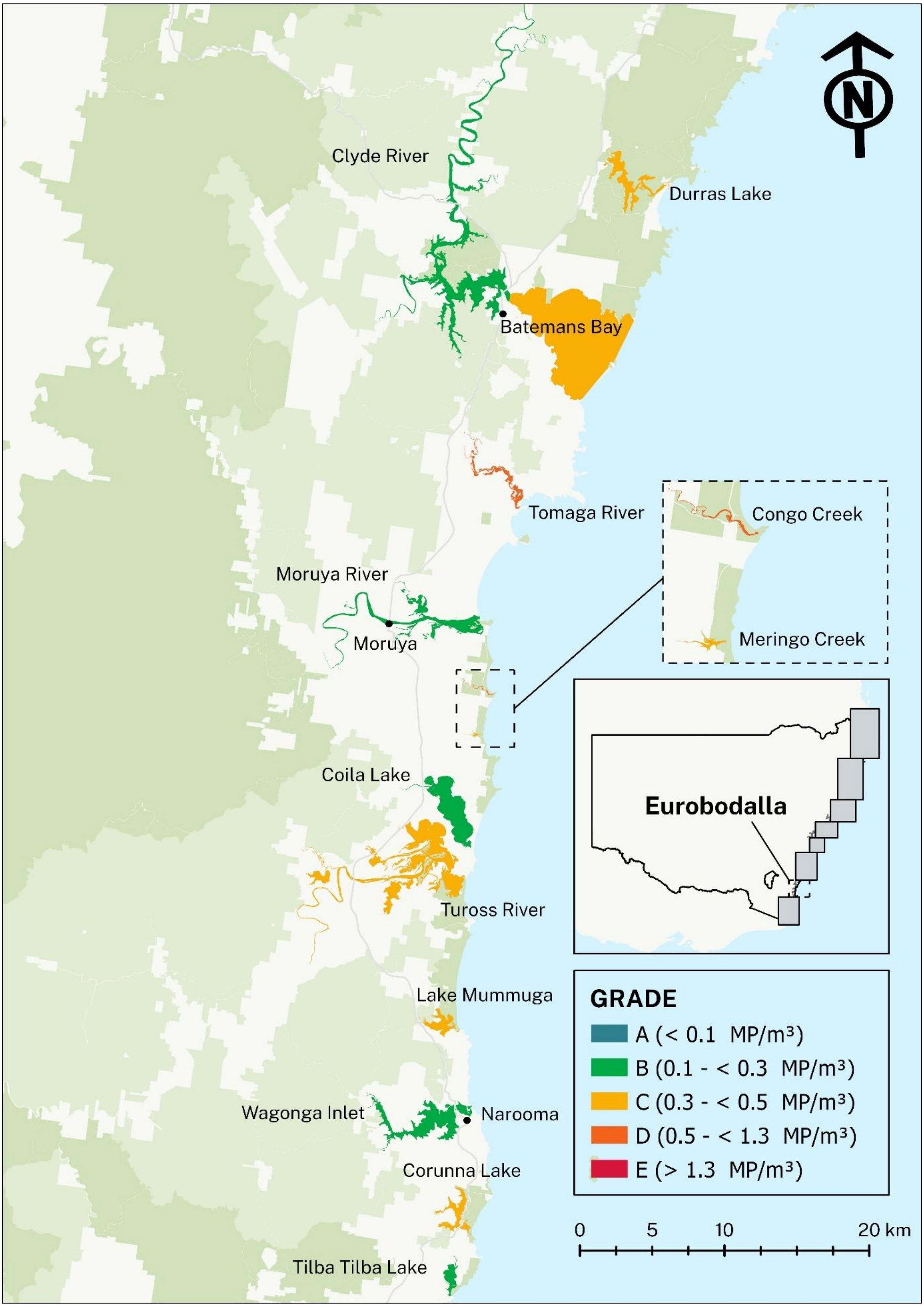


Figure 48 Spatial distribution of microplastic contamination grades (A–E) across coastal waterways in Eurobodalla region. Map credit Neda Sharifi Soltani

In the Eurobodalla region (Figure 48), 58 samples were collected across 13 waterways. Microplastic concentrations varied among systems but were generally within the low-moderate contamination range (Figure 49). There were no extreme contamination events relative to other NSW regions (Figure 50).

Five waterways were graded as a B (0.1–<0.3 MP/m^3), 6 were graded as a C (0.3–<0.5 MP/m^3), and 2 were graded as a D (0.5–<1.3 MP/m^3), no waterways in the region were graded as an A or E (Figure 49). In the statewide comparison, the Eurobodalla region ranked second (out of 8), indicating it was the second least contaminated by microplastics (Table 9).

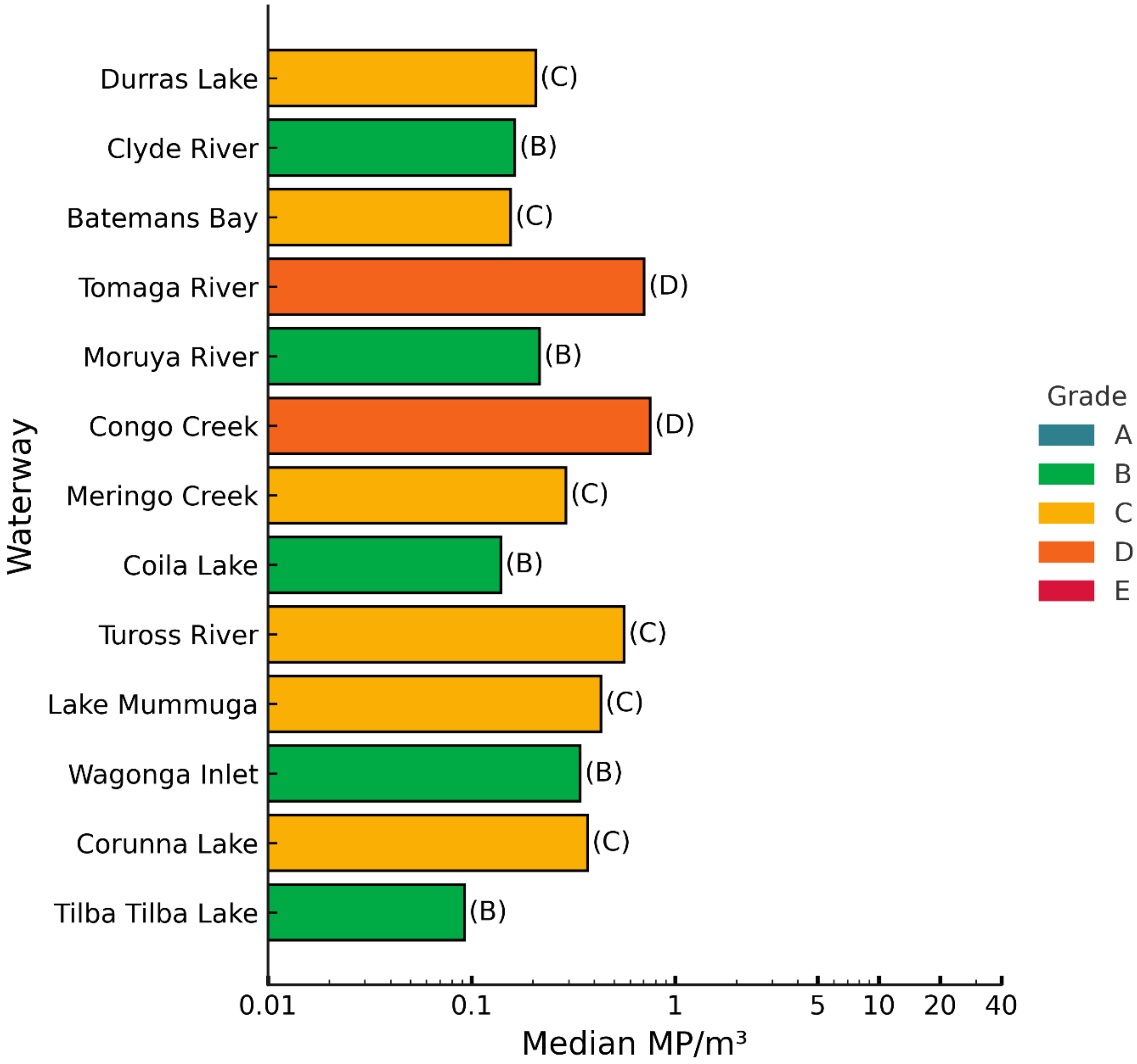


Figure 49 **The median microplastic concentration (MP/m^3) and microplastic contamination grade of each waterway in the Eurobodalla region**

Across all samples collected in the Eurobodalla region, the median microplastic concentration was 0.18 MP/m^3, with a mean of 0.41 MP/m^3 and a SD of 0.57 MP/m^3.

The highest concentration recorded in the region was 3.69 MP/m^3 at Batemans Bay, while the Clyde River — the major tributary feeding into Batemans Bay — periodically recorded no detectable microplastics (0 MP/m^3) (Figure 50), indicating localised sources contributing to Batemans Bay microplastic contamination.

No waterways in the Eurobodalla region exhibited median microplastic concentrations exceeding 1.3 MP/m^3 (Grade E), and most systems recorded median values below 0.5 MP/m^3, corresponding to Grade B–C classifications (Figure 49).

Despite overall low contamination levels, Tomaga River and Congo Creek showed comparatively elevated average concentrations (median of 0.70 MP/m^3 and 0.75 MP/m^3, respectively) (Figure 50), suggesting the presence of localised contamination inputs.

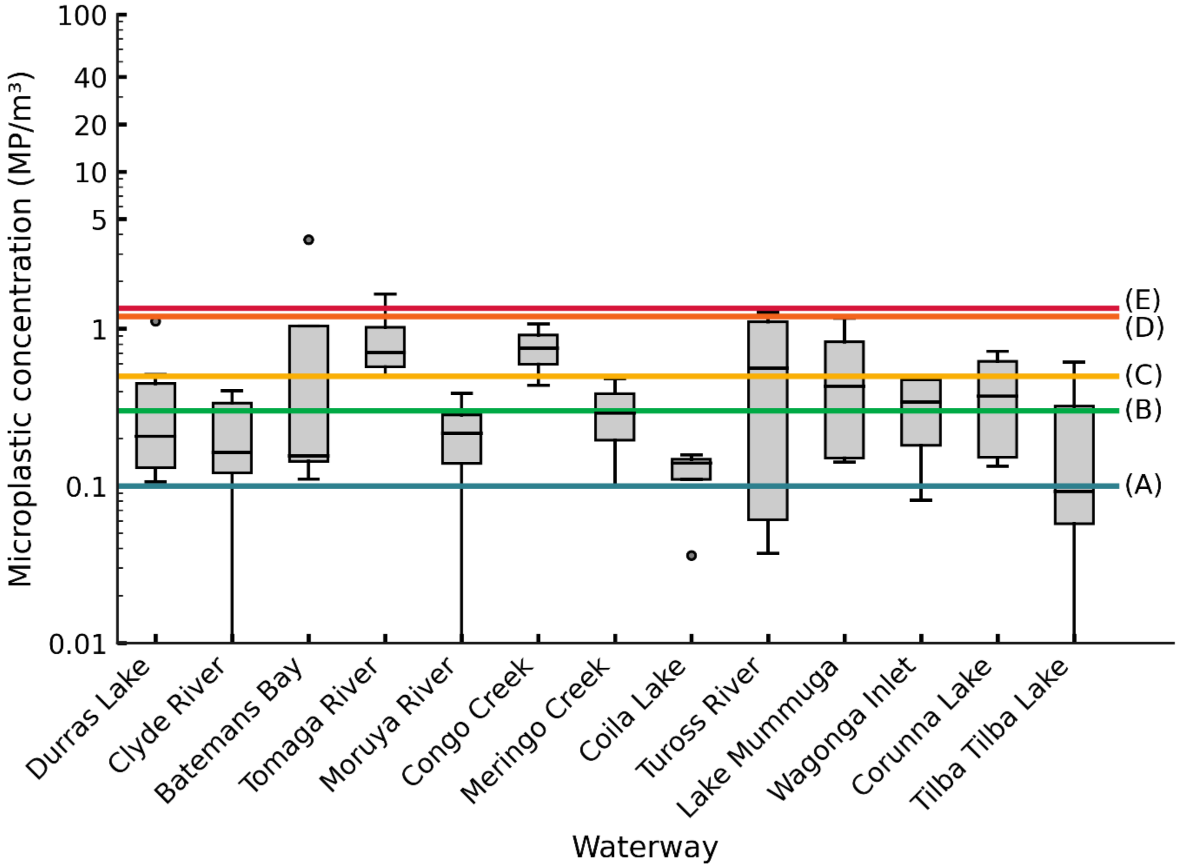


Figure 50 Box-and-whisker plot of microplastic concentration (MP/m^3) across waterways in the Eurobodalla region

Overall, the Eurobodalla region shows moderate to low microplastic contamination, with most waterways graded B–C and occasional higher readings linked to localised, manageable sources.

An estimated 665 particles were recorded (2% of the state total), with smaller particles (>0.25 – <1 mm) most common, accounting for 537 (81%).

Medium sized particles (1 – <2 mm) accounted for 14% of all particles found (93), and large particles (2 – <5 mm) accounted for only 5% of all particles found (35) (Figure 51). Of the larger particles characterised, fragment was the most abundant morphology, accounting for 54%, followed by foam 26%, and then film 20%. No artificial turf or pellets were recorded (Figure 52).

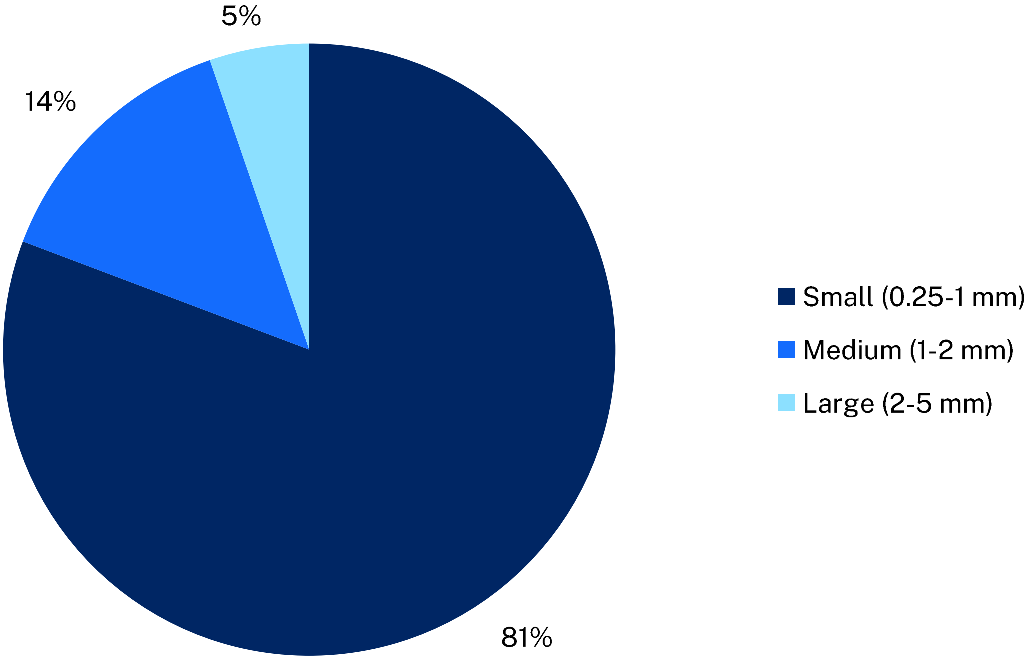


Figure 51 Proportion of microplastic particles by size across Eurobodalla region

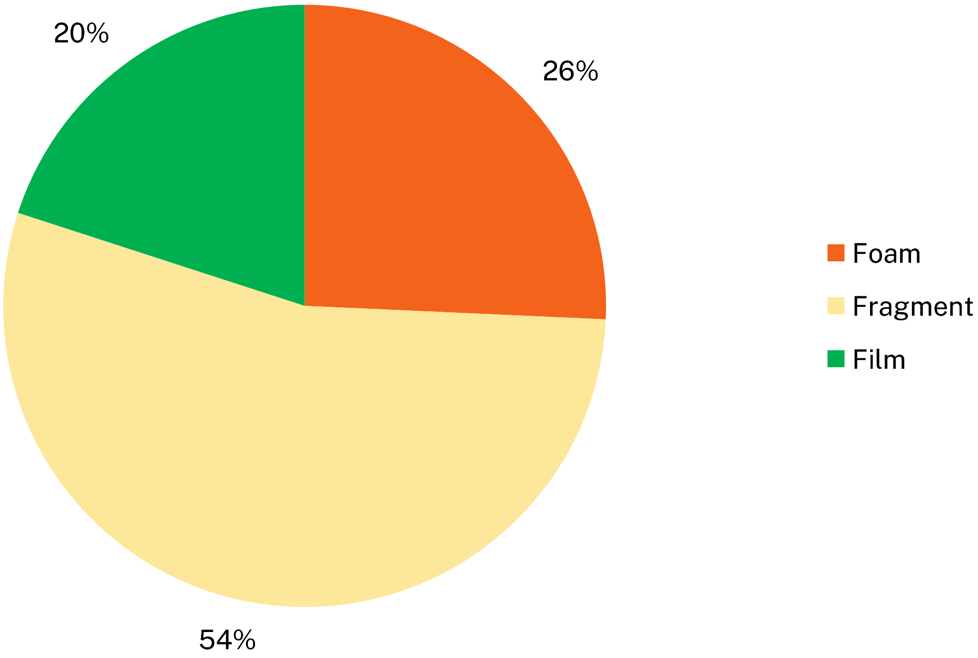


Figure 52 Proportion of microplastic particles by morphology across Eurobodalla region

3.2.8 Bega

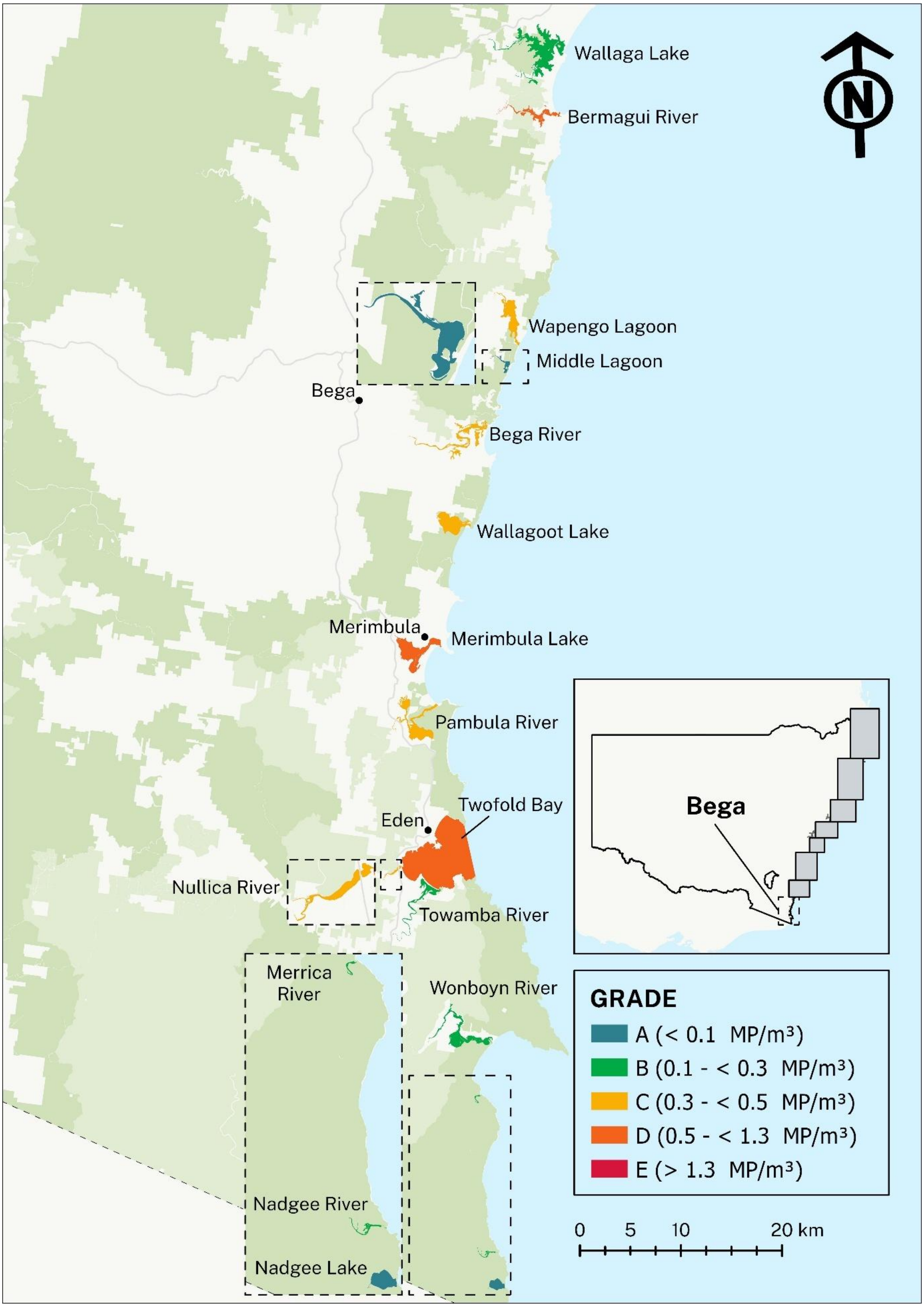


Figure 53 Spatial distribution of microplastic contamination grades (A–E) across coastal waterways in the Bega region. Map credit Neda Sharifi Soltani

In the Bega region (Figure 53), 58 samples were collected across 15 waterways. Microplastic concentrations varied among systems but were generally within the low-to-moderate contamination range. Two waterways were graded as an A (<0.1 MP/m^3), 5 waterways were graded as a B (0.1–<0.3 MP/m^3), 5 were graded as C (0.3–<0.5 MP/m^3), and 3 were graded as a D (0.5–<1.3 MP/m^3).

No waterways in the region were graded E (>1.3 MP/m^3) (Figure 54). Within the statewide comparison, the Bega region ranked third out of the 8 regions for overall microplastic contamination, indicating the third least contaminated with microplastic (Table 9).

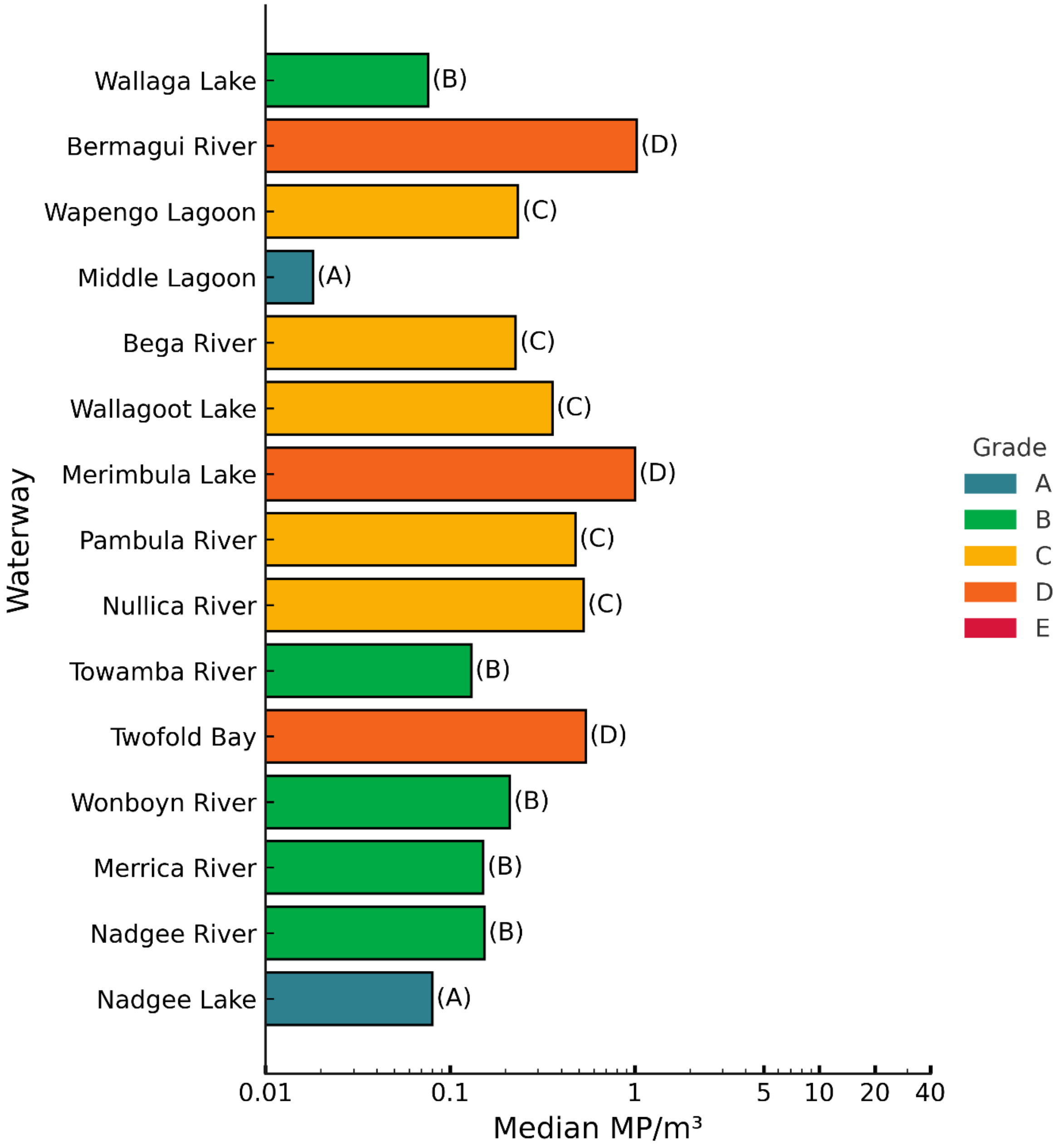


Figure 54 **The median microplastic concentration (MP/m^3) and microplastic contamination grade of each waterway in the Bega region**

Across all samples in the region, the median microplastic concentration was 0.21 MP/m^3, with a mean of 0.41 MP/m^3 and a SD of 0.45 MP/m^3. These concentrations place the Bega region among the least contaminated regions assessed in the statewide monitoring program.

The highest recorded concentration was 1.84 MP/m^3 in Nullica River, while several systems, including Nullica River periodically recorded 0 MP/m^3 (Figure 55).

No waterways in the Bega region recorded median microplastic concentrations exceeding 1.3 MP/m^3 (Grade E), and 3 systems demonstrated very low contamination, with median concentrations below 0.1 MP/m^3 (Grade A). These included Wallaga Lake, Middle Lagoon, and Nadgee Lake (Figure 55).

Middle Lagoon and Nadgee Lake both received an overall microplastic contamination grade of A, reflecting consistently low concentrations across all sampling events. Within the statewide ranking of 120 monitored waterways, Nadgee Lake ranked second and Middle Lagoon ranked third for lowest microplastic contamination (Table 8).

Nadgee Lake is a back dune lagoon system, that is predominantly groundwater-fed, experiences limited direct surface runoff and occurs within a catchment characterised by very low-disturbance, and no urban or agricultural pressure.

These findings strongly suggest that estuary type and catchment disturbance, play a central role in determining microplastic accumulation dynamics. The low concentrations observed in this waterway highlight the capacity for low-disturbance coastal lagoons to function as near-pristine reference sites within the NSW estuarine network.

Although the Bega region was generally characterised by low microplastic contamination, 3 waterways recorded a Grade D, including the Bermagui River, Merimbula Lake, and Twofold Bay. These waterways exhibited higher concentrations compared to the rest of the region, suggesting the influence of localised anthropogenic pressures.

While their median concentrations did not reach Grade E thresholds, the presence of repeated higher-level detections indicates that these waterways may act as regional hotspots, warranting ongoing monitoring to understand source pathways and temporal patterns of microplastic input.

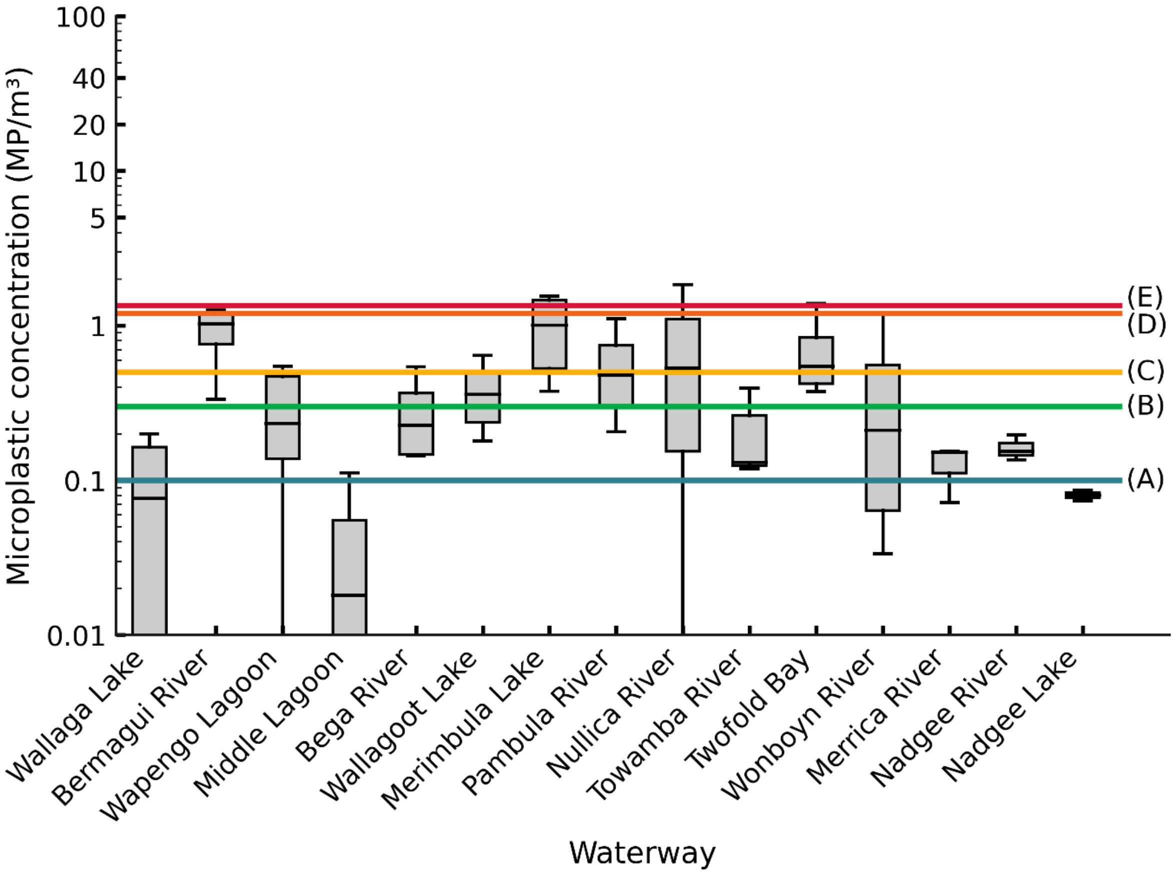


Figure 55 **Box-and-whisker plot of microplastic concentration (MP/m^3) across waterways in the Bega region**

Overall, the Bega region exhibited some of the lowest microplastic contamination levels recorded across the NSW coastline. Most waterways fell within Grades A–C, with several waterways, particularly Nadgee Lake, Middle Lagoon, and Wallaga Lake, demonstrating very low concentrations indicative of minimal catchment disturbance. The Bega region is one of the least impacted coastal regions in the state, with substantial microplastic contamination largely confined to a limited number of waterways with the most disturbed catchments.

There were an estimated 605 particles recorded across the region (2% of the states total particles). Smaller sized particles (>0.25 – <1 mm) were far more abundant (495), accounting for 82% of all particles found in the region. Medium sized particles (1 – <2 mm) accounted for 13% of all particles found (77), and large particles (2 – <5 mm) accounted for only 5% of all particles found (33) (Figure 56). Of the larger particles characterised, fragment was the most abundant morphology, accounting for 70%, followed by film 24%, and foam 6%. No artificial turf or pellets were recorded (Figure 57).

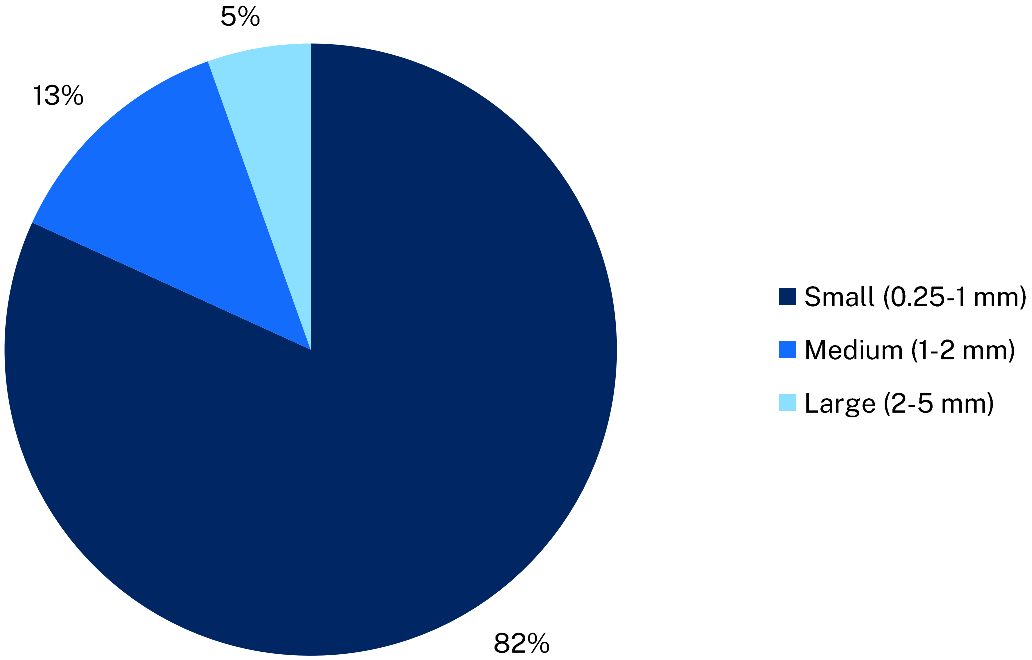


Figure 56 Proportion of microplastic particles by size across the Bega region

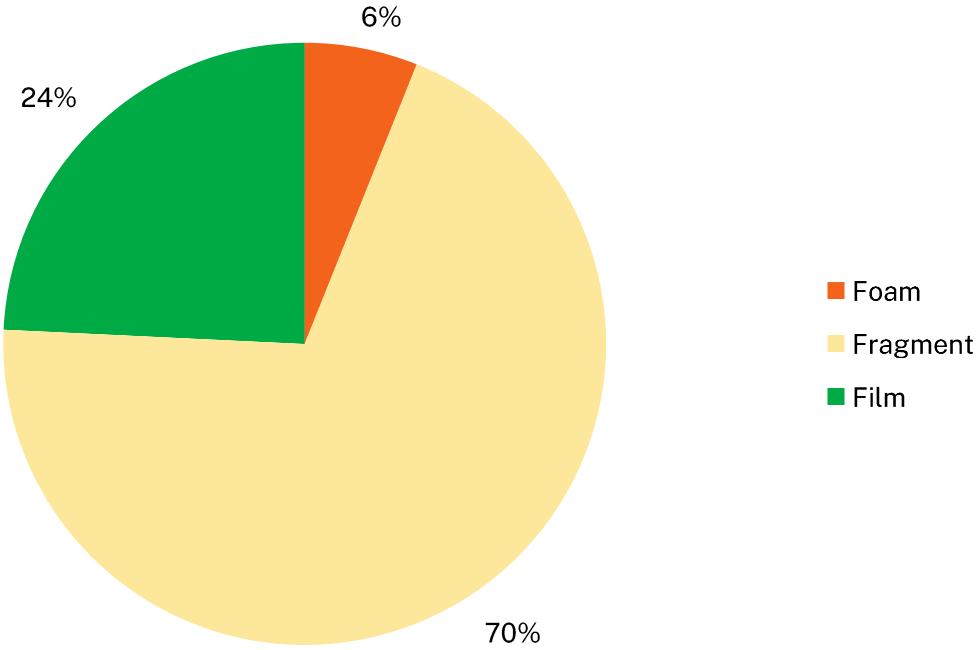


Figure 57 Proportion of microplastic particles by morphology across the Bega region

3.3 Annual sites

To assess temporal patterns in microplastic contamination and evaluate the robustness of the grading framework, 11 waterways across the state were sampled annually throughout the study period (2021 to 2024). These waterways included the Manning River, Khappinghat Creek, Wallis Lake, Wallamba River, Coolongolook River, Smiths Lake, Myall Lake, Myall Broadwater, Karuah River, Shoalhaven River, and Clyde River.

These longer-term monitoring sites provided repeated measurements of microplastic concentration, enabling the assessment of year-to-year variability (Figure 58) and the consistency of grade assignments over time (Figure 59).

Over the monitoring period (2021 to 2024), microplastic concentrations exhibited temporal variability across most sites, with a distinct peak in 2022 (Figure 58). This peak coincided with above-average rainfall and multiple high-intensity storm events associated with La Niña conditions.

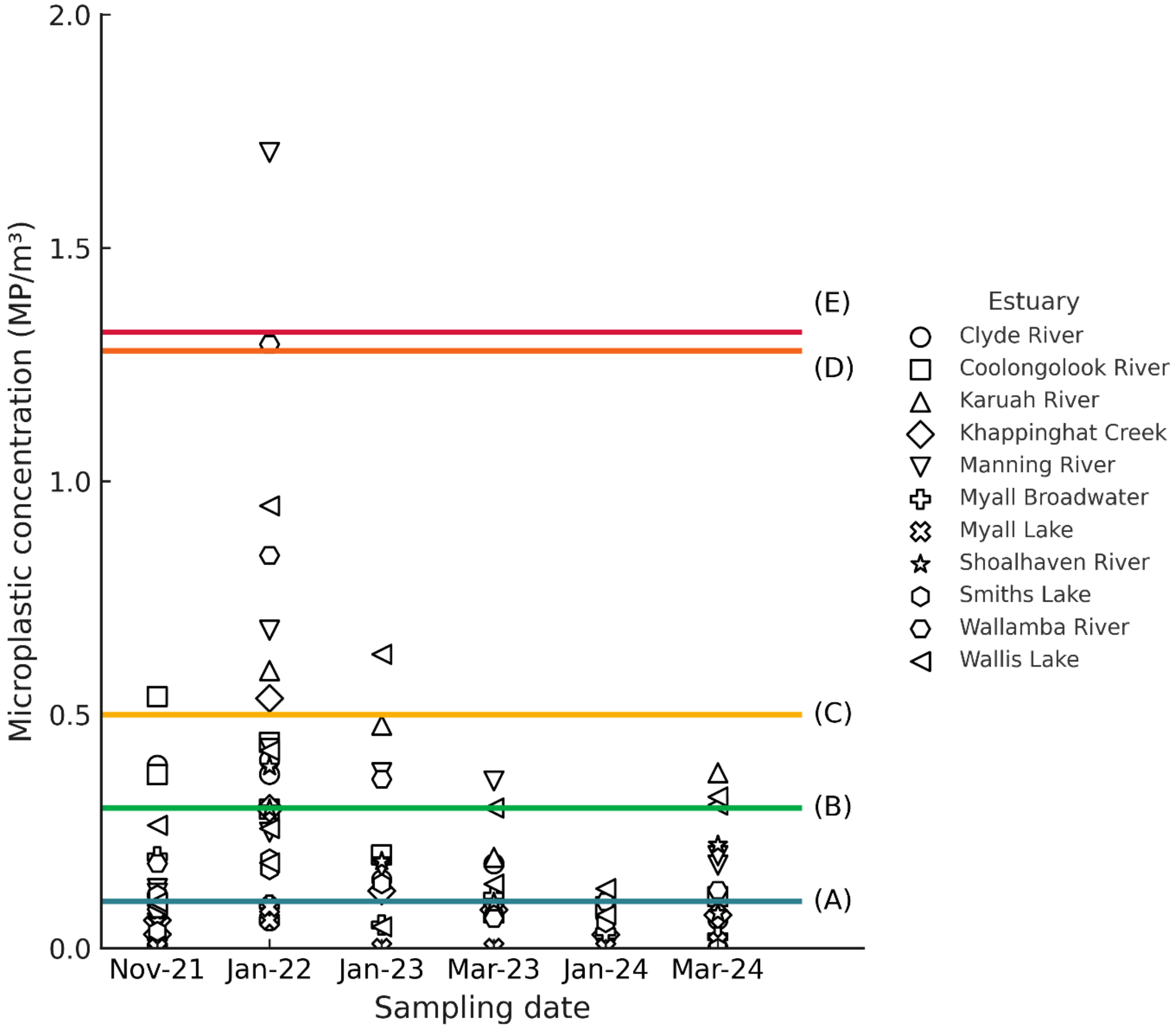


Figure 58 **Microplastic concentrations measured across annual sampling campaigns at longer-term monitoring sites**

Across the annual monitoring sites, coefficients of variation (CV) for microplastic concentrations ranged from 0.58 to 1.41, indicating high temporal variability. However, grade scores were markedly more stable (CV 0.00–0.65). This demonstrates that the grading framework effectively normalises variability, providing stable condition assessments over time.

Grade transitions were rare and generally limited to a one-grade increase, typically following major rainfall and runoff events in January 2022 and January 2023. Most sites remained within Grades A–B across sampling rounds, with only occasional shifts to the next highest grade.

Overall, grades were consistent over time, yet responsive enough to detect short-term contamination events (Figure 59).

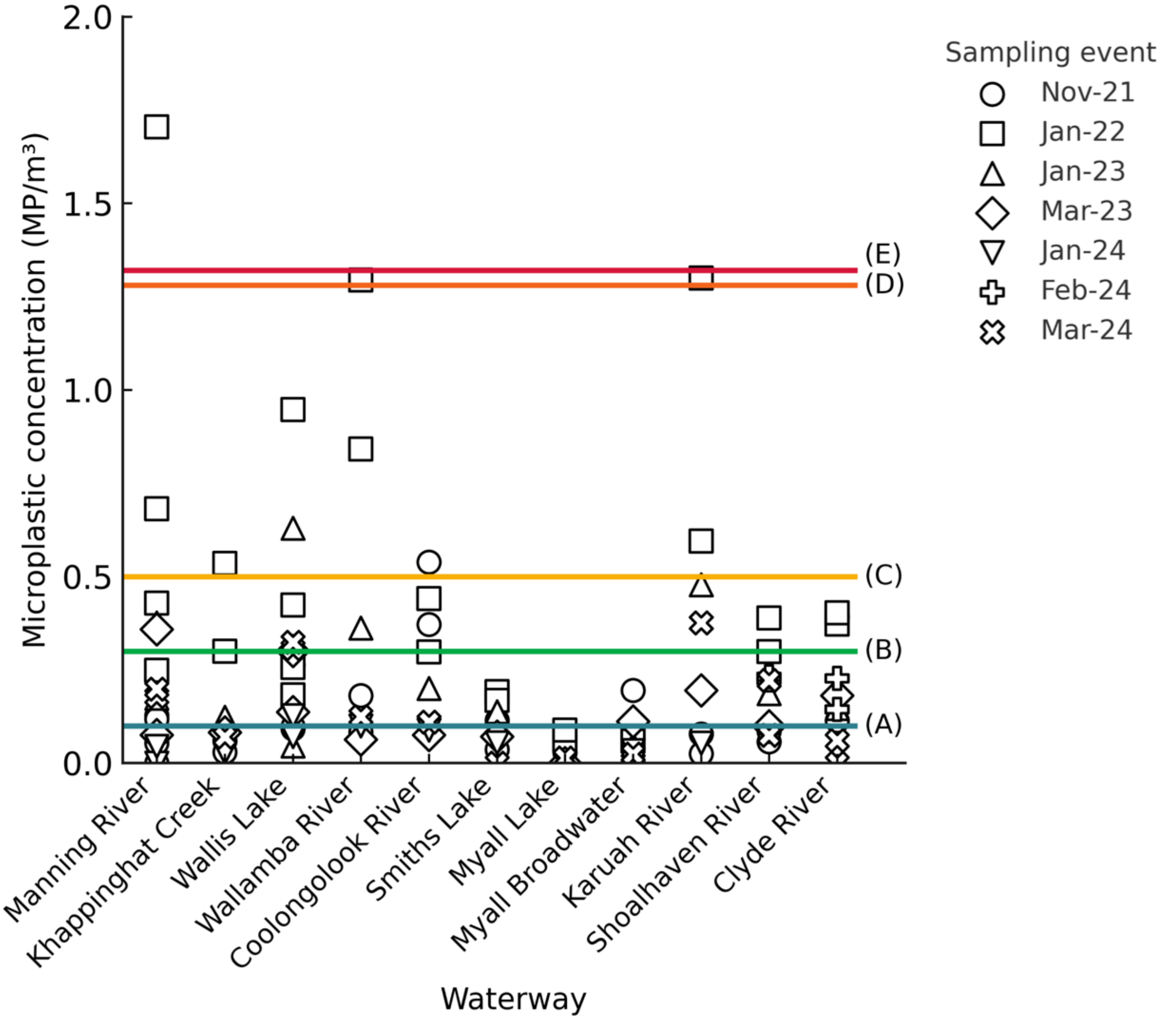


Figure 59 Microplastic concentrations measured across annual sampling sites over the broadscale microplastic assessment sampling period (2021–2024)

In summary, validation of the framework using annual sites to assess temporal consistency demonstrated an effective balance between sensitivity and robustness. It successfully detected meaningful variation without being overly influenced by fine-scale temporal fluctuations.

Results from the annual monitoring sites indicate that, despite high variability in microplastic concentrations, the grading framework provided consistent and interpretable classifications. This makes it suitable for long-term reporting, regional comparisons, and trend analysis across NSW coastal waterways.

3.4 Estuary type and microplastic contamination

Across most regions, rivers were predominantly assigned higher grades, indicating lower microplastic contamination compared to other estuary types. This observation prompted further analysis of the influence of estuary type on microplastic contamination levels.

Waterways were grouped by estuary type and assessed by their proportional distribution across contamination grades (Figure 60).

The results showed that open systems with high rates of tidal flushing such as rivers, and systems with large receiving basins and substantial internal dilution (lakes) were typically graded A–C, reflecting comparatively lower contamination.

In contrast, smaller systems such as lagoons with limited tidal flushing and smaller internal dilution capacity exhibited a higher proportion of Grade D and E classifications, indicating greater contamination.

Open bays and flooded valleys also exhibited a higher proportion of Grade D and E classifications, indicating greater contamination likely due to both estuary utilisation such as increased port development, and catchment disturbance.

Back dune lagoons displayed a relatively even distribution across all grades, which is likely attributable to catchment disturbance rather than estuary type (Figure 60).

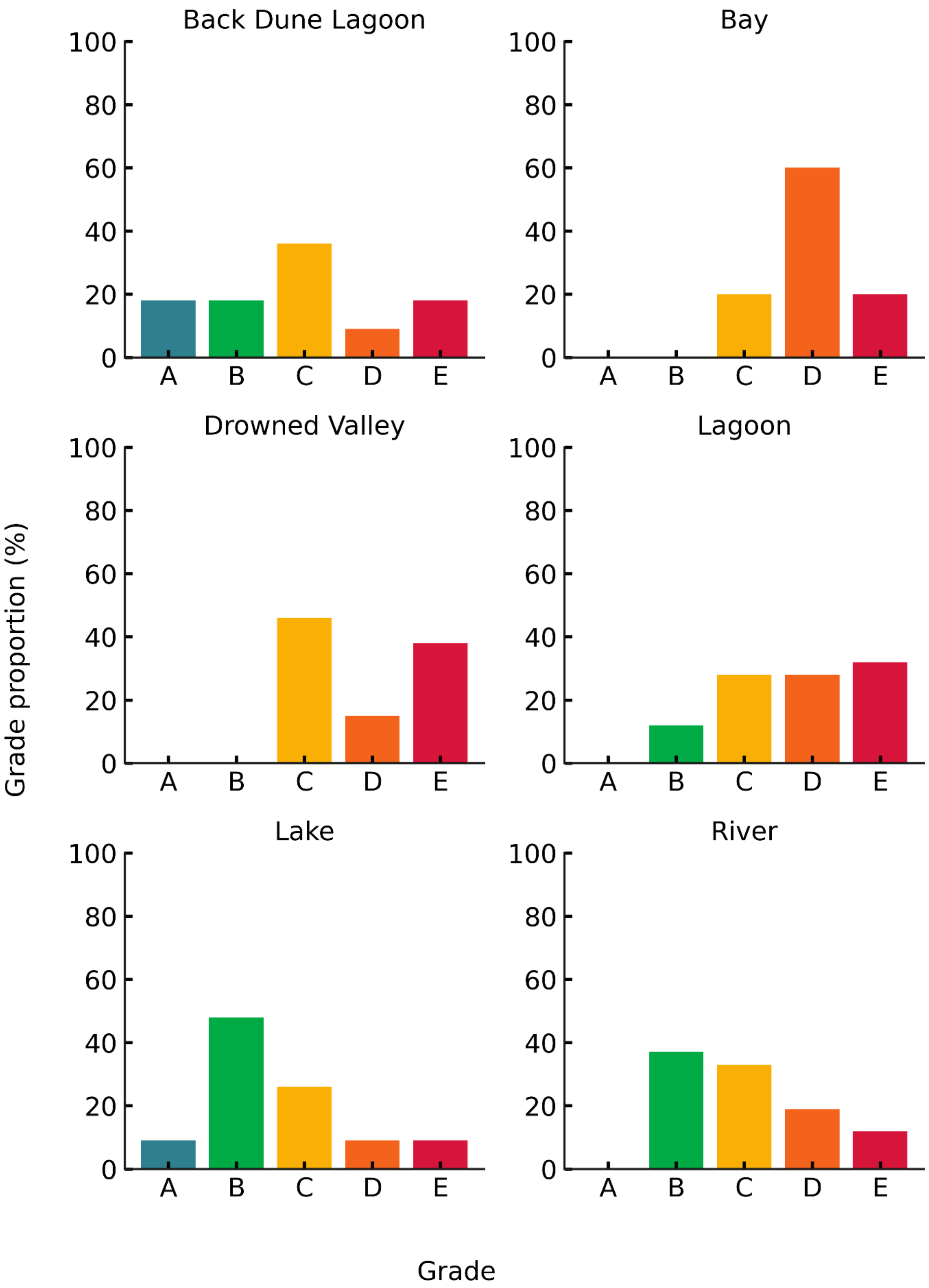


Figure 60 Proportion of microplastic contamination grades (A–E) by estuary type (Back dune lagoon n=11, Bay n=5, Drowned valley n=13, Lagoon n=25, Lake n= 23, and River n=43)

3.5 Catchment disturbance and microplastic contamination

The distribution of microplastic contamination grades across catchment disturbance categories is shown in Figure 61. Microplastic contamination grades were strongly associated with catchment disturbance (Figure 61).

No highly disturbed catchments were graded A, and only one low-disturbance catchment was graded E. In general, Grade A systems occurred in low-disturbance catchments, while Grade E systems were concentrated in highly disturbed catchments.

The exceptions to this require examination. The D and E graded systems with very low-disturbance catchments are each represented by just one system: Wattamolla Creek and Carama Creek, respectively. Wattamolla Creek is a very small system with a minimally disturbed national park catchment that is subject to intense visitor utilisation within the receiving waters providing a potential local microplastic source independent of wider catchment delivery.

In the case of Carama Creek, the driver of microplastic accumulation is likely more hydrodynamic, representing tidal delivery from the more disturbed receiving system (Jervis Bay, Grade D) and accentuated by wind driven circulation from the strong southerly winds experienced during sampling events leading to accumulation in the sampling location near the systems entrance.

In the A graded Middle Lagoon, the moderate catchment disturbance is solely due to agricultural development in the mid reaches of the catchment. In this case, the lack of urban and industrial development and the undisturbed lower catchment with intact riparian zones and fringing wetlands that may trap incoming plastic particles are likely acting to reduce contamination levels within the lagoon itself.

In contrast, the E graded Moona Moona Creek also has a moderately disturbed catchment with the development comprised entirely of urban land use clustered around the receiving basin indicating a very local source of contamination independent of the greater portion of the catchment.

These patterns indicate that while catchment disturbance is a strong predictor of microplastic contamination, estuary utilisation and hydrodynamics can override catchment-scale influences. Further analysis of estuary uses, and localised inputs is needed to better understand their role in attributing to diffuse-source pollution.

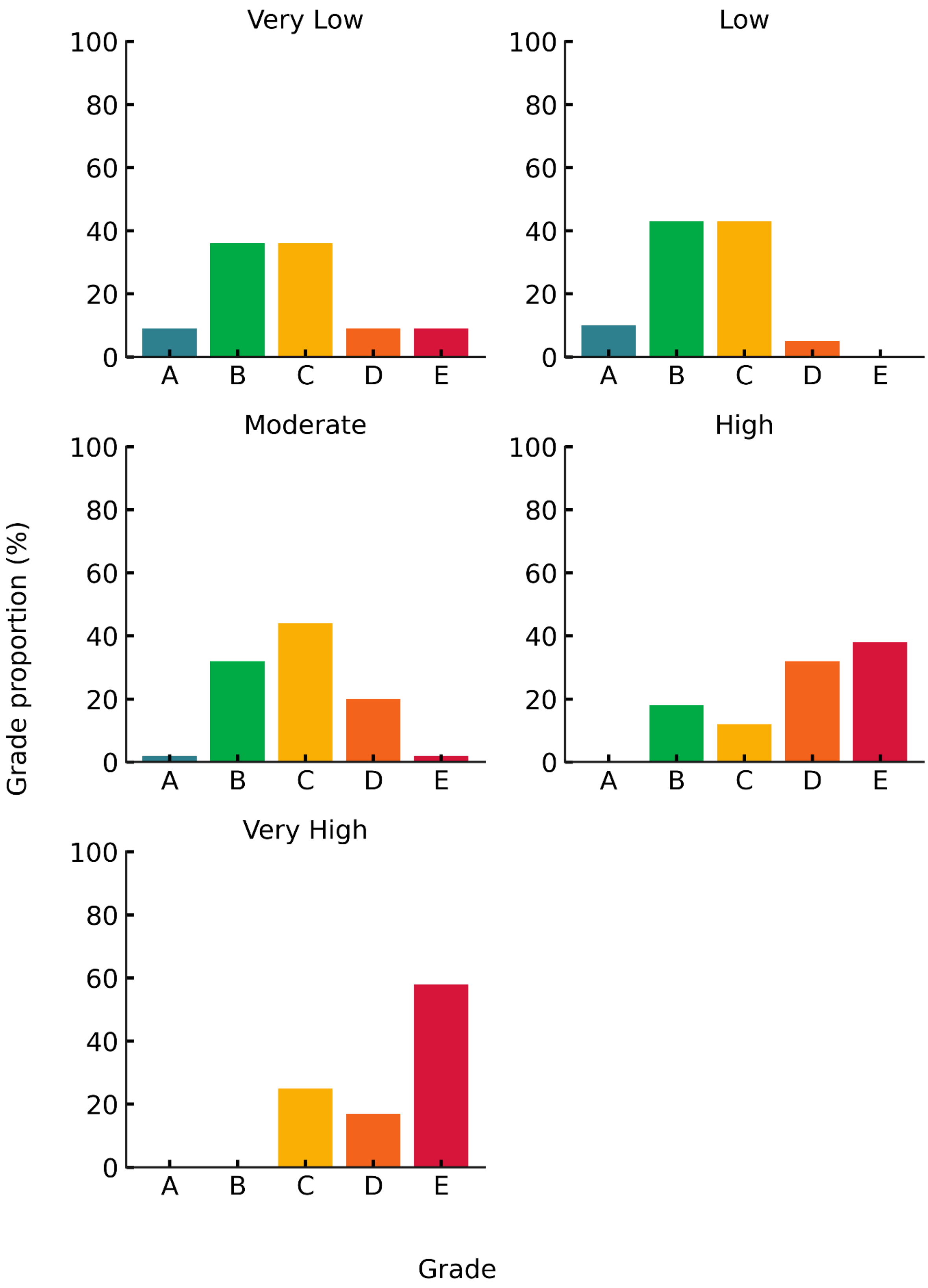


Figure 61 Distribution of microplastic contamination grades (A–E) across catchment disturbance categories (Very Low n=11, Low n=21, Moderate n=41, High n=34, Very High n=12)

4. Discussion

4.1 Overview

The *Broadscale microplastic assessment of NSW estuaries* achieved its primary objectives by:

- Establishing a baseline dataset for microplastic contamination across NSW coastal waters.
    - A comprehensive survey was conducted across 120 coastal waterways where each waterway was systematically sampled using a rapid analysis method.
    - The microplastic concentrations in samples from each waterway were quantified (in MP/m^3) and median and mean values determined, providing a detailed statewide snapshot of microplastic contamination.
    - Larger microplastics were characterised by morphology, providing an overview of microplastic type across each of the waterways.
- Developing microplastic contamination grades.
    - Based on percentiles of the measured microplastic concentrations, each waterway was assigned a contamination grade on a scale from A (very low contamination) to E (very high contamination).
    - This grading system enabled a standardised, comparative assessment across all sites, highlighting that most waterways were moderate in microplastic contamination (Grade C), while only a few exhibited either very low (Grade A) or very high (Grade E) microplastic contamination.
- Generating a microplastic contamination heat map.
    - The grades were used to generate a spatial distribution of comparative microplastic contamination for waterways in the NSW marine estate.
    - This map illustrated regional variation in microplastic contamination and highlighted contamination hotspots, particularly within urban areas such as the Hawkesbury–Sydney region.
- Characterising microplastic types to inform prioritisation of management interventions.
    - This project characterised larger microplastics by morphology, with a focus on identifying the microplastic types that contributed disproportionately to overall contamination, and which may warrant targeted management and intervention.

4.2 Baseline data

This study represents the first broadscale study of microplastic contamination across coastal waterways in New South Wales and, to our knowledge, is one of the most comprehensive spatial evaluations of estuarine microplastics undertaken in Australia, and possibly the world. Prior Australian studies have largely focused on specific estuaries or near or offshore marine environments, with limited replication across such diverse systems (Reis-Santos et al., 2022).

Furthermore, very few studies have as large a spatial coverage (eastern seaboard of New South Wales), especially when considering estuarine systems. The only comparable large-scale efforts nationally are that of Reisser et al. (2013), who used surface net tows to quantify floating plastic debris across Australia's coastal and oceanic waters, and the IMOS National Marine Microplastics Program which includes marine sampling sites across all coastal states of Australia.

While the Reisser's study encompasses many sampling sites, its coverage is primarily limited to offshore waters. In contrast, IMOS provides data from just 10 locations closer to the coast, with only one site located in New South Wales. This highlights the comprehensive nature of the *Broadscale microplastic assessment of NSW estuaries* in terms of quantifying microplastic contamination across NSW estuaries.

Microplastic contamination is widespread across NSW estuarine systems, with microplastics detected in all 120 sampled waterways. Across all waterways, microplastic concentrations were on average 2.15 MP/m^3 (± 7.96, SD), equivalent to an Olympic swimming pool (~2,500 m^3) containing approximately 5,375 microplastics.

This average microplastic concentration is concerning when placed in an international context. For example, extremely populated areas such as Dongshan Bay in China, an urbanised estuarine system, reported a lower mean concentration of 1.66 MP/m^3 (Pan et al., 2021), while the Yangtze River in China had an even lower mean concentration (1.01 MP/m^3; Wu et al., 2024).

Our study also demonstrated relatively high variability across regions and estuary types, with the Mid North Coast having the lowest overall mean microplastic concentration (0.23 MP/m^3), and the Hawkesbury–Sydney region having the highest overall mean microplastic concentration (8.20 MP/m^3).

In the absence of other broadscale estuarine studies in the Australian context, national comparative analysis is limited. Nationally, and internationally, specific estuarine monitoring efforts exist (Hitchcock and Mitrovic, 2019; Hitchcock, 2020) but methodological inconsistencies, such as variations in mesh size, depth, volume filtered, and analytical identification, complicate comparisons (Hitchcock and Mitrovic, 2019; Hitchcock, 2020; Horton et al., 2017; Löder and Gerdts, 2015).

The substantial differences in the methodologies limit the value of global comparative assessments of estuarine microplastics and highlight the absence of a globally standardised monitoring protocol for its research.

Consequently, assessing long-term trends or benchmarking regional contamination levels remains difficult in these important ecosystems, estuaries, key transport pathways for microplastics (Biltcliff-Ward et al., 2022).

However, some comparable studies do exist (e.g., Motti and Santana, 2025) and were used to contextualise results. When compared with other Australian coastal environments, several NSW estuaries with very low microplastic concentrations

(<0.1 MP/m^3) aligned closely with levels reported by IMOS for offshore Australian waters.

The IMOS National Marine Microplastics Program recorded average concentrations of 0.02–0.13 MP/m^3 in 2024. In this study, estuaries with microplastic concentrations below 0.1 MP/m^3 (Grade A) were rare; however, when present, these values closely matched the offshore concentrations reported for Australian marine waters, suggesting background conditions.

The applied grading system (A–E) revealed that most NSW waterways fell within low (Grade B; n=32) to moderate (Grade C; n=38) microplastic contamination categories, with 19% of waterways assessed as Grade E (n=23; microplastic concentrations exceeding 1.3 MP/m^3) (Figure 11).

Waterways with median concentrations exceeding 5 MP/m^3 represent the most heavily impacted areas and had mean microplastic concentrations higher than what has been found in the River Seine in Paris (0.28–0.47 MP/m^3; Dris et al., 2018), Tampa Bay in Florida (4.5 MP/m^3; McEachern et al., 2019), and the Yangtze River estuary in China (1.01 MP/m^3; Wu et al., 2024).

4.3 Spatial assessment

A strong spatial correlation was observed between catchment development intensity and microplastic contamination. Unsurprisingly, waterways draining highly urbanised or industrialised catchments exhibited substantially elevated microplastic contamination. Duck River, within the Sydney metropolitan area, recorded a mean microplastic concentration of 34.80 MP/m^3, representing a 16-fold increase over the statewide average (2.15 MP/m^3).

Of the 23 waterways that were assessed as Grade E, nearly half were located in the Hawkesbury–Sydney region, including the 4 most contaminated systems statewide. Other Grade E systems were associated with urban centres in Wollongong, Newcastle, or regional hubs such as Coffs Harbour, all of which are characterised by dense residential and commercial land use.

This data supports the hypothesis that urban runoff, industrial discharges, and population density contribute significantly to microplastic loads in estuarine systems (Hitchcock and Mitrovic, 2019; Hitchcock, 2020; Klein et al., 2022; Wu et al., 2024).

These findings also align with previous studies that have established clear links between human population density, land-use intensity, and microplastic abundance. For instance, Hitchcock and Mitrovic (2019) demonstrated that estuaries near densely populated areas in New South Wales exhibited higher microplastic loads, while Klein et al. (2022) reported a positive correlation between intertidal microplastic concentrations and coastal population size across South Australia.

The illustrated relationship between elevated microplastic concentrations and urbanised catchments is likely driven by 2 interrelated factors: the increased use and disposal of primary plastic materials in densely populated areas, and the proliferation of impervious surfaces associated with intensified land use (Ross et al., 2023).

These surfaces enhance stormwater runoff, accelerating the mobilisation and transport of diffuse-source contaminants, including microplastics, into receiving waters.

Consistent with this rationale, estuarine systems with the lowest microplastic contamination were typically located in less disturbed regions, with catchments largely protected within national parks or undisturbed areas (Figure 61).

These Grade A systems highlight the protective role of intact catchment vegetation and minimal human activity in reducing microplastic transport to receiving waters. From a management perspective, these areas represent important benchmarks, identifying the conditions that can maintain or enhance estuarine water quality.

However, exceptions to this relationship — where low-disturbance catchments exhibit elevated contamination — highlight additional influencing factors. Highly utilised waterways within otherwise undisturbed catchments can experience significant microplastic inputs from localised sources (Figure 61).

Our findings suggest that estuary utilisation and hydrodynamic processes can override catchment-scale influences. Further investigation into estuary use patterns and localised inputs is needed to better understand their contribution to diffuse-source pollutants such as microplastics.

The confirmation that urbanised areas are hotspots for microplastic contamination is important from a land management perspective, as they signal where intervention and further monitoring should be prioritised.

Targeted management interventions, such as improved stormwater filtration, containment of plastic infrastructure, and source-specific pollution controls can act to reduce the downstream transport of microplastics to coastal and marine environments.

Although substantial investments have been made in the installation of gross pollutant traps (GPTs), public clean-up initiatives and anti-littering campaigns aimed at reducing macro plastic pollution, few measures have been implemented specifically to address smaller plastic particles (Hossain et al., 2024).

For example, GPTs have been found to be inefficient at removing microplastics (Lange et al., 2021). Furthermore, if not properly scoped, maintained, and serviced, some pollution control systems may inadvertently contribute to microplastic pollution.

Potentially, accumulated macro plastics within GPTs may degrade in situ through physical and environmental weathering processes, thereby becoming a secondary source of microplastic contamination.

A strong spatial correlation was observed between catchment development intensity and microplastic contamination in this study (Figure 61) and is consistent with previous studies identifying urban stormwater runoff as a major pathway for microplastic transport into aquatic environments (Ross et al., 2023).

This relationship highlights the need to focus mitigation strategies on highly urbanised catchments, where impervious surfaces and concentrated human activity significantly increase the risk of plastic debris entering waterways.

Our results indicate that highly urbanised catchments should be prioritised for future research and targeted intervention, including enhanced stormwater management through the installation of effective pollution control infrastructure such as bioretention cells, rain gardens, sustainable urban drainage systems, and constructed wetlands (Hoang et al., 2025), as well as the implementation of source reduction measures to minimise microplastic generation and mobilisation.

4.4 Sample variability

Due to their small size and buoyant nature, microplastics are highly mobile within aquatic systems and are subject to temporary, small-scale accumulation driven by wind, waves, tides, and currents (Defontaine and Jalón-Rojas, 2023; Reisser et al., 2013).

The use of broadscale surface tow sampling methods in this study limited the ability to avoid or specifically target these dynamic accumulation zones, which likely contributed to the high variability observed between individual tows within many waterways.

Additionally, the large spatial scope of the program constrained opportunities to standardise sampling based on antecedent rainfall conditions. Hitchcock (2020) convincingly demonstrates that microplastic pollution in urban waterways is not constant but episodic, sharply linked to hydrological events such as storm-related runoff.

Addressing storm-related runoff is therefore crucial for managing microplastic contamination in aquatic ecosystems. The integration of data collected over multiple years further compounded variability, making it difficult to isolate the influence of specific environmental drivers.

To improve the precision of future assessments, targeted sampling should include both baseflow and post-rainfall (event) conditions, as well as seasonal coverage to capture climatic fluctuations and patterns of human activity.

This approach would enable a clearer understanding of the temporal and hydrological factors influencing microplastic concentrations and distribution. Moreover, ongoing long-term monitoring would not only increase sample size, enhancing statistical confidence, but also enable the detection of interannual trends and the evaluation of the effectiveness of emerging management interventions.

While catchment land use and estuary utilisation appear to be the primary drivers of microplastic inputs into estuarine environments, the morphology of each estuary also directly impacts the retention and resulting concentrations of microplastics in receiving waters. Two key hydrodynamic features govern this retention: internal dilution capacity and flushing rate (Roper et al., 2011).

Internal dilution capacity refers to the ratio of estuarine basin volume to the volume of incoming runoff. Estuaries with large receiving basins and relatively small catchments, such as coastal lakes, tend to have higher dilution capacities, meaning microplastics are more dispersed upon entry (Figure 62).

In contrast, systems such as lagoons, with relatively smaller basins and larger catchment areas have reduced dilution capacity, often resulting in higher concentrations of microplastics for a given input load (Figures 60 and 63).

In turn, flushing rate, defined as the inverse of residence time, describes how quickly water (and associated contaminants) is exchanged with the open ocean.

Estuaries with wide, deep, permanently open entrances, such as Sydney Harbour or the larger northern rivers, exhibit strong tidal exchange and short residence times, facilitating rapid export of microplastics and limiting accumulation in the system, for example the Richmond River and the Clarence River (Figure 62).

Conversely, estuaries with restricted or intermittently closed entrances have reduced flushing rates and longer residence times, creating conditions for microplastic accumulation, such as Dee Why, which potentially increases the threat of microplastics on ecosystems (Figure 63).

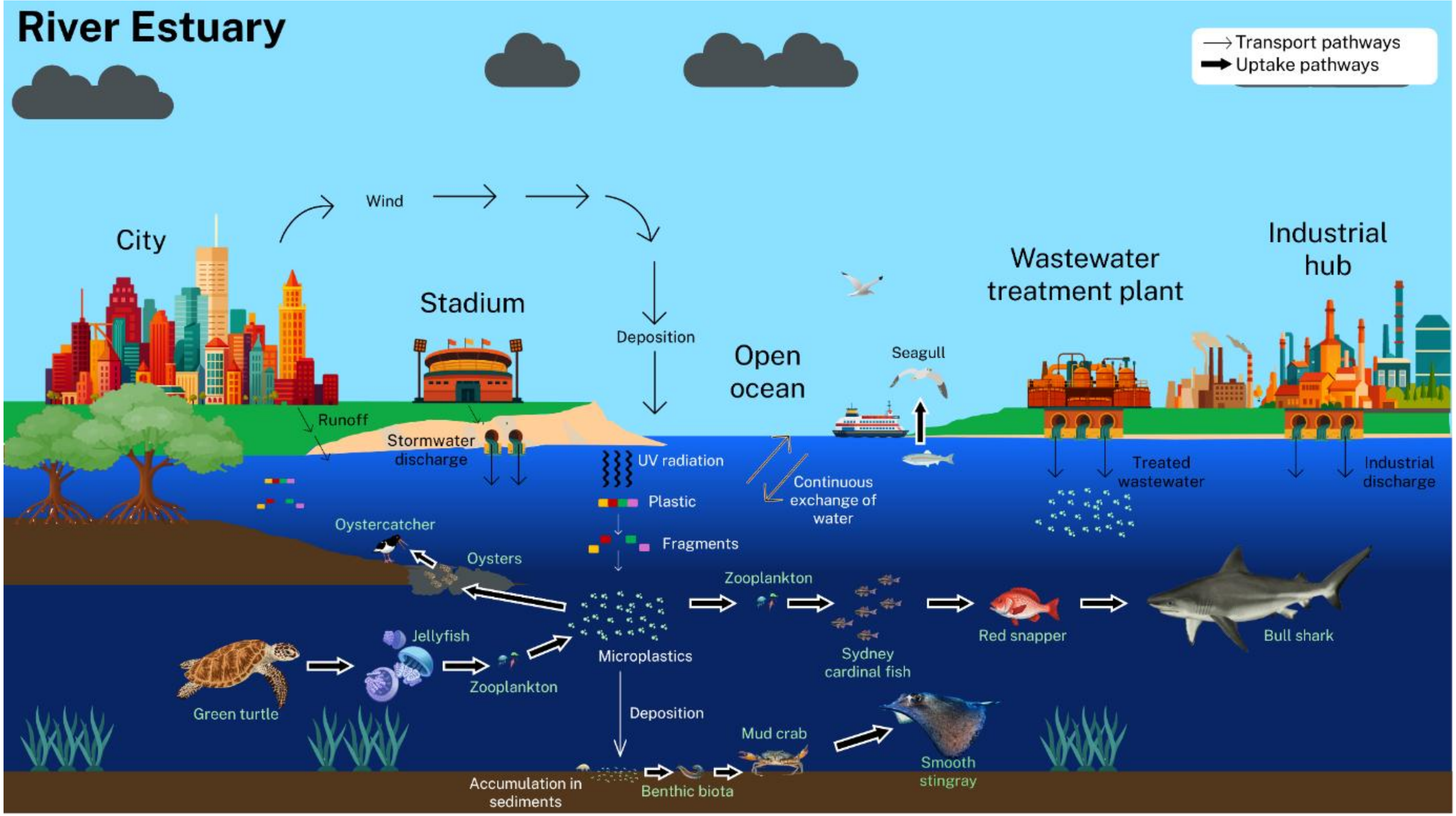


Figure 62 Conceptional diagram of a permanently open system (Rivers) facilitating greater dilution and increased flushing rates. Created by Tim Remaili

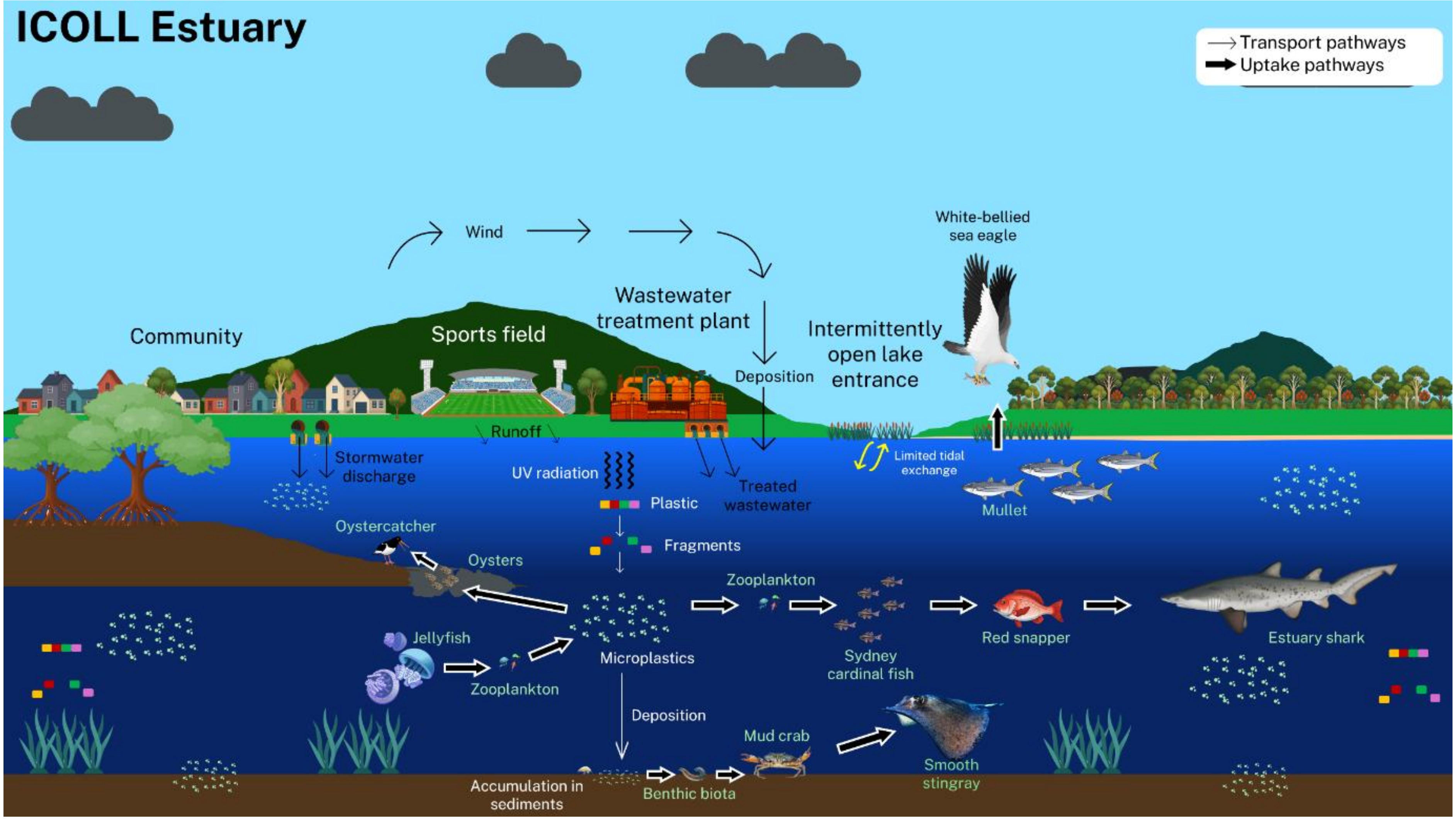


Figure 63 Conceptional diagram of an ICOLL experiencing reduced dilution and flushing rate. Created by Tim Remaili

Hydrodynamics help explain some of the patterns observed in this study. For example, large, disturbed rivers with high flushing rates such as the Clarence and Richmond in the Northern Rivers region had low microplastic concentrations, potentially due to short residence times. This is further supported by studies conducted in South Australia, which also found river flow velocity decreases microplastic abundance (Hayes et al., 2021).

However, this has implications when considering some of the metropolitan systems that had particularly high microplastic concentrations, like Cooks River, Parramatta River, and Duck River. These systems were found to have some of the highest microplastic concentrations in the state, despite being relatively well-flushed. This suggests high catchment loading overwhelms the natural flushing capacity of these systems.

In contrast, systems that are rarely open such as Dee Why Lagoon, or with very restricted entrances like Manly Lagoon, will likely be particularly variable with regard to microplastic concentrations. This is a response to episodic flushing events when they open to the ocean to a significant degree. In such systems, microplastics are potentially accumulating over extended periods of time during closure, with concentrations rising due to continued baseflow delivery.

When significant rainfall events force the entrance to open, large quantities of accumulated microplastics will likely be flushed (exported) to the ocean alongside additional loads of microplastics mobilised by stormwater runoff.

As a result, for highly open systems (e.g., large rivers), measured concentrations are likely reflective of typical microplastic catchment loads passing through the system. In contrast, for ICOLLs, concentrations may underestimate total catchment loads following rainfall events and overestimate incoming loads during prolonged closure, reflecting short-term accumulation dynamics rather than steady-state conditions. Thus, as suggested by Defontaine and Jalón-Rojas (2023), recording the tide state, rainfall conditions, wind, entrance state, and number of days since open/closed is critical for understanding input loads of microplastics, concentration, and comparing to other estuarine systems.

At a regional scale, the results of the current study reinforced patterns observed at the statewide scale. The Mid North Coast emerged as the least impacted region, exhibiting the lowest microplastic concentrations overall, while the Hawkesbury–Sydney region was the most heavily affected, with multiple sites classified as Grade E.

In contrast, the North Coast, Hunter–Central Coast, and Illawarra–Shoalhaven regions displayed a mix of consistently elevated concentrations at some sites and high intra-site variability at others.

This heterogeneity points to a combination of contributing factors, including catchment population density, land use, estuary morphology, flushing dynamics, estuary utilisation, and rainfall patterns.

Overall, results underscore the importance of context specific monitoring and intervention strategies regionally and locally, particularly within urbanised estuaries, while also highlighting the need to account for local hydrodynamics and environmental conditions when designing microplastic pollution mitigation efforts (Kaimathuruthy et al., 2025).

The marked spatial variability across regions and the identification of key contamination hotspots further reinforces the need for strategic, regionally tailored monitoring and remediation programs to effectively address microplastic pollution in vulnerable estuarine systems.

4.5 Microplastic size and morphology and priority items

Within the particle size range assessed in this study (0.25–5 mm), microplastic abundance was inversely related to size, with smaller particles being substantially more common. The smallest size class (0.25–1 mm) accounted for approximately two-thirds (68%) of all microplastics identified, while the medium class (1–2 mm) made up 18% and the largest size class (2–5 mm) comprised just 14%.

This trend is consistent with previous findings. Hitchcock and Mitrovic (2019), also found that particle abundance continues to increase as size decreases, even beyond the lower detection threshold of this study. Future research should also target smaller microplastics (<0.25 mm).

Despite their lower abundance, larger microplastic particles are considered a proxy for smaller microplastics as most items found in the environment are secondary microplastics and thereby a result of the fragmentation of larger plastic debris, including larger microplastics.

Moreover, these items are highly valuable for targeted management, as the distinct morphological characteristics of many make them difficult to misidentify, hence allowing effective source attribution. For example, primary microplastics, such as industrial feedstock (pellets) are predominantly found in the >1 mm range. These originate from a limited number of plastic manufacturing or processing facilities, making them more straightforward targets for regulation, intervention, and source control.

Consequently, morphological characterisation in this study focused on the larger microplastic size fractions (>2 mm), where particles are more readily identifiable. Across all samples, the dominant morphologies were hard plastic fragments (37%), plastic foam pieces (37%), and plastic films (19%). Smaller proportions of artificial turf fragments (5%) and industrial feedstock (pellets) (2%) were also recorded.

While the relative abundance of these morphologies varied across regions, fragments, foams, and films remained the most common microplastic types statewide. Notably, no pellets or artificial turf fragments were detected in the Mid North Coast, Eurobodalla, or Bega regions, while pellets were also absent from the Hunter–Central Coast region.

Although morphologies such as 'fragments' and 'films' were highly abundant across NSW estuaries, these are also secondary microplastics originating from the breakdown of a wide range of consumer and industrial products, hindering the development of targeted management strategies aimed at reducing them (i.e. specific bans).

The reduction of these contaminants in the environment is more appropriately addressed through comprehensive macro plastic reduction programs, stormwater improvement devices, and waste management strategies. Foam, artificial turf fragments, and pellets, on the other hand, can be categorised as ‘priority items’ due to their distinct and traceable origins.

Foam, artificial turf fragments, and pellets originate from packaging materials, fishing and boating products, synthetic playing surfaces, and industrial plastic resins. Their source specificity makes them suitable candidates for targeted interventions through containment, source reduction, or regulatory controls.

These 3 items, collectively accounted for 44% of all microplastics characterised across NSW estuarine waterways and were also dominant in urbanised catchments (Figure 64). Of these, foam was the most prevalent, comprising 37%, followed by artificial turf fragments (5%) and pellets (2%).

In the Hawkesbury–Sydney region, these items represented an even greater share of total microplastic pollution (49%), with foam alone constituting 41%, artificial turf fragments 6%, and pellets 2%.

Foam was particularly abundant in Duck River (59%), Coffs Creek (55%), and Muddy Creek (43%). Artificial turf fragments were a major proportion in Manly Lagoon (57%), Port Jackson (29%), and Middle Harbour (25%). Pellets were most concentrated in Parramatta River (6%), Georges River (5%), and Saltwater Creek, Frederickton (5%).

These findings are consistent with international studies (Rose et al., 2023), with some NSW estuarine waterways such as Manly Lagoon, Port Jackson, and Middle Harbour reported in this assessment as having a higher concentration than Rose et al. (2023). A complete list of estuaries containing pellets or artificial turf fragments is provided below (Table 10).

Following its widespread adoption, artificial turf, commonly used in recreational public spaces and playgrounds, has recently emerged as a significant source of microplastic pollution in Australia and globally. Despite its relatively recent introduction, it has quickly become a significant contributor to microplastic debris in the marine environment.

For example, de Haan et al. (2023) reported that artificial turf fragments made up as much as 15% of the microplastic load in the Guadalquivir River, Spain. The study estimated that approximately 20,000 fragments are transported downstream daily, with concentrations peaking near densely populated areas and during the rainy season, when surface runoff enhances the release of these particles into aquatic systems.

In the current study, artificial turf fragments were present in 17% of the waterways surveyed and comprised 5% of all microplastics. This supports growing evidence that artificial turf contributes significantly to plastic pollution in the environment, in addition to its other known environmental impacts such as chemical leaching, climate change implications, and biodiversity loss (de Haan et al., 2023).

Pellets, used in industrial plastic manufacturing, were detected in 10% of surveyed waterways, but accounted for only 2% of all microplastics detected across the 120 estuaries. However, this likely underrepresents their true presence within the broader estuarine environment.

Pellets are typically transported from stormwater drains into estuaries, where wind and tidal forces can redistribute them onto shoreline sediments. A recent study from the United Kingdom found that pellets comprised up to 23% of all microplastics in shoreline sediments (Rose et al., 2023). Given this, it is recommended future assessments include shoreline sediments from estuaries where they were found in the water.

Table 10 **List of the waterways that contained pellets and artificial turf fragments**

Artificial turf fragments	Pellets
–	Belongil Creek
Cudgen Creek	–
Cooks River	Cooks River
Duck River	Duck River
Dee Why Lagoon	Dee Why Lagoon
Fairy Creek	–
Georges River	Georges River
Haslams Creek	Haslams Creek
Hawkesbury River	–
Lane Cove River	–
Manly Lagoon	Manly Lagoon
Middle Harbour	–
Muddy Creek	Muddy Creek
Parramatta River	Parramatta River
Port Jackson	–
–	Saltwater Creek (Frederickton)
Terrigal Lagoon	–
Throsby Creek	–
Toongabbie Creek	Toongabbie Creek
Towradgi Creek	–
Terranora Creek	–
Ulladulla	Ulladulla

Figure 64 **Microplastic morphology categories and their proportional representation across New South Wales. The image on the left shows the full range of morphologies identified in NSW waterways, including fragments, films, foam, artificial turf, and industrial pellets. The image on the right shows the same sample with foam, artificial turf, and pellets removed, illustrating the potential benefits of targeted interventions focused on these priority microplastic types. Photos: Jaimie Loa-Kum-Cheung/DCCEEW**

While this study identified priority items based on morphology, namely foam, artificial turf fragments, and industrial pellets, future iterations of the *Broadscale microplastic assessment of NSW estuaries* will incorporate chemical analyses across all size fractions. This will allow for a more comprehensive understanding of the specific polymer types present and help identify those requiring prioritisation based on chemical composition.

Subsequent research should focus on assessing the hazard profiles of the most frequently detected polymers in estuarine environments (both water and sediment) and evaluating their toxicity to inform risk-based management strategies.

4.6 Priority items

The priority items are considered those which have a predominant identifiable source:

- foam
- artificial turf fragments
- pellets

Targeted intervention to reduce the presence of foam, artificial turf fragments and industrial pellets could lead to a reduction of up to 44% in the abundance of larger microplastics in estuarine waterways (Figure 64), assuming the smaller microplastics found in samples were a result of the fragmentation of larger plastics, including microplastics > 2 mm.

4.7 Priority waterways

The priority waterways are those which were consistently classified as having a high microplastic concentration. These waterways should be prioritised for targeted research and management interventions to better understand and mitigate microplastic contamination. These include:

- Cooks River and its tributary Muddy Creek
- Dee Why Lagoon
- Parramatta River and its tributaries (Toongabbie Creek, Duck River, and Haslams Creek)
- Throsby Creek
- Coffs Creek
- South West Rocks Creek
- Manly Lagoon
- Middle Harbour
- Ulladulla Harbour/Millards Creek.

4.8 Limitations

Despite the broad geographic scale and valuable insights generated by this study, several limitations must be acknowledged:

- **Temporal and seasonal constraints:** sampling occurred primarily during summer and the beginning of autumn, limiting the ability to capture seasonal variability. Additionally, a portion of the sampling took place during La Niña climate conditions, potentially skewing baseline microplastic concentrations due to elevated rainfall and runoff.
- **Limited replication:** each waterway was sampled, on average, only 4 times (2 replicate samples on 2 trips). This restricted replication contributes to high variability in microplastic concentrations and increases sensitivity to outliers. Limited data collection reduces the ability to detect consistent spatial or temporal patterns and weakens confidence in trend detection.
- **Surface water focus:** sampling was confined to surface waters, excluding sediments and sub-surface layers. This approach may underestimate total microplastic loads and fails to account for particles more bioavailable to benthic organisms or those stored in sedimentary sinks.
- **Restricted size range:** only microplastics between 0.25 and 5 mm were assessed. This omits smaller particles in the 0.01–0.25 mm range, which are often more abundant and more likely to be ingested by aquatic organisms. As a result, overall microplastic abundance may be underestimated and risk assessments using this data will be skewed to the largest size range of microplastics.
- **Lack of particle mass measurements**: the study focused solely on particle counts (MP/m^3), without corresponding mass data. While particle abundance offers insight,

mass-based metrics are important for understanding pollutant loading and potential chemical impacts.

- **Sampling method limitations:** the use of large-scale surface tows does not allow for targeted sampling of small-scale accumulation zones driven by tides, winds, or hydrodynamics. This may contribute to intra-site variability and limit comparability between systems.
- **Inability to standardise for hydrological events**: sampling was not standardised for preceding rainfall, tidal phase, or storm events, which are known to influence microplastic mobilisation and transport.
- **Inability to capture point source signals:** the broadscale nature of the assessment dilutes the influence of localised point sources, limiting the ability to identify priority land use areas and management sites.
- **Focus on larger microplastics in morphology:** morphological characterisation was limited to particles >2 mm, potentially overlooking the dominant morphologies of smaller size fractions. Future iterations of this program will include morphology and polymer analysis across all size classes.

Some of these data constraints restrict the ability to fully understand system dynamics or effectively mitigate the risks of microplastic contamination.

Future efforts should focus on expanding sampling frequency, covering multiple seasons, and include chemical and mass-based analyses across different media (water, sediment, and biota). Repeated sampling over time will improve trend detection, reduce uncertainty, and strengthen confidence in regional and system-level assessments of microplastic contamination.

5. Conclusion and recommendations

5.1 Conclusion

This *Broadscale microplastic assessment of NSW estuaries* study represents the most comprehensive assessment of microplastic contamination across estuarine waters in New South Wales to date. The high spatial resolution of the study makes it one of the most significant of its kind to be published recently and offers a valuable benchmark for ongoing monitoring and management.

A statewide baseline of microplastic concentration was established through the systematic sampling of 120 waterways, with the results revealing widespread microplastic contamination coupled with significant spatial variability.

The mean microplastic concentration across NSW estuaries was 2.15 MP/m^3, and the median 0.38 MP/m^3, with the highest levels observed in urbanised catchments within the Hawkesbury–Sydney region. These concentrations are an order of magnitude higher than what is found in NSW marine waters and exceeds those reported in comparable studies from Europe and China.

Similarly to other global research, catchment disturbance was identified as one of the primary drivers of microplastic contamination in NSW estuaries. This study developed a contamination grading system (Grades A–E) and a spatial heat map for New South Wales.

Around 19% of NSW waterways were found to be highly contaminated with microplastics (Grade E), with urban systems such as Duck River and Cooks River recording concentrations exceeding those observed in other global estuarine case studies. These results highlight the need to prioritise highly urbanised catchments for microplastics mitigation efforts.

Plastic morphological characterisation revealed that foam, artificial turf fragments, and pellets, all predominately traceable to distinct sources, accounted for 44% of the larger microplastic particles.

While secondary microplastics from fragmented consumer products were more abundant overall, their diffuse origins make them more difficult to manage and are better addressed through broader waste reduction initiatives. This study therefore suggests targeting foam, artificial turf fragments, and pellets as priority items through policy and source reduction in order to reduce contamination in NSW estuarine environments.

Methodologically, this study was restricted seasonally, focused solely on surface waters, and microplastics larger than 0.25 mm. These limitations affect the temporal representativeness of the data and might underestimate the total microplastic loads found in the estuaries of New South Wales and their potential biological risks. Further work is recommended to include year-round and event-based sampling, sampling of other abiotic compartments (e.g., sediment sampling), and chemical characterisation of polymers across all size fractions, to better inform risk-based prioritisation.

Ultimately, the current study provided a repeatable framework for ongoing monitoring, identification of priority waterways and materials for intervention and offers critical insights to guide evidence-based management of microplastic pollution.

Ongoing monitoring and refinement of methods are considered essential to track trends, assess mitigation effectiveness, and reduce the environmental impacts of microplastics in New South Wales's estuarine ecosystems.

Greater scientific insights into microplastic contamination helps guide policy development, enhances pollution management strategies and ultimately helps mitigate the environmental impacts of microplastic contamination in NSW waterways.

Given the important value of estuaries and the increasing pressures they face, a sound understanding and reporting of their condition is imperative for effective management, resilience, and sustainable development.

5.2 Recommendations

Ongoing monitoring and enhanced research are critical to addressing some of the limitations identified in this study. Regular assessment of microplastic concentrations is necessary to fully understand the influence of environmental and human factors associated with microplastic contamination, but also for detecting trends and evaluating the success of mitigation strategies.

Given the limitations of this baseline assessment and the ongoing risk posed by microplastic contamination in estuarine environments, it is recommended that both monitoring and management efforts be significantly strengthened. Specifically, it is recommended that the following actions be prioritised:

- Establish a long-term monitoring program

  The EPA should consider implementing a long-term microplastic monitoring program which:
  - establishes representative sampling locations across various estuary types and contamination grades
  - establishes sentinel sites to create baseline microplastic concentration benchmarks, like what is being done for offshore Australian waters
  - captures seasonal patterns and the influence of climatic conditions
  - tracks changes and emerging trends over time
  - measures the effectiveness of management and mitigation interventions.
- Expand sampling scope and methodology

  Future assessments should focus on:
  - including smaller microplastics (<0.25 mm)
  - incorporation of sediment and biota sampling

  - conducting sampling during baseflow and flood events to understand hydrological influences on transport and accumulation
  - assessing microplastic source inputs (e.g., stormwater).
- Develop standardised national methodologies

  Collaborations with government, research institutions and national agencies (for example, EPA, AIMS, CSIRO) should occur to:
  - establish standardised sampling protocols for estuarine microplastic monitoring to enable comparative assessment
  - facilitate the integration of microplastic assessment into broader marine debris monitoring frameworks.
- Ecosystem risk assessments:

  The EPA and relevant government and academic research institutions should consider conducting further estuarine ecosystem impact assessments to:
  - determine the extent to which microplastics are bioavailable to aquatic organisms across different size classes and habitats
  - investigate the potential for bioaccumulation and biomagnification of microplastics and associated contaminants through estuarine food webs
  - evaluate the toxicological impacts of microplastics and their additives on key indicator species, including invertebrates and fish
  - compare biological, chemical, and ecological indicators between highly contaminated estuaries and low-contaminated sites to assess ecosystem-level responses and resilience
  - identify vulnerable species or communities that may serve as indicators for monitoring ecosystem health in relation to microplastic pollution.
- Target priority microplastic sources

  The EPA should consider implementing specific measures to address microplastic contamination of waterways from identifiable sources:
  - foam packaging (polystyrene): regulation, phase out, or improved containment
  - artificial turf fragments: phase out, and implementation of appropriate containment solutions at sports fields and other public areas
  - pellets (nurdles): continue to work with Operation Clean Sweep and enforce improved handling and containment practices at manufacturing and transport sites.
- Assess polymer composition and toxicity risk

  Undertake chemical characterisation of microplastics across size fractions to:
  - identify dominant polymer types in NSW estuaries
  - assess their hazard ratings and ecological risk potential
  - inform risk-based prioritisation of materials for future regulation or replacement.

- Prioritise high-risk urban catchments for intervention

  The EPA and relevant government and academic research institutions should consider focusing research and management efforts on highly urbanised and industrial catchments, particularly those in the Hawkesbury–Sydney region, where microplastic concentrations are highest. This could include:

  - working with the EPA to pilot the *Streets to Sea* program with a focus on microplastics
  - conducting a litter flow analysis, aimed at source tracking of microplastics
  - identifying problem land use areas (e.g., residential, industrial sites/areas)
  - assessing stormwater treatment systems effectiveness (for example, bioretention basins, constructed wetlands, containment devices with microplastic specific enhancements)
  - improvements in plastic waste containment and control near waterways.

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7. Appendix

Appendix Table 1 **Table of summary statistics for all waterways surveyed listed north to south**

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m^3	Min. MP/m^3	Max. MP/m^3	Mean MP/m^3	SD MP/m^3
Tweed River	TWD	1	River	High	31	B	2.25	4.00	0.27	0.08	0.86	0.37	0.34
Terranora Creek	TRN	1.1	River	High	49	C	2.75	4.00	0.31	0.00	2.22	0.71	1.02
Cudgen Creek	CGN	2	River	Very high	93	E	4.00	4.00	2.98	0.00	7.67	3.41	3.17
Brunswick River	BRN	5	River	High	81	D	3.50	4.00	0.86	0.27	0.95	0.73	0.31
Belongil Creek	BLG	6	Creek	High	100	E	4.50	4.00	1.61	1.04	3.22	1.87	1.03
Tallow Creek	TLW	7	Lagoon	High	91	D	4.00	4.00	1.05	0.45	1.30	0.96	0.37
Richmond River	RIC	9	River	High	12	B	1.75	4.00	0.26	0.07	0.30	0.22	0.11
North Creek	NRC	9.1	River	High	53	C	2.75	4.00	0.38	0.08	0.71	0.39	0.28
Lake Ainsworth	AIN	9.5	Back dune lagoon	–	101	E	4.50	4.00	1.76	0.74	2.99	1.81	1.16
Evans River	EVN	11	River	High	92	D	4.00	4.00	1.37	0.41	2.91	1.52	1.27
Clarence River	CLR	13	River	Moderate	16	B	2.00	4.00	0.16	0.03	0.44	0.20	0.18
Oyster Channel	OYC	13.1	River	Moderate	64	C	3.00	4.00	0.45	0.19	0.99	0.52	0.40

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m³	Min. MP/m³	Max. MP/m³	Mean MP/m³	SD MP/m³
Lake Arragan	ARA	14	Lake	Very low	67	C	3.00	2.00	0.58	0.26	0.90	0.58	0.45
Sandon River	SAN	16	River	Very low	42	C	2.50	4.00	0.33	0.00	0.85	0.38	0.37
Wooli Wooli River	WLI	17	River	Very low	18	B	2.00	4.00	0.18	0.00	0.76	0.28	0.34
Station Creek	STN	18	Lagoon	Very low	41	C	2.50	4.00	0.31	0.00	1.19	0.45	0.56
Corindi River	CRD	19	River	Moderate	38	C	2.50	4.00	0.27	0.08	1.26	0.47	0.55
Darkum Creek	DRK	22	Creek	Very high	98	E	4.50	4.00	1.34	1.03	2.63	1.59	0.71
Woolgoolga Lake	WGG	23	Lagoon	Very high	40	C	2.50	4.00	0.30	0.00	0.96	0.39	0.41
Flat Top Point Creek	FTP	24	Creek	Very high	73	C	3.25	4.00	0.54	0.16	6.30	1.88	2.96
Hearns Lake	HRN	25	Lagoon	Very high	68	C	3.00	4.00	0.62	0.10	1.38	0.68	0.65
Moonee Creek	MNE	26	River	High	95	D	4.25	4.00	1.24	0.37	1.76	1.15	0.58
Coffs Creek	CFS	28	River	Very high	115	E	5.00	4.00	3.40	2.70	8.28	4.45	2.58
Bellinger River	BLN	32	River	Low	71	C	3.25	4.00	0.51	0.16	1.29	0.62	0.49
Nambucca River	NMB	36	River	Moderate	63	C	3.00	4.00	0.45	0.22	0.99	0.53	0.32
Macleay River	MCL	37	River	Moderate	54	C	2.75	4.00	0.66	0.07	3.83	1.31	1.77
South West Rocks Creek	SWR	38	Lake	High	114	E	5.00	3.00	2.92	2.69	6.80	4.14	2.31

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m³	Min. MP/m³	Max. MP/m³	Mean MP/m³	SD MP/m³
Saltwater Creek (Frederickton)	SWF	39	Lagoon	High	86	D	3.75	4.00	3.91	0.23	8.22	4.07	4.39
Hastings River	HST	43	River	Moderate	50	C	2.75	4.00	0.33	0.19	0.52	0.34	0.15
Maria River	MIR	43.1	River	Moderate	57	C	3.00	4.00	0.37	0.08	2.52	0.84	1.13
Cathie Creek	CAT	44	Lagoon	Moderate	76	D	3.50	4.00	0.57	0.35	0.90	0.60	0.28
Camden Haven River	CDH	46	Lake	Moderate	59	C	3.00	4.00	0.42	0.17	1.26	0.57	0.50
Manning River	MNG	47	River	Moderate	25	B	2.19	16.00	0.18	0.00	1.70	0.30	0.42
Khappinghat Creek	KHP	48	Lagoon	Moderate	7	B	1.63	8.00	0.08	0.03	0.54	0.15	0.18
Wallis Lake	WAL	50	Lake	Low	26	B	2.19	16.00	0.22	0.05	0.95	0.27	0.24
Wallamba River	WLB	50.2	River	Moderate	27	B	2.25	8.00	0.15	0.06	1.29	0.38	0.45
Wallamba Cove	WLC	50.3	River	Moderate	51	C	2.75	4.00	0.35	0.15	0.72	0.39	0.26
Coolongolook River	COO	50.4	River	Moderate	30	B	2.25	8.00	0.25	0.08	0.54	0.27	0.17
Smiths Lake	SMT	51	Lake	Moderate	6	B	1.50	8.00	0.09	0.00	0.19	0.10	0.07
Myall River	MYR	52	River	Low	11	B	1.75	4.00	0.15	0.06	0.23	0.15	0.07
Myall Lake	MYL	52.1	Lake	Low	1	A	1.00	8.00	0.01	0.00	0.09	0.02	0.03

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m^3	Min. MP/m^3	Max. MP/m^3	Mean MP/m^3	SD MP/m^3
Myall Broadwater	MYB	52.2	Lake	Low	4	A	1.25	8.00	0.05	0.00	0.20	0.07	0.06
Karuah River	KRH	53	River	Moderate	36	B	2.38	8.00	0.29	0.03	1.30	0.39	0.42
Tilligerry Creek	TLG	54	Lake	High	17	B	2.00	4.00	0.18	0.10	0.43	0.22	0.14
Port Stephens	PST	55	Drowned valley	Moderate	72	C	3.25	4.00	0.51	0.18	1.01	0.55	0.35
Hunter River	HNT	56	River	High	35	B	2.33	6.00	0.34	0.04	0.46	0.27	0.18
Throsby Creek	THR	56.1	River	High	116	E	5.00	4.00	5.42	2.51	17.96	7.83	7.18
Glenrock Lagoon	GLN	57	Creek	High	88	D	4.00	1.00	0.50	0.50	0.50	0.50	
Lake Macquarie	LMC	58	Lake	Moderate	23	B	2.06	32.00	0.12	0.00	3.32	0.30	0.59
Tuggerah Lakes	TUG	61	Lake	Moderate	34	B	2.33	9.00	0.20	0.01	1.93	0.41	0.61
Wamberal Lagoon	WBL	62	Back dune lagoon	High	43	C	2.50	2.00	0.41	0.09	0.73	0.41	0.45
Terrigal Lagoon	TGL	63	Lagoon	High	104	E	4.67	3.00	3.04	0.77	7.93	3.91	3.66
Avoca Lake	AVO	64	Back dune lagoon	High	82	D	3.67	3.00	0.73	0.38	0.76	0.62	0.21

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m^3	Min. MP/m^3	Max. MP/m^3	Mean MP/m^3	SD MP/m^3
Cockrone Lake	CKR	65	Back dune lagoon	Moderate	62	C	3.00	3.00	0.43	0.21	0.58	0.41	0.19
Brisbane Water	BRB	66	Lake	High	61	C	3.00	3.00	0.43	0.21	0.94	0.53	0.37
Hawkesbury River	HWK	67	Drowned valley	Moderate	74	C	3.33	9.00	0.65	0.09	2.20	0.77	0.65
Cowan Creek	CWN	67.1	Drowned valley	Moderate	69	C	3.25	4.00	0.45	0.21	23.86	6.24	11.75
Berowra Creek	BWR	67.2	Drowned valley	Moderate	48	C	2.75	4.00	0.28	0.06	2.17	0.69	0.99
Pittwater	PTW	68	Drowned valley	Moderate	65	C	3.00	4.00	0.48	0.11	0.75	0.45	0.26
Broken Bay	BKN	69	River	Moderate	21	B	2.00	4.00	0.23	0.06	0.43	0.24	0.19
Narrabeen Lagoon	NRB	70	Lake	Moderate	96	D	4.25	4.00	2.62	0.21	5.43	2.72	2.32
Dee Why Lagoon	DWH	71	Back dune lagoon	Very high	119	E	5.00	4.00	9.98	5.11	64.73	22.45	28.49
Manly Lagoon	MAN	73	Creek	Very high	113	E	5.00	4.00	2.52	1.88	47.27	13.55	22.49
Middle Harbour Creek	MHR	74	Drowned valley	High	111	E	4.78	9.00	1.99	0.49	41.82	7.19	13.39

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m^3	Min. MP/m^3	Max. MP/m^3	Mean MP/m^3	SD MP/m^3
Lane Cove River	LNC	75	Drowned valley	High	97	D	4.40	10.00	1.69	0.20	10.56	2.83	3.30
Parramatta River	PAR	76	Drowned valley	High	112	E	4.80	10.00	6.18	0.60	102.04	15.39	30.89
Toongabbie Creek	TNG	76.1	Creek	High	117	E	5.00	4.00	8.57	7.60	21.57	11.58	6.68
Duck River	DKR	76.2	Drowned valley	High	103	E	4.50	4.00	24.70	0.99	88.83	34.80	42.29
Haslams Creek	HSL	76.3	Drowned valley	High	110	E	4.75	4.00	9.35	0.92	15.10	8.68	6.13
Port Jackson	PJA	77	Drowned valley	High	87	D	3.80	10.00	0.61	0.16	10.59	2.22	3.55
Cooks River	CKS	78	River	Very high	120	E	5.00	6.00	14.43	3.99	55.24	19.89	19.69
Muddy Creek	MUD	78.1	River	Very high	118	E	5.00	4.00	8.83	3.14	48.86	17.41	21.14
Georges River	GRG	79	Drowned valley	Very high	107	E	4.67	6.00	7.07	0.62	10.60	5.74	4.16
Botany Bay	BOB	80	Bay	Very high	77	D	3.50	4.00	0.59	0.45	1.27	0.72	0.38
Port Hacking	PHK	81	Drowned valley	Low	58	C	3.00	2.00	0.41	0.13	0.70	0.41	0.40
Wattamolla Creek	WAT	82	Creek	Very low	90	D	4.00	1.00	1.01	1.01	1.01	1.01	

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m³	Min. MP/m³	Max. MP/m³	Mean MP/m³	SD MP/m³
Towradgi Creek	TRG	90	Creek	High	102	E	4.50	2.00	2.87	1.00	4.74	2.87	2.64
Fairy Creek	FRY	91	Creek	High	105	E	4.67	6.00	3.24	1.04	7.64	3.44	2.45
Lake Illawarra	ILL	94	Lake	High	13	B	1.80	5.00	0.15	0.00	0.36	0.15	0.16
Minnamurra River	MIN	96	River	High	99	E	4.50	4.00	1.37	0.75	2.56	1.51	0.85
Werri Lagoon	WRR	99	Creek	High	84	D	3.75	4.00	0.75	0.30	1.06	0.71	0.35
Crooked River	CRK	100	River	High	75	D	3.50	4.00	0.44	0.37	0.55	0.45	0.09
Shoalhaven River	SHO	101	River	Moderate	9	B	1.70	10.00	0.20	0.06	0.39	0.19	0.11
Cararma Creek	CRM	104	Lake	Very low	109	E	4.75	4.00	2.44	0.91	3.01	2.20	0.91
Currambene Creek	CRB	107	River	Moderate	78	D	3.50	4.00	0.61	0.43	0.77	0.60	0.17
Moona Moona Creek	MMC	108	Creek	Moderate	106	E	4.67	3.00	6.30	1.09	7.57	4.99	3.44
Jervis Bay	JEB	112	Bay	Moderate	80	D	3.50	4.00	0.83	0.17	1.29	0.78	0.49
St Georges Basin	STG	113	Lake	Low	28	B	2.25	4.00	0.18	0.12	0.34	0.20	0.10
Swan Lake	SWA	114	Back dune lagoon	Moderate	19	B	2.00	6.00	0.19	0.05	0.53	0.21	0.17
Conjola Lake	CON	117	Lake	Low	22	B	2.00	4.00	0.23	0.05	0.46	0.24	0.17

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m^3	Min. MP/m^3	Max. MP/m^3	Mean MP/m^3	SD MP/m^3
Ulladulla	ULD	121	Bay	High	108	E	4.75	4.00	2.05	0.50	4.40	2.25	1.67
Burrill Lake	BUR	122	Lake	Moderate	55	C	3.00	4.00	0.33	0.28	0.67	0.40	0.18
Durras Lake	DUR	128	Lake	Low	45	C	2.67	6.00	0.21	0.11	1.12	0.38	0.39
Clyde River	CLY	132	River	Low	24	B	2.10	10.00	0.16	0.00	0.40	0.20	0.14
Batemans Bay	BAB	133	Bay	Low	46	C	2.75	4.00	0.16	0.11	3.69	1.03	1.77
Tomaga River	TOM	135	River	Moderate	89	D	4.00	4.00	0.70	0.49	1.67	0.89	0.53
Moruya River	MOR	138	River	Low	20	B	2.00	4.00	0.22	0.00	0.39	0.21	0.16
Congo Creek	CGO	139	Creek	Moderate	79	D	3.50	2.00	0.75	0.44	1.07	0.75	0.45
Meringo Creek	MEC	140	Back dune lagoon	Moderate	39	C	2.50	2.00	0.29	0.10	0.48	0.29	0.27
Coila Lake	COI	142	Lake	Low	10	B	1.75	4.00	0.14	0.04	0.16	0.12	0.06
Tuross River	TUR	143	River	Low	44	C	2.50	4.00	0.56	0.04	1.26	0.61	0.64
Lake Mummuga	MUM	147	Lagoon	Low	60	C	3.00	4.00	0.43	0.14	1.17	0.54	0.49
Wagonga Inlet	WGN	149	Lake	Low	32	B	2.25	4.00	0.34	0.08	0.48	0.31	0.20
Corunna Lake	CRN	153	Lagoon	Moderate	56	C	3.00	4.00	0.37	0.13	0.72	0.40	0.30
Tilba Tilba Lake	TIL	154	Back dune lagoon	High	14	B	2.00	6.00	0.09	0.00	0.61	0.21	0.24
Wallaga Lake	WAG	156	Lake	Moderate	5	B	1.50	4.00	0.08	0.00	0.20	0.09	0.10

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m^3	Min. MP/m^3	Max. MP/m^3	Mean MP/m^3	SD MP/m^3
Bermagui River	BRM	157	River	Moderate	85	D	3.75	4.00	1.03	0.33	1.26	0.91	0.41
Wapengo Lagoon	WAP	162	Lake	Low	37	C	2.50	6.00	0.23	0.00	0.55	0.28	0.22
Middle Lagoon	MID	163	Back dune lagoon	Moderate	3	A	1.25	4.00	0.02	0.00	0.11	0.04	0.05
Bega River	BEG	165	River	Moderate	47	C	2.75	4.00	0.23	0.14	0.54	0.28	0.19
Wallagoot Lake	WLG	166	Back dune lagoon	Low	52	C	2.75	4.00	0.36	0.18	0.64	0.38	0.21
Merimbula Lake	MBL	169	Lake	Moderate	94	D	4.25	4.00	1.01	0.38	1.55	0.98	0.59
Pambula River	PAM	170	River	Low	70	C	3.25	4.00	0.48	0.21	1.11	0.57	0.40
Nullica River	NLC	173	Lagoon	Very low	66	C	3.00	4.00	0.53	0.00	1.84	0.73	0.83
Towamba River	TOW	175	River	Low	33	B	2.33	3.00	0.13	0.12	0.39	0.21	0.16
Twofold Bay	TFB	177	Bay	Low	83	D	3.75	4.00	0.54	0.37	1.39	0.71	0.47
Wonboyn River	WBN	180	River	Very low	29	B	2.25	4.00	0.21	0.03	1.19	0.41	0.54
Merrica River	MRC	181	Creek	Very low	8	B	1.67	3.00	0.15	0.07	0.15	0.13	0.05
Nadgee River	NDR	183	Creek	Very low	15	B	2.00	3.00	0.15	0.14	0.20	0.16	0.03

Estuary name	Code	Number	Type	Catchment disturbance	MP rank	Grade	Mean grade score	No of tows	Median MP/m^3	Min. MP/m^3	Max. MP/m^3	Mean MP/m^3	SD MP/m^3
Nadgee Lake	NDL	184	Back dune lagoon	Very low	2	A	1.00	3.00	0.08	0.07	0.09	0.08	0.01

8. More information

Project funding

This project is an initiative of the NSW Environment Protection Authority under the NSW Government's *Waste and Sustainable Materials Strategy*.

This project was part funded by the *Marine Estate Management Strategy*.

For further information please visit:

- Microplastics monitoring
- Broadscale Microplastic Assessment Dashboard
- Marine debris threat and risk assessment
- Stat on pixels – Microplastic automated count script
- Streets to Sea
- Waste and Sustainable Materials Strategy

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[1] To learn more about NSW estuaries please watch this video on Monitoring, evaluating and reporting on estuaries

[2] Microplastic sampling video on microplastics across NSW coastal waterways