A preliminary assessment of the prevalence of microplastics in Australian fish and invertebrates

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Contents

Tables

Figures

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We acknowledge the support and feedback of the steering committee throughout this project (see appendices).

Executive Summary

What the report is about

Microplastics are becoming of increasing concern in the environment but there is currently little information on their prevalence in Australian fish and invertebrates. A team of researchers led by the University of Adelaide investigated microplastics in Australian fish and invertebrates collected from seafood processors in capital cities of all coastal states and territories. They found that although around 44% of the ~1800 organisms examined contained microplastics, the average number of microplastics per organism was low at around 1 piece. This study represents the first Australian wide assessment of microplastics across a broad range of species.

Background

Plastic pollution is a significant worldwide issue with an increasing number of studies finding that organisms of many taxa ingest microplastics. To date, little of this research has been undertaken in Australia. There is potential for microplastics and associated pollutants to bioaccumulate through the food chain ultimately ending up in humans.

Aims

The aim of this study was to determine the prevalence of microplastics in Australian fish and invertebrates sold for human consumption and to place the resulting information in an international context.

Methodology

Fish and invertebrates from 25 different species (15 finfish, 6 crustacea, 3 bivalves, 1 cephalopod) were sourced from commercial fishers, seafood processors or sales outlets throughout Australia including from Perth, Adelaide, Melbourne, Hobart, Sydney, Brisbane and Darwin. Organisms were dissected and the gastrointestinal tract removed and digested prior to sorting under a dissecting microscope. Plastic particles were counted for each individual organism. Frequency of occurrence (number of organisms with plastic particles present) and plastic load (number of pieces of microplastic) were recorded and analysed using negative binomial models. A systematic review of international literature on plastics in seafood was undertaken using several search terms and used to place the Australian results in an international context.

Results/key findings

Microplastics were found in 44% of all organisms examined, but this ranged from 17% in Southern Calamari to 56% in filter feeding molluscs (oysters and mussels). Some variation in frequency of occurrence was found among states for finfish, crustaceans and filter feeding molluscs, but not for Southern Calamari.

Microplastic load varied greatly among organisms with maximum recorded numbers per individual of 17 pieces in a finfish, 9 pieces in a crustacea, 29 pieces in a filter feeding mollusc and 2 pieces in a squid. The average microplastic load in all fish and invertebrates was just 1.02 pieces; averages ranged from 0.8 in crustaceans to 1.4 pieces in filter feeding molluscs. For individual species the lowest average microplastic load was in Australian Sardines from SA, whereas the highest average microplastic load was in Common Coral Trout from Queensland. Microplastic load varied by state for finfish and filter feeding molluscs but not for crustaceans or Southern Calamari.

Comparisons to international literature suggest that the frequency of microplastic occurrence for Australian finfish, crustaceans and molluscs is around the median of other studies. Microplastic loads in Australian finfish and invertebrates were low in comparison to many international studies.

Implications and recommendations

This study has provided industry, managers and policy makers with baseline data on microplastics in Australian fish and invertebrates. It has provided consumers with confidence that the seafood industry is taking a proactive stance in relation to potential microplastic pollution in fish and invertebrates. Next steps would be to ascertain whether pollutants from plastics are found in tissue samples of organisms at high enough concentrations to be of concern.

Keywords

Fish, finfish, invertebrates, oysters, mussels, crustaceans, prawns, crabs, microplastics, plastic load

Introduction

Background and need

Plastic pollution has become a significant environmental issue worldwide. World annual plastic production has increased from around 1.9 million tons in 1950 to more than 330 million tons in 2013 (Worm et al. 2017). There is increasing global concern regarding plastics in the marine environment (Rochman et al. 2013, Worm et al. 2017). Besides plastic objects entering the ocean and being broken down into smaller pieces, wastewater and runoff also carry microplastics (plastics <5mm) and other debris into the ocean. These microplastics can take up toxic compounds from within seawater and are often mistaken for food by marine organisms (Andrady 2011, Cole et al. 2011, Seltenrich 2015). After ingestion by marine organisms, contaminants from microplastics may leach and be transferred to the tissues of organisms (e.g. Rochman et al. 2014). Through trophic transfer and the possible bioaccumulation of microplastic and associated pollutants, there is also the potential for effects on human health (Worm et al. 2017), although to date there is little evidence of this.

Governments are reviewing risks around plastics and seafood consumption (e.g. Government of Hong Kong Special Administrative Region) and the Parliament of Australia referred the threat of marine plastic pollution to a Senate committee (April 2016). Recommendations included that future policies should be underpinned by sound, peer-reviewed research, and that the Government actively support research into the effects of marine plastic pollution. To date, few studies have investigated microplastics in Australian fish and invertebrates and no studies have directly sampled from fish markets. Despite this, understanding the importance of microplastics in Australian seafood and placing such information in the context of international research is recognised as important.

Previous work in Australia had shown that microplastics have been found in coastal seafloor sediments (Ling et al. 2017). As such, there was a need for our study to identify if Australian fish, crustacean and mollusc species are consuming microplastics by analysing their gastrointestinal tracts. This study represents a preliminary investigation to ascertain if microplastics are found in seafood in Australia – depending on the outcome of this research, subsequent work may be required to investigate linkages between plastics in seafood and human health, identifying the main sources/types of microplastic contamination entering the marine environment, as well as considering microplastic contamination in seafood risk assessments. As part of this research we will also collect tissue samples for further analysis, if required, to determine if toxic substances are leaching from microplastics into tissue, however these samples will not be analysed as part of this study. The most cost-effective approach to determining if there is an issue around microplastics and seafood is first to determine if fish are consuming microplastics.

Objectives

The objectives are to:

1. Determine how widespread the presence of plastics in Australian seafood sold for human consumption is and how this varies across the country including from metropolitan and non-metropolitan markets*;

2. Place the presence/absence of plastics in Australian seafood into the international context.

*Samples were only collected from metropolitan seafood markets but may comprise both metropolitan and non-metropolitan caught organisms.

Method

Sample collection

Fish and invertebrates were sourced from commercial fishers, seafood processors or sales outlets throughout Australia. Selected species came from a range of habitats (e.g. reef, pelagic, benthic) and each state was sampled at markets in the capital city (e.g. Perth, Adelaide, Melbourne, Hobart, Sydney, Brisbane and Darwin) (see Table 1).

Table 1. Summary of species sampled from each state showing common name, scientific name and numbers of samples. × indicates no samples of that species were obtained.

Common name	Scientific name	WA	SA	Vic	Tas	NSW	Qld	NT
Australian Salmon	*Arripis trutta*	×	45	20	21	×	×	×
Snapper	*Chrysophyrys auratus*	19	15	20	×	21	×	×
Dusky Flathead	*Platycephalus fuscus*	×	×	10	×	18	×	×
Blackspotted Rockcod	*Epinephelus malabaricus*	15	×	×	×	×	×	20
Southern Garfish	*Hyporhamphus melanochir*	×	23	25	21	21	×	×
Goldband Snapper	*Pristipomoides multidens*	22	×	×	×	×	20	12
Australian Herring	*Arripis georgianus*	20	20	×	×	×	×	×
King George Whiting	*Sillaginodes punctatus*	24	108	19	×	10	×	×
Moses Snapper	*Lutjanus russellii*	22	×	×	×	×	×	18
Sea Mullet	*Mugil cephalus*	20	17	×	×	17	21	20
Australian Sardine	*Sardinops sagax*	20	17	28	20	20	×	×
Tiger Flathead	*Platycephalus richardsoni*	×	27	14	22	×	×	×
Paddletail	*Lutjanus gibbus*	×	×	×	×	×	18	×
Bluestriped Goatfish	*Upeneichthys lineatus*	×	×	×	×	20	×	×
Common Coral Trout	*Plectropomus leopardus*	×	×	×	×	×	14	×
Sub-total		*162*	*272*	*136*	*84*	*127*	*73*	*70*
Banana Prawn	*Penaeus merguiensis*	×	×	×	×	×	25	40
Blue Endeavour Prawn	*Metapenaeus endeavouri*	×	×	×	×	×	10	×
Grooved Tiger Prawn	*Penaeus semisulcatus*	10	×	×	×	×	35	30
Western King Prawn	*Melicertus latisulcatus*	40	20	×	×	30	60	20
Blue Swimmer Crab	*Portunus armatus*	40	20	×	×	×	20	×
Giant Mud Crab	*Scylla serrata*	×	×	×	×	×	15	×
Sub-total		*90*	*40*	*0*	*0*	*30*	*165*	*90*
Mussels	*Mytilus* spp	40	30	40	40	×	×	10
Pacific Oyster	*Crassostrea gigas*	×	220	×	24	6	×	×
Sydney Rock Oyster	*Saccostrea glomerata*	×	×	×	×	19	×	×
Southern Calamari	*Sepioteuthis australis*	×	9	20	10	5	20	×
Sub-total		*40*	*259*	*60*	*74*	*30*	*20*	*10*
Total		292	571	196	158	187	258	170

Analytical methods

Animals were dissected and the various components (see below) removed and placed in individual sample jars. At the same time a sample of tissue was obtained and frozen for future research. Dissection of bivalve species consisted of shucking and removing all soft tissue. For crustaceans, the exoskeleton was removed and soft tissues along with the gastrointestinal tract was used for digestion (Devriese et al. 2015, Cau et al. 2019). The gastrointestinal tracts and gills of crabs were removed and digested (Waddell et al. 2020). Methods followed Rochman *et al.* (2015) who sampled microplastics from fish and bivalves collected for human consumption in Indonesia and USA. To extract microplastics from the samples, dissected components were added to sample jars filled with a 10% potassium hydroxide (KOH) solution in ultrapure water that represented 3× the volume of the gastrointestinal or other tissue. Samples were incubated overnight at 60°C. All sampling containers were pre-cleaned and equipment rinsed with ultrapure water three times between samples. In addition, methods included steps to avoid and/or quantify procedural contamination, cross-contamination and/or misidentification. For example, hot pink laboratory coats were worn at all times and any pink microplastics removed from further analyses if identified – no pink microplastic pieces were found. Open sample containers were also used at each stage of the process. Potential laboratory sources of microplastic contamination were tested using a similar approach to that used on the fish samples (see below). There was no evidence of microplastic contamination through the laboratory procedures.

Digested material from each fish's gastrointestinal tract or soft tissues of shellfish was sieved through two fine mesh sieves, 36µm and 1mm. Both sieves were then examined under a dissecting microscope. Microplastic particles were counted and summed from both sieves per individual animal. Following this, particles were placed in aluminum foil and retained for each organism to allow for further investigation into the type/sources of microplastic identified. This will occur via Fourier Transform Infrared Spectroscopy (but was not part of this project and is not included in this report).

The relationship between frequency of occurrence (number of organisms with microplastics present) and microplastic load (number of microplastics per individual organism) throughout Australia was investigated using several modelling approaches. Presence/absence data indicated frequency of occurrence of microplastics in organisms therefore binomial models were used for these analyses. For microplastic load data (count data), an initial Poisson model was fitted to the data and checked for over dispersion. Subsequently, negative binomial models were used as the data were highly skewed with many small values. State was used as a fixed effect in all models to investigate spatial differences for each of finfish, crustaceans and molluscs where all species were included. Separate analyses were undertaken on filter feeding molluscs (oysters and mussels) and other molluscs (Southern Calamari). Additional analyses were also undertaken on individual species that were sampled from five states of the seven states, namely Sea Mullet, Australian Sardines, prawns (all species combined) and mussels. All analyses were undertaken in R Studio.

Placing Australian studies in an international context

Literature on microplastics in seafood products was reviewed to place the Australian study in an international context. A systematic review of the literature using several databases (e.g. Web of Science, Scopus) was used to obtain all published studies on microplastics in fish, crustaceans and molluscs. The following search terms were used: (*plastic*) AND (fish*) AND (consum* OR ingest* OR eat*) where either fish*, crustace* or mollus* was used, where the asterisks act as a wildcard allowing all derivatives of the terms to be identified. This search was completed on the 31st of March 2020 for fish and 24 June 2020 for crustaceans and molluscs. Information from this search was incorporated into an Excel database to enable comparisons with our results.

Results and Discussion

Plastic frequency of occurrence in fish and invertebrates

Microplastics were found in all species examined (Fig. 1). Despite this, not all individuals of each species contained microplastics. Overall, the frequency of occurrence was 43.9% for all finfish, crustacean and mollusc samples combined. Frequency of occurrence ranged from 39.4% in finfish to 45.5% in crustaceans and 50.9% in molluscs (Table 2). There were however notable differences within molluscs with the frequency of occurrence of microplastics in filter feeders (oysters and mussels) being much higher than in Southern Calamari (55.9% in oysters and mussels compared to 17.2% in Southern Calamari). Subsequent analyses therefore considered filter feeding molluscs and other molluscs separately.

Variation in frequency of occurrence in finfish (χ^2 52.131, df 6, $p<0.0001$), crustaceans (χ^2 11.743, df 4, $p=0.0194$) and filter feeding molluscs (χ^2 12.440, df 4, $p=0.0144$) was found among the states (Fig. 2; Table 2). Other molluscs (i.e. Southern Calamari) showed no significant difference in frequency of occurrence among states (χ^2 2.065, df 4, $p<0.7239$) (Fig. 2D). When the overall analysis included all finfish regardless of species, more finfish from Queensland and South Australia tended to have microplastics in their gastrointestinal tracts, whereas fewer Tasmanian finfish had microplastics in their gastrointestinal tracts (Fig. 2A). For crustaceans, little variation among states was found in terms of microplastic frequency of occurrence, with the only significant difference being between NSW and SA where greater numbers of crustaceans from SA had microplastics compared to crustaceans collected from NSW (Fig. 2B). For filter feeding molluscs, WA had fewer molluscs with microplastics compared to samples collected from the other states, although significant differences were only found between WA and SA, Tasmania and NSW (Fig. 2C).

For Sea Mullet significant differences in frequency of occurrence occurred among states, although the only significant difference was that Queensland had greater numbers of fish with microplastics than the NT (Fig. 3A). No significant differences in frequency of occurrence among states were found for Australian Sardines (χ^2 3.742, df 4, $p<0.4421$), prawns (χ^2 3.9621, df 4, $p<0.4112$) and mussels (χ^2 9.0969, df 4, $p<0.0587$) (Fig. 3B, C, D). Thus, consistent patterns were not observed between individual species and the broad groups of finfish, crustaceans and filter feeding molluscs. Analyses at the individual species level also showed considerable variability for samples from some states.

At present, our study is the largest sample of finfish investigated for microplastics in Australia and the only one to obtain samples from commercial seafood markets. Our results are generally within the range of other Australian studies where frequency of occurrence ranged from 19% for freshwater fish collected in Victoria (Su et al. 2019) through to 95% for finfish collected from the Great Barrier Reef in Queensland (Kroon et al. 2018, Jensen et al. 2019). Only Kroon et al. (2018) investigated a commercially important species, albeit juveniles. One study in Australia found a much lower frequency of occurrence, however that study used different methods to most other studies including a larger sieve size and no digestion of samples (0.3% FO, Cannon et al. 2016). It may therefore have missed some smaller microplastics. A prior study found that all sampled Sydney Rock Oysters contained microplastics (Jahan et al. 2019), whereas our study only found 63% of Sydney Rock Oysters contained microplastics. We are not aware of any studies that have investigated microplastics in commercially important crustaceans or cephalopods from Australia.

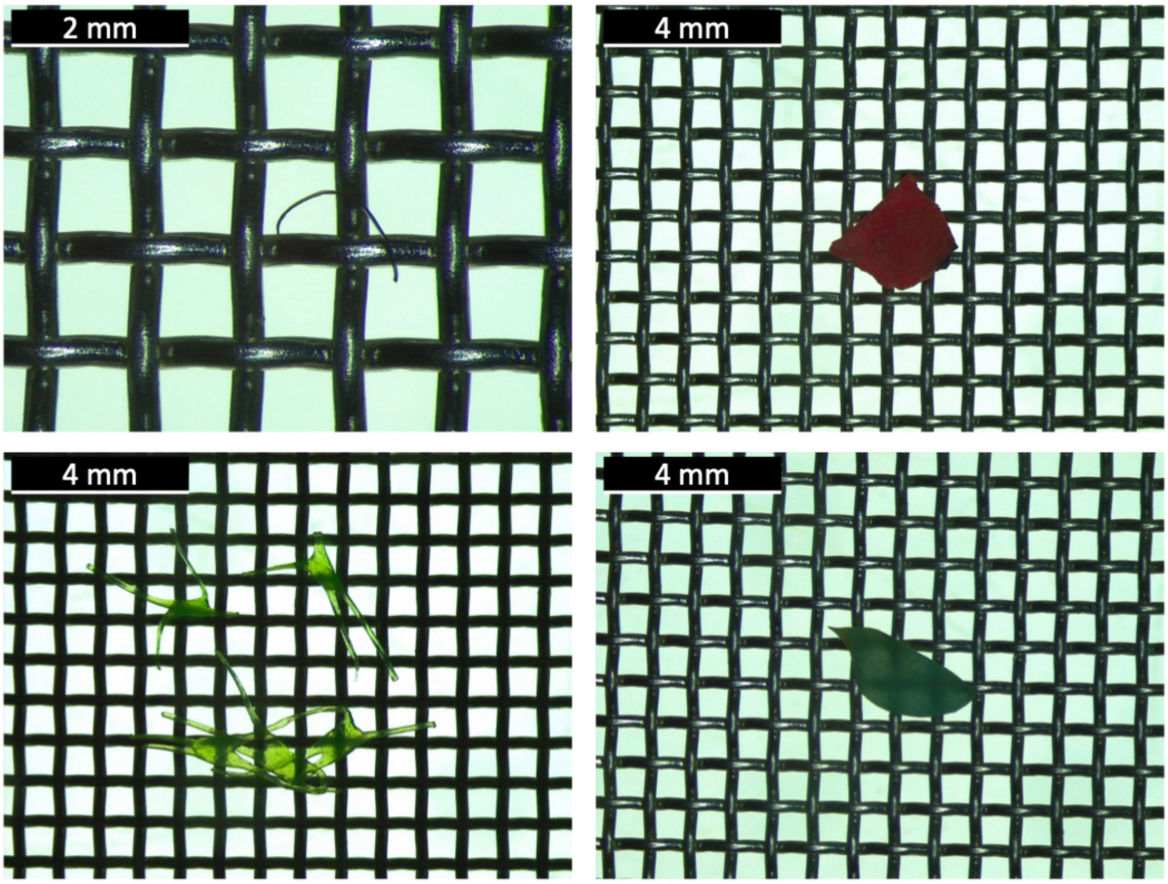


Figure 1. Images of microplastics from finfish. Images: Nina Wootton.

Table 2. Frequency of occurrence of microplastic ingestion by state and species of finfish, crustaceans and molluscs showing percent containing microplastics. Scientific names are indicated in Table 1. Between 5 and 108 samples were examined for each species and state. Numbers in red had a sample size of less than 10. Cells with a × indicate that samples were not obtained for that species and state.

Common name	WA	SA	Vic	Tas	NSW	Qld	NT
Australian Salmon	×	60	25	23.8	×	×	×
Snapper	36.8	20	35	×	28.6	×	×
Dusky Flathead	×	×	80	×	22.2	×	×
Blackspotted Rockcod	33.3	×	×	×	×	×	60
Southern Garfish	×	43.5	20	9.5	19.1	×	×
Goldband snapper	31.8	×	×	×	×	15	66.7
Australian Herring	25	35	×	×	×	×	×
King George Whiting	12.5	61.1	36.8	×	50	×	×
Moses Snapper	27.3	×	×	×	×	×	44.4
Sea Mullet	50	52.9	×	×	47.1	81	25
Australian Sardine	10	5.9	17.9	10	25	×	×
Tiger Flathead	×	22.2	50	36.4	×	×	×
Paddletail	×	×	×	×	×	88.9	×
Bluestriped Goatfish	×	×	×	×	90	×	×
Common Coral Trout	×	×	×	×	×	71.4	×
Banana Prawn	×	×	×	×	×	40	30
Blue Endeavour Prawn	×	×	×	×	×	40	×
Grooved Tiger Prawn	70	×	×	×	×	48.6	43.3
Western King Prawn	35	50	×	×	26.7	45	60
Blue Swimmer Crab	40	75	×	×	×	60	×
Giant Mud Crab	×	×	×	×	×	80	×
Mussels	30	60	57.5	47.5	60	×	×
Pacific Oyster	×	57.7	×	79.2	66.7	×	×
Sydney Rock Oyster	×	×	×	×	63.2	×	×
Southern Calamari	×	22.2	10	30	20	15	×

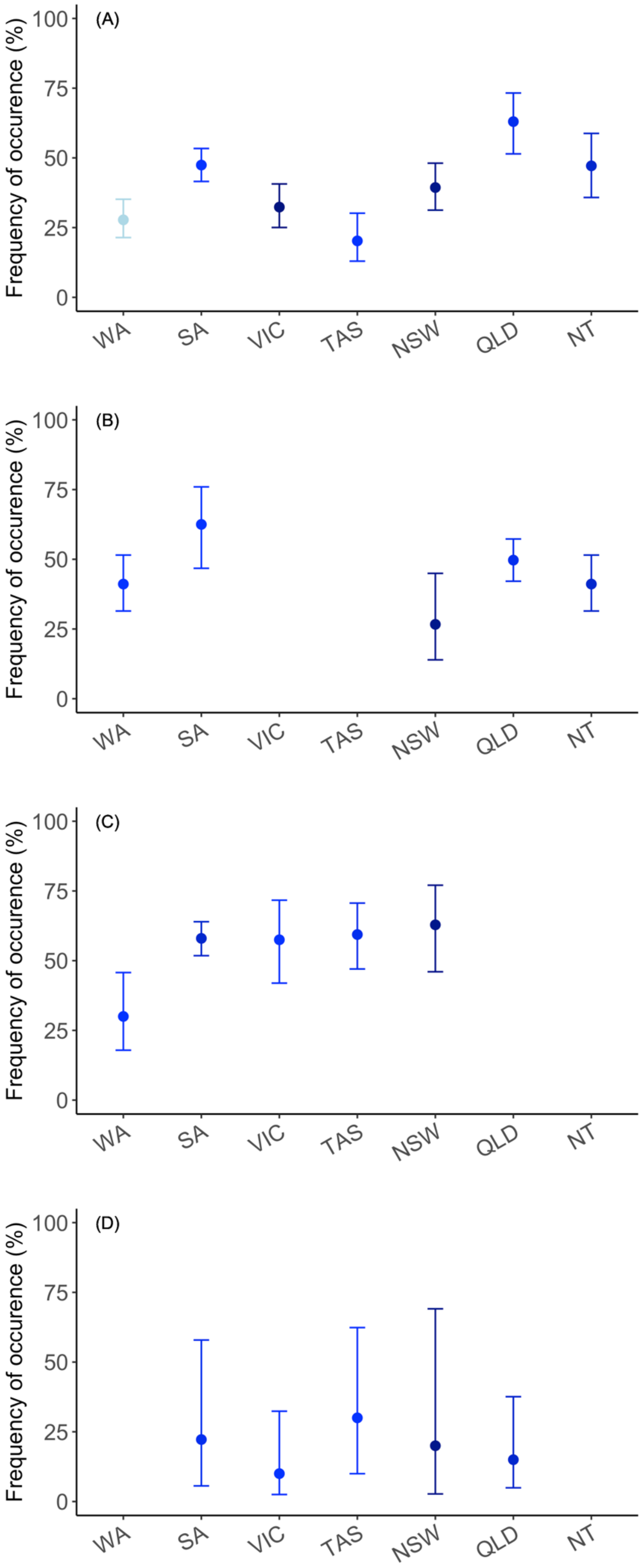


Figure 2. Expected frequency of occurrence of microplastics in all species of (A) finfish, (B) crustaceans, (C) filter feeding molluscs and (D) other molluscs collected from each state. Shown are the expected mean percent of finfish with at least one piece of microplastics along with the upper and lower confidence intervals for data fitted to a binomial model.

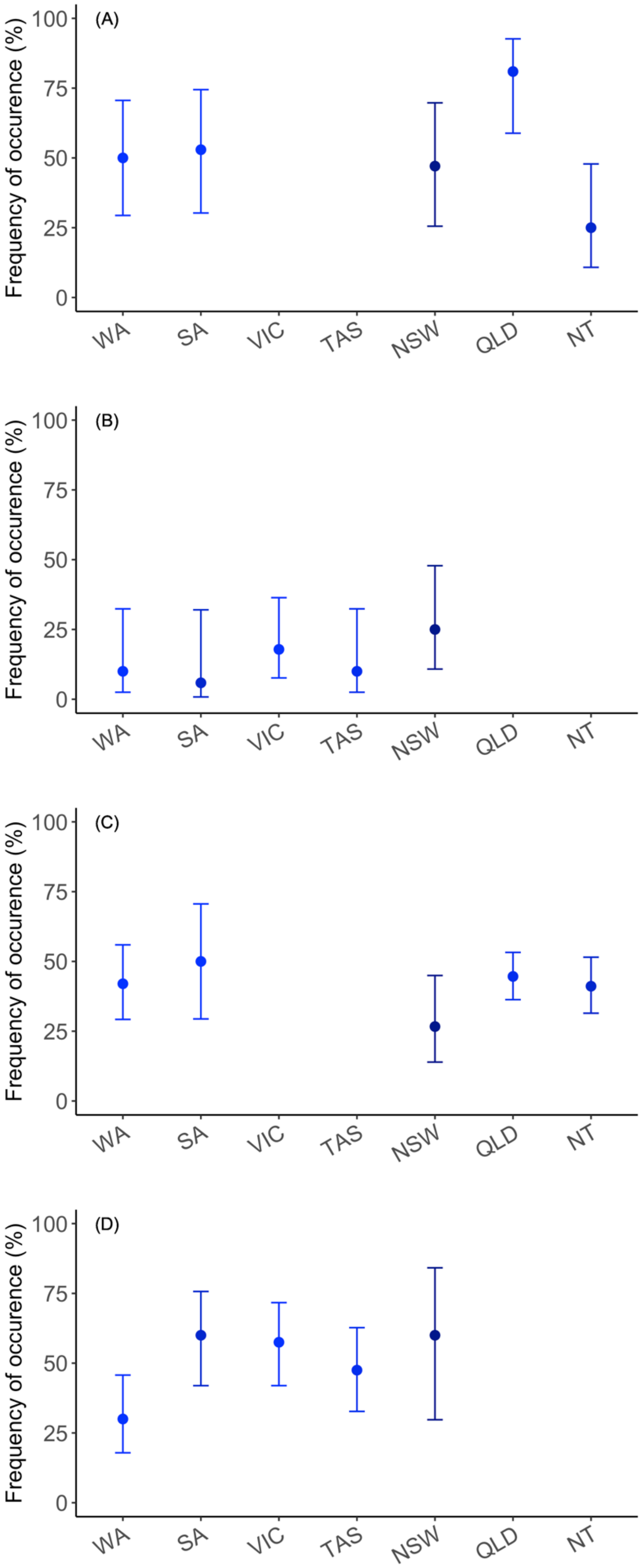


Figure 3. Expected frequency of occurrence of microplastics in (A) Sea Mullet, (B) Australian Sardine, (C) all species of prawns and (D) mussels collected from each state. Shown are the expected mean percent of fish with at least one piece of microplastics along with the upper and lower confidence intervals for data fitted to a binomial model.

Plastic load in fish and invertebrates

Similarly, microplastic load (number of microplastic pieces per organism) also varied greatly among samples – it ranged from no pieces of microplastics through to 29 pieces found in an oyster from South Australia (Fig. 4). The maximum microplastic load was 17 pieces in finfish (Fig. 4A), 9 pieces in crustaceans (Fig. 4B), 29 pieces in filter feeding molluscs (Fig. 4C) and 2 pieces in other molluscs (Fig. 4D). For all types of organisms, there was a trend of decreasing numbers of individuals as microplastic loads increased (Fig. 4). For example, only three crustaceans (<1%) had greater than 4 pieces of microplastics and only 9 (2%) filter feeding molluscs contained greater than 7 pieces of microplastics relative to 54% of crustaceans and 44% of filter feeding molluscs with no microplastics. The average microplastic load was 1.02 pieces per individual but varied from 0.99 pieces in finfish to 0.82 pieces in crustaceans, 1.4 pieces in filter feeding molluscs and 0.19 pieces in Southern Calamari (Table 3).

Microplastic load in finfish varied by state, showing a similar pattern to frequency of occurrence data (χ^2 57.574, df 6, $p<0.0001$; Fig. 5A). Microplastic load was significantly greater in finfish from SA and Queensland than in finfish from Tasmania and WA (Fig. 5A). In addition, SA finfish samples also had higher microplastic loads than finfish samples from WA, and Victorian finfish had higher microplastic loads than Tasmania finfish. Despite differences in microplastic loads for finfish from different states estimates of mean microplastic load ranged from 0.3 pieces (Tasmania) to 1.5 pieces (SA) (Fig. 5A). Sea Mullet microplastic load also differed by state (χ^2 12.790, df 4, $p<0.0123$; Fig. 6A), but no significant variation was found for Australian Sardines (χ^2 5.306, df 4, $p<0.2573$; Fig. 6B). These results suggest spatial variation among individual species in terms of microplastic load.

No significant difference in microplastic load among states was found for crustaceans (χ^2 7.073, df 4, $p=0.1321$) with the mean microplastic loads ranging from 0.5 pieces (NSW) to 1.2 pieces (SA) (Fig. 5B). Similarly, microplastic load in prawns did not differ among states ranging from 0.5 pieces (NSW) to 0.9 pieces (NT) (χ^2 3.847, df 4, $p=0.4271$) (Fig. 6C). Filter feeding molluscs showed significant differences in microplastic load among states (χ^2 16.388, df 4, $p=0.0025$) with WA having lower microplastic loads (0.5) than the other states (Fig. 5C). Mean microplastic loads for the other states ranged from 1.2 (Tasmania) to 1.6 pieces (SA). Mussels showed similar patterns (χ^2 11.516, df 4, $p=0.0213$) to all filter feeding molluscs ranging from 0.5 pieces (WA) to 1.3 pieces (Victoria) (Fig. 6D). Other molluscs showed no significant differences in microplastic load among states (χ^2 0.951, df 4, $p=0.9172$) ranging from 0.15 (Victoria and Queensland) to 0.3 pieces (Tasmania) (Fig. 5D). Although low numbers of microplastics were found, there was however large variation.

The average microplastic load for our samples (1.02 pieces per sample) was generally lower than other studies that have undertaken sampling in more specific locations. A previous study investigating three species of finfish in Sydney Harbour found a microplastic load of 2.7 pieces per individual (Halstead et al. 2018), whereas samples of finfish from the Great Barrier Reef averaged between 5.8 and 7.6 pieces of microplastics per individual (Kroon et al. 2018, Jensen et al. 2019). Our results for finfish are more similar to those of Su et al. (2019) (1.02 versus 0.6 pieces). A previous study on Sydney Rock Oysters recorded an average of between 0.06 and 0.83 pieces of microplastic per gram wet weight of the organism depending on location (Jahan et al. 2019), whereas our research recorded 1.42 pieces per organism.

Additional studies in Australia have investigated plastic concentrations in surface waters around Australia (Reisser et al. 2013) and in seafloor sediments in south eastern Australia (Ling et al. 2017). Microplastics in surface waters were similar to levels in the Caribbean Sea and Gulf and Maine but lower than those found in the Mediterranean Sea (Reisser et al. 2013). Microplastics were found at all of the 42 coastal and estuarine sites (Ling et al. 2017). A national litter survey of 175 sites around Australia has also investigated debris along the coastline finding that ocean currents and wind patterns partially drive debris concentrations (Hardesty et al. 2017). In addition, litter density was higher in closer proximity to urban areas and plastic made up 75% of all litter (Hardesty et al. 2017). The key trend seems to be the ubiquitous nature of plastics in the marine environment (including in sediment) and therefore their ability to be found in organisms.

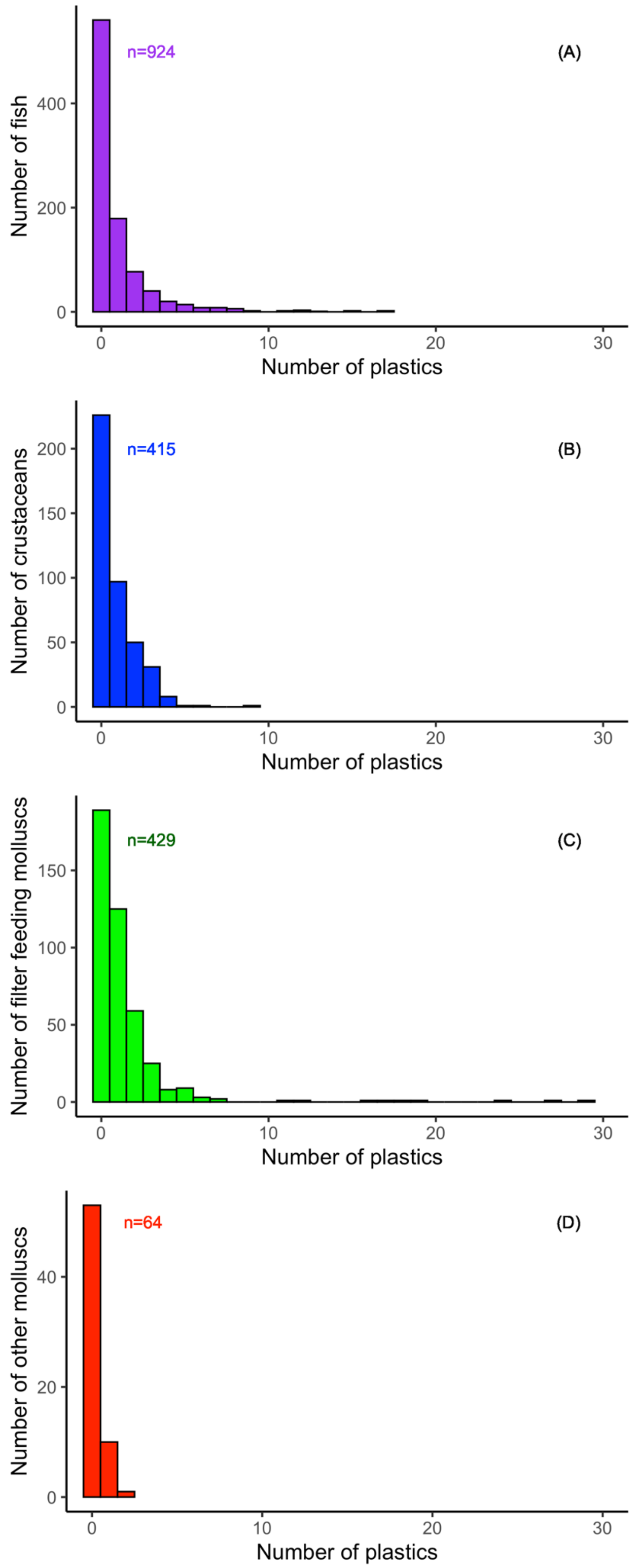


Figure 4. Frequency distribution of number of organisms with different numbers of microplastics in their gastrointestinal tract for (A) finfish, (B) crustaceans, (C) filter feeding molluscs and (D) other molluscs. Data are for all species within each group and for all states combined. Sample sizes are shown on each figure. Note Y-axis scale differs for each plot.

Table 3. Microplastic load in finfish, crustaceans and molluscs collected throughout Australia showing average microplastic load for each species from each state. Scientific names are indicated in Table 1. Between 5 and 108 samples were examined for each species and state. Cells with a × indicate that samples were not obtained for that species and state.

Common name	WA	SA	Vic	Tas	NSW	Qld	NT
Australian Salmon	×	2.31	1.20	0.43	×	×	×
Snapper	1.32	0.80	1.45	×	0.62	×	×
Dusky Flathead	×	×	2.70	×	0.28	×	×
Blackspotted Rockcod	0.47	×	×	×	×	×	1.05
Southern Garfish	×	0.57	0.20	0.10	0.20	×	×
Goldband Snapper	0.45	×	×	×	×	0.15	0.92
Australian Herring	0.50	0.70	×	×	×	×	×
King George Whiting	0.13	2.21	0.53	×	0.60	×	×
Moses Snapper	0.64	×	×	×	×	×	0.78
Sea Mullet	0.70	1.06	×	×	1.12	1.29	0.30
Australian Sardine	0.80	0.06	0.25	0.20	0.30	×	×
Tiger Flathead	×	0.30	1.14	0.50	×	×	×
Paddletail	×	×	×	×	×	1.89	×
Bluestriped Goatfish	×	×	×	×	2.15	×	×
Common Coral Trout	×	×	×	×	×	2.80	×
All fish species combined	**0.61**	**1.50**	**0.87**	**0.31**	**0.76**	**1.48**	**0.74**
Banana Prawn	×	×	×	×	×	0.64	0.55
Blue Endeavour Prawn	×	×	×	×	×	0.80	×
Grooved Tiger Prawn	1.40	×	×	×	×	0.91	0.83
Western King Prawn	0.50	0.70	×	×	0.47	0.55	1.60
Blue Swimmer Crab	0.85	1.65	×	×	×	1.05	×
Giant Mud Crab	×	×	×	×	×	1.60	×
All crustacean species combined	**0.76**	**1.18**	**×**	**×**	**0.46**	**0.81**	**0.88**
Mussels	0.50	1.10	1.25	0.68	0.70	×	×
Pacific Oyster	×	1.72	×	2.04	1.50	×	×
Sydney Rock Oyster	×	×	×	×	1.42	×	×
All filter-feeding molluscs combined	**0.50**	**1.64**	**1.25**	**1.19**	**1.23**	**×**	**×**
Southern Calamari	×	0.22	0.15	0.30	0.20	0.15	×

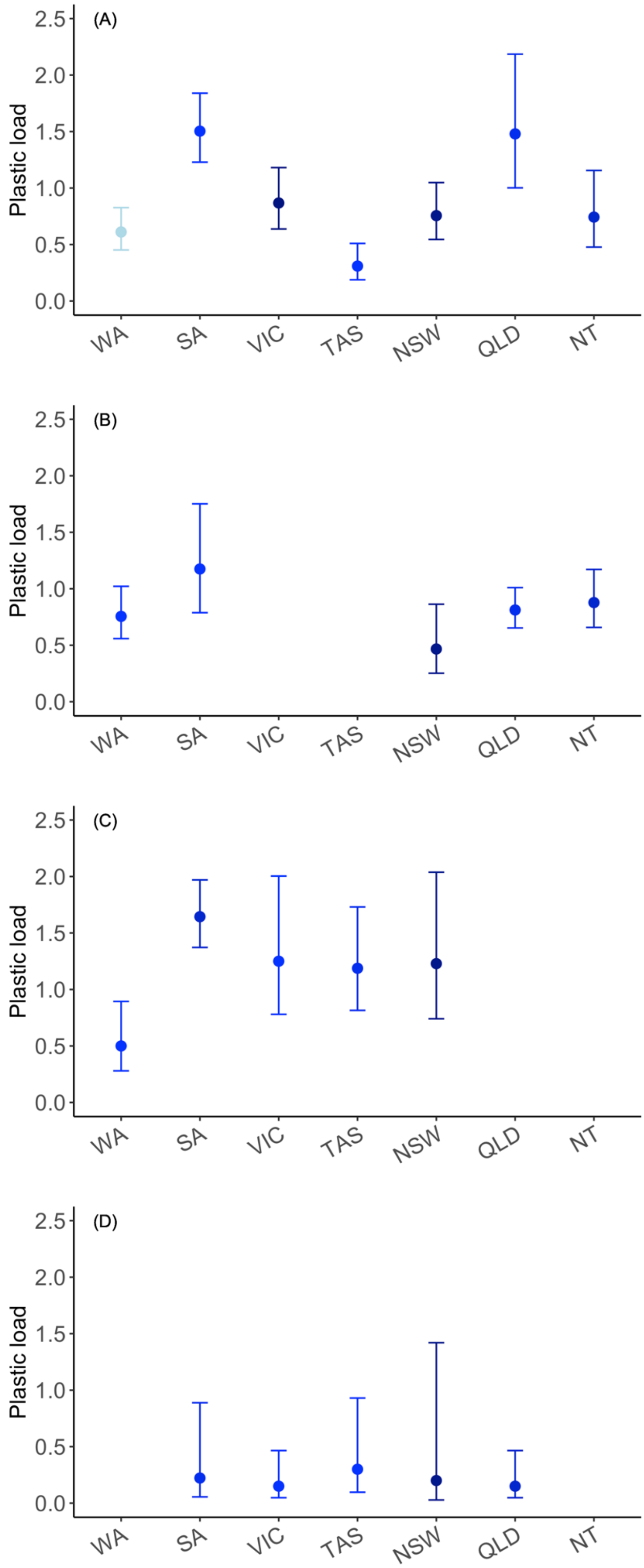


Figure 5. Expected microplastics load for all species of (A) finfish, (B) crustaceans, (C) filter feeding molluscs and (D) other molluscs collected from each state. Shown are the expected mean microplastic load along with the upper and lower confidence intervals for data fitted to a negative binomial model.

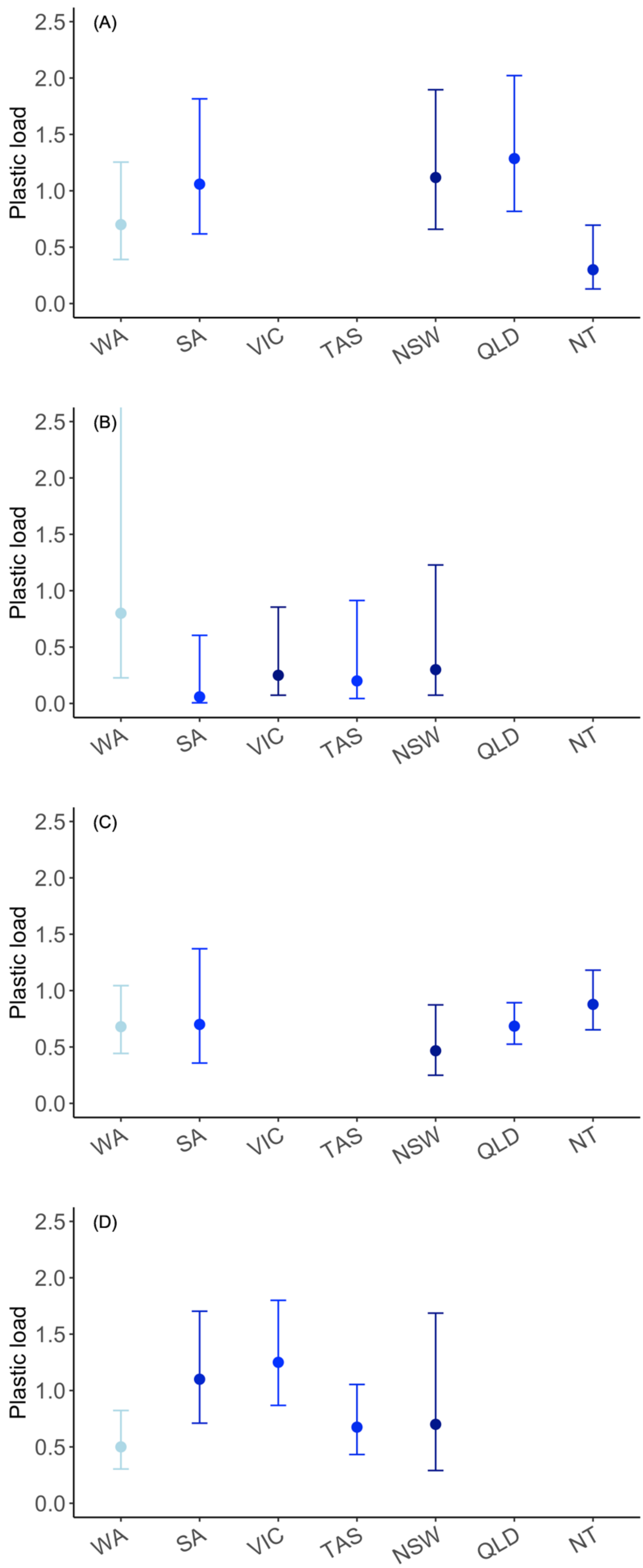


Figure 6. Expected microplastics load for (A) Sea Mullet, (B) Australian Sardine, (C) all species of prawns and (D) mussels collected from each state. Shown are the expected mean microplastic load along with the upper and lower confidence intervals for data fitted to a negative binomial model. The upper confidence limit for WA in (B) is 2.8.

Placing Australian studies in an international context

Few studies investigated microplastic loads prior to 1990. Since this time there has been a significant increase in the number of studies such that 171 studies have examined microplastic loads in finfish. While fewer studies have investigated microplastics in commercially important crustaceans (n=26) and molluscs (n=47) the number of studies is also increasing. Studies investigating microplastics in finfish, crustaceans and molluscs have been undertaken throughout the world (Fig. 7), although not all studies provide information on frequency of occurrence or microplastic load to compare to our research.

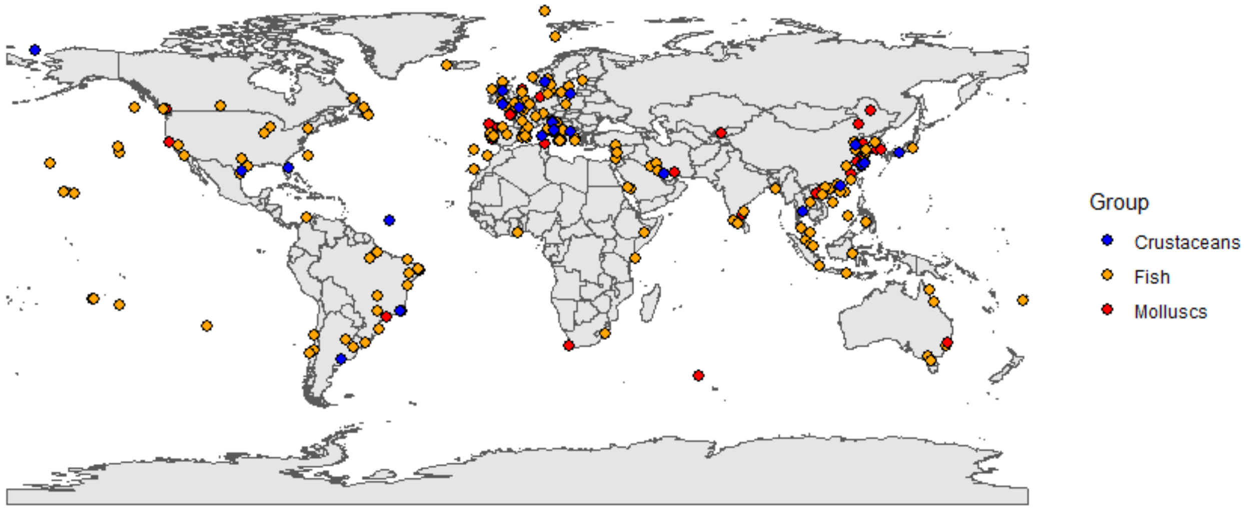


Figure 7. Map indicating where studies examining microplastics in fish, crustaceans and molluscs have been undertaken.

The majority of studies (n=171) have been undertaken on fish. Frequency of occurrence for individual species across all studies showed two peaks, one around 0-5% frequency of occurrence and the other around 95-100% (Fig. 8A). There was a decrease in number of studies from 5 to 95% frequency of occurrence (Fig. 8A). Our study found an overall mean frequency of occurrence for 15 species of finfish of 39% which is slightly below the average frequency of occurrence (range 5.9-90% depending on species).

Worldwide, only 19 studies provide information on frequency of occurrence for commercially important crustaceans. Frequency of occurrence ranged from 5.5% for decapod crabs from the northern Adriatic Coast, Italy to 100% for decapod crabs in Hong Kong (Piarulli et al. 2019, Not et al. 2020) (Fig. 8B). We are not aware of studies investigating microplastic occurrence in commercially important crustaceans from Australia, but our results found on average 46% of crustaceans from six species contained microplastics (range 26.7-80% depending on species). Similarly, a wide range of frequency of occurrence was found for studies across the world investigating filter and suspension feeding molluscs (Fig. 8C) including a previous study that found all Sydney Rock Oysters contained microplastics (Jahan et al. 2019). On average 56% percent of filter feeding molluscs representing three species in our study contained microplastics (range 30-79.2% depending on species).

Comparing microplastic load is more difficult as different measures have been used depending on the study. Most studies measure either microplastic load as number of pieces of microplastic per organism or digestive tract, or number of pieces of microplastic per gram wet weight of the organism. The maximum average microplastic loads for crustaceans were 60.5 pieces per organism (Not et al. 2020) or 2 microplastic pieces per gram wet weight (Xu et al. 2020) (Table 4). Much higher loads were found in molluscs – 178 pieces per organism or 1482.8 pieces per gram wet weight (Mathalon & Hill 2014, Abidli et al. 2019). Finfish averages ranged between 0 and 366 pieces of microplastic being highest for a study from Indonesia (Ningrum et al. 2019).

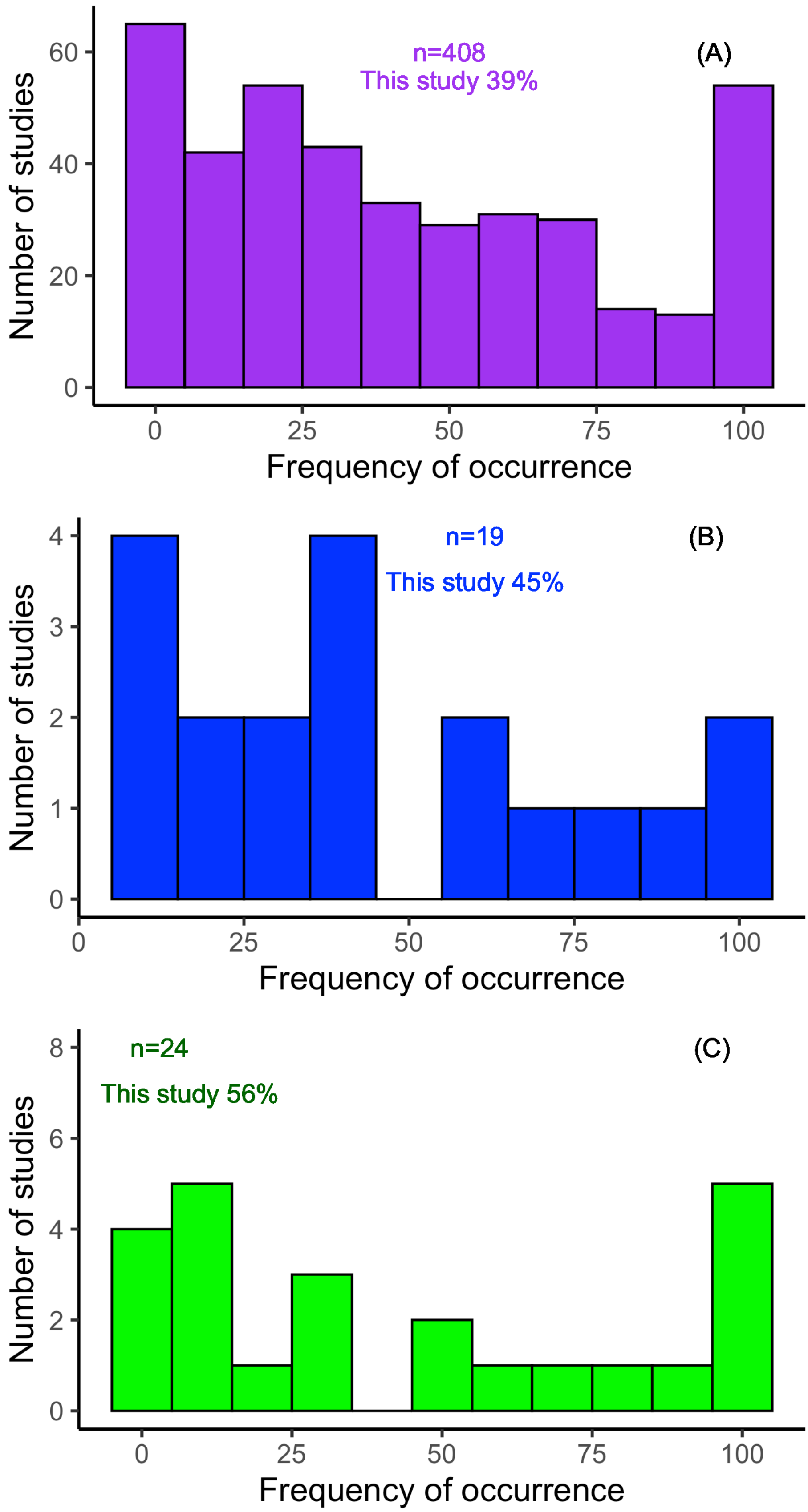


Figure 8. Review of international literature showing frequency distribution for individual species within studies by frequency of occurrence for (A) finfish, (B) crustaceans and (C) molluscs. Sample sizes represent

the number of species for which information was available with potential for multiple species from an individual study and are shown along with the results from this study. Note Y-axis scale differs for each plot.

Table 4. Range of values for average microplastic load per organism/digestive tract or microplastic load per g wet weight of organism for studies from the international literature. Also shown are the number of studies for each group which may represent individual studies or multiple species from a single study. Data from the current study are also provided.

Seafood	Microplastics per organism	Microplastics per g wet weight	Current study – microplastics per organism
Finfish	0-366 (n=408)		0.98
Crustaceans	0.07-60.5 (n=19)	0.08-2 (n=10)	0.82
Molluscs	0-178 (n=62)	0-1482.8 (n=40)	1.40
Squid	NA	NA	0.19

Conclusion

An Australian wide assessment of microplastics across a broad range of commercially important species has demonstrated that less than half of all organisms contained microplastics and that in general microplastic loads were low. Placed in an international context median levels of frequency of occurrence of microplastics within organisms were found. Similarly, the average microplastic load was at the lower end of the range found in international studies. Our results provide baseline data on which to assess future changes in the frequency and accumulation of microplastics in Australian seafood species.

Implications & Recommendations

The project provides seafood consumers and the fishing industry with baseline data on microplastics in Australian fish and invertebrates. The results generally demonstrated some spatial variation throughout Australia and among groups of organisms or species, but the trends were not consistent. While all species contained microplastics, not all individuals contained microplastics and therefore overall microplastic loads were generally low.

We investigated the frequency of occurrence and microplastic load in organisms or their digestive system as an initial indicator of the issue. Although low levels of microplastics were found in fish and invertebrates, a common concern is whether components of plastics or pollutants which can sorb onto the plastic surface are found in tissue samples of the organisms. Plastics may act as both vectors of transport as well as contain hazardous chemicals added during their production (Campanale et al. 2020). Of concern are additives including bisphenol A, phthalates, heavy metals and flame retardants (Campanale et al. 2020). Little research has investigated whether these compounds are found in tissue samples of fish and invertebrates. Initial research has developed a method for testing plastic-associated compounds, with preliminary analyses suggesting higher concentrations in liver than tissue samples, although levels were low for both tissue types (Dolling, Williams and Gillanders, unpublished data). Further research could assess plastic-associated compounds in a broad range of fish and invertebrate species.

Little is known of the potential impacts of plastic additives or pollutants sorbed onto their surface on human health, but it is assumed that the main entry point is through ingestion of water and contaminated food. It is important to recognise that besides fish and invertebrates microplastics have also been found in sugar, salt, alcohol, bottled water, and in fruits and vegetables (Smith et al. 2018, World Health Organisation 2019, Campanale et al. 2020). Thus, intake is likely via a range of sources. Additional entry points may also occur through inhalation or skin contact. After intake the fate and effects of microplastics are not well known, but both physical and chemical effects are possible (Smith et al. 2018, Campanale et al. 2020).

Further, the focus of this research was on fish and invertebrates collected from Australian waters and sold in markets. Additional research could focus on aquaculture species and on imported seafood.

Extension and Adoption

Given the issue of microplastics in seafood is an emerging field, there was the potential for negative miscommunication of facts. As such, it was imperative that there was engagement with the seafood industry and regulators to appropriately disseminate the findings and manage the perception of the research. To do this, a project Steering Committee comprised of FRDC, Food Standards Australia New Zealand, postharvest representatives from Sydney Fish Markets and Simplot Australia, a seafood industry representative from Seafood Industry Australia/Seafood Industry Victoria and Safefish was convened. The objectives of the committee were to provide strategic direction to the project team, assist with determining an appropriate sampling framework, to develop a communication strategy and extension and adoption plan, to assist with dissemination of project findings and information, and to provide recommendations for future work that could be undertaken.

To date, results of this project have been communicated at several symposia/seminars including:

- School of Biological Sciences, University of Adelaide Annual Postgraduate Research day, July 2019
- Seafood Directions 2019, Melbourne, 9-11 October 2019
- Australian Society for Fish Biology Annual Conference, Canberra, 14-17 October 2019
- School of Biological Sciences, University of Adelaide 3MT, July 2020

Results will also be presented at the World Fisheries Congress (postponed until September 2021).

An infographic was developed (see project materials developed) to provide seafood processors and others interested in the project with an overview of the initial project specifically outlining the aims and why the work came about. Given the low prevalence of microplastics detected across all species tested, and in line with the communication strategy, a set of talking points on the findings will be developed for the seafood industry. In addition to this, a final info-graphic will also be produced and disseminated to identified stakeholders highlighting the major outcomes of the research.

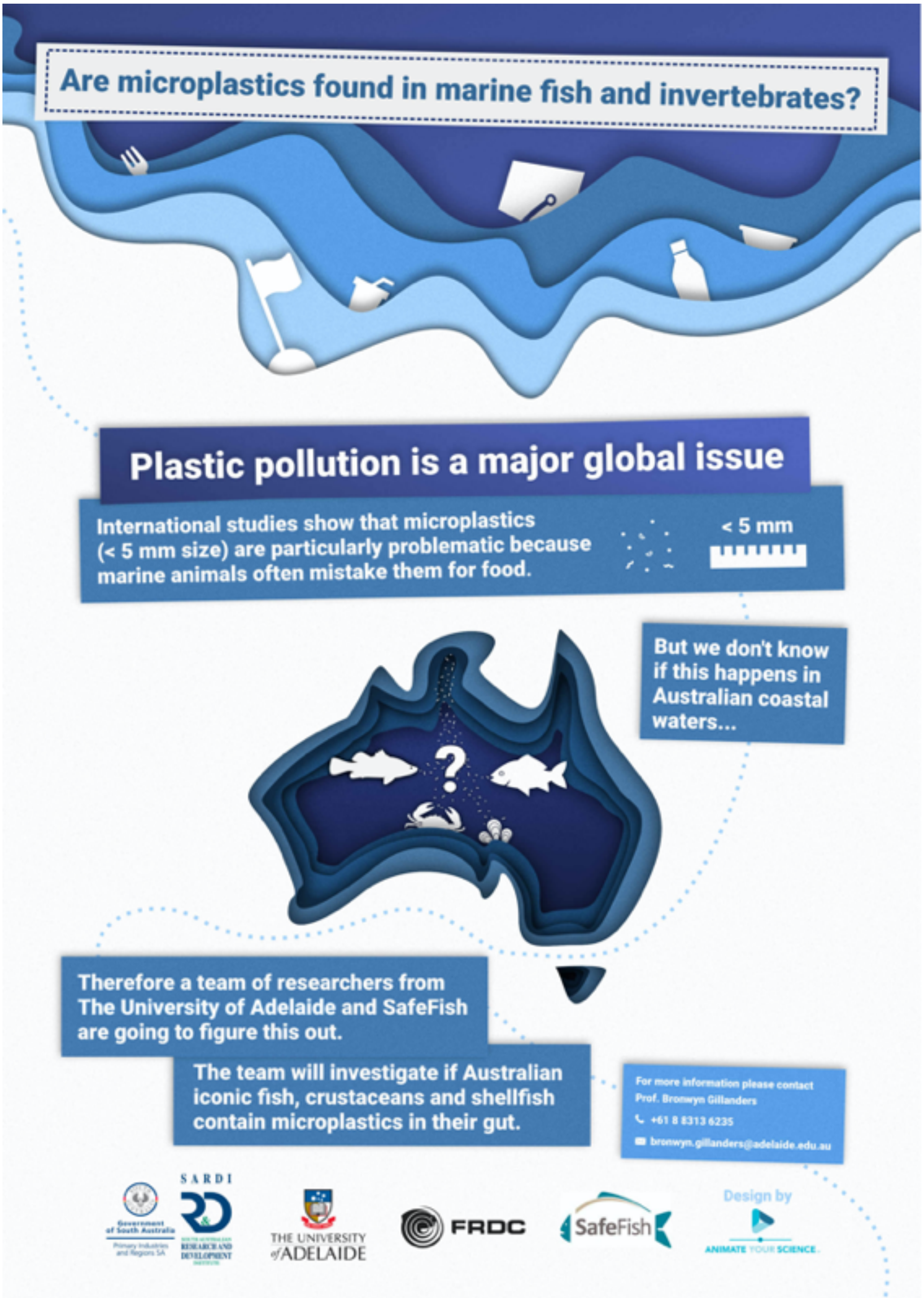
Research publications are also currently in preparation.

Project coverage

The project was covered in an Advertiser media article by science reporter Claire Peddie, and subsequently also reported in the Sunday mail and some on-line websites.

Project materials developed

The following infographic was developed in relation to initial sample collection.



References

Abidli, S., Lahbib, Y., Trigui El Menif, N. 2019. Microplastics in commercial molluscs from the lagoon of Bizerte (Northern Tunisia). Marine Pollution Bulletin 142, 243-252.

Andrady, A.L. 2011. Microplastics in the marine environment. Marine Pollution Bulletin 62, 1596-1605.

Campanale, C., Massarelli, C., Savino, I., et al. 2020. A detailed review study on potential effects of microplastics and additives of concern on human health. International Journal of Environmental Research and Public Health 17.

Cannon, S.M.E., Lavers, J.L., Figueiredo, B. 2016. Plastic ingestion by fish in the Southern Hemisphere: A baseline study and review of methods. Marine Pollution Bulletin 107, 286-291.

Cau, A., Avio, C.G., Dessi, C., et al. 2019. Microplastics in the crustaceans *Nephrops norvegicus* and *Aristeus antennatus*: Flagship species for deep-sea environments? Environmental Pollution 255, 113107.

Cole, M., Lindeque, P., Halsband, C., et al. 2011. Microplastics as contaminants in the marine environment: a review. Marine Pollution Bulletin 62, 2588-2597.

Devriese, L.I., van der Meulen, M.D., Maes, T., et al. 2015. Microplastic contamination in brown shrimp (*Crangon crangon*, Linnaeus 1758) from coastal waters of the Southern North Sea and Channel area. Marine Pollution Bulletin 98, 179-187.

Hardesty, B.D., Lawson, T.J., van der Velde, T., et al. 2017. Estimating quantities and sources of marine debris at a continental scale. Frontiers in Ecology and the Environment 15, 18-25.

Jahan, S., Strezov, V., Weldekidan, H., et al. 2019. Interrelationship of microplastic pollution in sediments and oysters in a seaport environment of the eastern coast of Australia. Science of the Total Environment 695, 133924.

Jensen, L.H., Motti, C.A., Garm, A.L., et al. 2019. Sources, distribution and fate of microfibres on the Great Barrier Reef, Australia. Scientific Reports 9, 9021.

Kroon, F.J., Motti, C.E., Jensen, L.H., et al. 2018. Classification of marine microdebris: A review and case study on fish from the Great Barrier Reef, Australia. Scientific Reports 8, 16422.

Ling, S.D., Sinclair, M., Levi, C.J., et al. 2017. Ubiquity of microplastics in coastal seafloor sediments. Marine Pollution Bulletin 121, 104-110.

Mathalon, A. & Hill, P. 2014. Microplastic fibers in the intertidal ecosystem surrounding Halifax Harbor, Nova Scotia. Marine Pollution Bulletin 81, 69-79.

Ningrum, E.W., Patria, M.P., Sedayu, A. 2019. Ingestion of microplastics by anchovies from Talisayan harbor, East Kalimantan, Indonesia. Journal of Physics: Conference Series 1402, 033072.

Not, C., Lui, C.Y.I., Cannicci, S. 2020. Feeding behavior is the main driver for microparticle intake in mangrove crabs. Limnology and OCeanography Letters 5, 84-91.

Piarulli, S., Scapinello, S., Comandini, P., et al. 2019. Microplastic in wild populations of the omnivorous crab *Carcinus aestuarii*: A review and a regional-scale test of extraction methods, including microfibres. Environmental Pollution 251, 117-127.

Reisser, J., Shaw, J., Wilcox, C., et al. 2013. Marine plastic pollution in waters around Australia: Characteristics, concentrations, and pathways. Plos One 8.

Rochman, C.M., Browne, M.A., Halpern, B.S., et al. 2013. Classify plastic waste as hazardous. Nature 494, 169.

Rochman, C.M., Lewison, R.L., Eriksen, M., et al. 2014. Polybrominated diphenyl ethers (PBDEs) in fish tissue may be an indicator of plastic contamination in marine habitats. Sciene of the Total Environment 476-477, 622-633.

Rochman, C.M., Tahir, A., Williams, S.L., et al. 2015. Anthropogenic debris in seafood: Plastic debris and fibers from textiles in fish and bivalves sold for human consumption. Scientific Reports 5, 14340.

Seltenrich, N. 2015. New link in the food chain? Marine plastic pollution and seafood safety. Environmental Health Perspectives 123, A34-41.

Smith, M., Love, D.C., Rochman, C.M., et al. 2018. Microplastics in seafood and the implications for human health. Current Environmental Health Reports 5, 375-386.

Su, L., Nan, B., Hassell, K.L., et al. 2019. Microplastics biomonitoring in Australian urban wetlands using a common noxious fish (*Gambusia holbrooki*). Chemosphere 228, 65-74.

Waddell, E.N., Lascelles, N., Conkle, J.L. 2020. Microplastic contamination in Corpus Christi blue crabs, *Callinectes sapidus*. Limnology and OCeanography Letters 5, 92-102.

World Health Organisation 2019. Microplastics in drinking-water.

Worm, B., Lotze, H.K., Jubinville, I., et al. 2017. Plastic as a persistent marine pollutant. Annual Review of Environment and Resources 42, 1-26.
Xu, X., Wong, C.Y., Tam, N.F.Y., et al. 2020. Microplastics in invertebrates on soft shores in Hong Kong: Influence of habitat, taxa and feeding mode. Science of the Total Environment 715, 136999.

Appendices

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- Koster Sarakinis, University of Adelaide
- Solomon Ogunola, University of Adelaide
- Dr Patrick Reis Santos, University of Adelaide
- Natalie Dowsett, Safefish
- Alison Turnbull, Safefish

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- Alison Turnbull, Safefish
- Cristina Lesseur, Simplot Australia
- Jason Goode, Simplot Australia/Australian Packaging Covenant
- Erik Poole, Sydney Fish Market
- Keith Henderson, Food Standards Australia, New Zealand
- Matthew O'Mullane, Food Standards Australia, New Zealand
- Alex Craven, Food Standards Australia, New Zealand
- Jonathon Davey, Seafood Industry Australia/Seafood Industry Victoria
- Peter Horvat, Fisheries Research and Development Corporation
- Nina Wootton, University of Adelaide (permanent observer)
- Koster Sarakinis, University of Adelaide (permanent observer)
- Natalie Dowsett, Safefish (permanent observer)