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Periodic review of the risk assessment

Seafood food safety scheme

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Glossary

ABARES	Australian Bureau of Agricultural and Resource Economics
ACT	Australian Capital Territory
AIHW	Australian Institute of Health and Welfare
AiV-A	Aichivirus A
APC	aerobic plate count
ASQAP	Australian Shellfish Quality Assurance Program
ASP	amnesic shellfish poisoning
AST	amnesic shellfish toxin
ATDS	Australian Total Diet Study
AZT	azaspiracid shellfish toxin
BfR	German Federal Institute for Risk Assessment
BOM	Bureau of Meteorology (Australia)
CC	clonal complex
CCFH	Codex Committee on Food Hygiene
CCP	critical control point

CDC	Centers for Disease Control and Prevention (United States)
CFIA	Canadian Food Inspection Agency
CoOL	Country of Origin Labelling
CoP	Code of Practice
CRC	Cooperative Research Centre
CSIRO	Commonwealth Scientific and Industrial Research Organisation (Australia)
CTX	ciguatoxin
DAFF	Department of Agriculture, Fisheries and Forestry (Australia)
DCCEEW	Department of Climate Change, Energy, the Environment and Water (Australia)
DHAC	Department of Health and Aged Care (Australia) *formerly the Department of Health*
DISR	Department of Industry, Science and Resources (Australia)
DLCs	dioxin-like compounds
DL-PCBs	dioxin-like polychlorinated biphenyls
DPE	Department of Planning and Environment (NSW)
DPI	Department of Primary Industries (NSW)
DPIPWE	Department of Primary Industries, Parks, Water and Environment (TAS)
DPIRD	Department of Primary Industries and Regional Development (NSW)
DSP	diarrhetic shellfish poisoning
DST	diarrhetic shellfish toxin
DTX	dinophysistoxin
EC	European Commission
ECDC	European Centre for Disease Control and Prevention
EFSA	European Food Safety Authority
EPA	Environment Protection Authority (NSW)
ERIS	Emerging Risk Identification System (New Zealand)
EU	European Union
FAO	Food and Agriculture Organization (United Nations)
FDA	Food and Drug Administration (United States)
FRDC	Fisheries Research and Development Corporation (Australia)
FSA	Food Standards Agency (UK)
FSANZ	Food Standards Australia New Zealand
FSP	Food Safety Program
FWEM	Food Water and Environmental Microbiology (United Kingdom)
GDP	gross domestic product
GTX	gempylotoxin
GVP	gross value of production

HAB	harmful algal bloom
HAV	Hepatitis A virus
HBGVs	Health Based Guidance Values
HPP	high-pressure processing
ICMSF	International Commission on Microbiological Specifications for Foods
IFIS	Imported Food Inspection Scheme (Australia)
IFSAC	Interagency Food Safety Analytics Collaboration (United States)
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
L3	third larval stage
LC-MS	liquid chromatography — mass spectrometry
LC-MS/MS	liquid chromatography — tandem mass spectrometry
LPS	lipopolysaccharides
MBMP	Marine Biotoxin Management Plan
MCs	microcystins
MPI	Ministry for Primary Industries (New Zealand)
NATA	National Association of Testing Authorities (Australia)
NDL-PCBs	non-dioxin-like polychlorinated biphenyls
NHMRC	National Health and Medical Research Council (Australia)
NOAEL	no observed adverse effect level
NORS	National Outbreak Reporting System (United States)
NoV	norovirus
NMDS	National Minimum Dataset (New Zealand)
NRS	National Residue Survey (Australia)
NST	neurotoxic shellfish toxin
NSW	New South Wales
NT	Northern Territory
NZ	New Zealand
NZFS	New Zealand Food Safety
NZFSSRC	New Zealand Food Safety Science & Research Centre
OA	okadaic acid
PAL	phytoplankton action limit
PCBs	polychlorinated biphenyls
PCDDs	polychlorinated dibenzo-p-dioxins
PCDFs	polychlorinated dibenzofurans
PCR	polymerase chain reaction
PFASs	per- and polyfluoroalkyl substances

PFHxS	perfluorohexane sulfonate
PFOA	perfluorooctanoic acid
PFOS	perfluorooctane sulfonate
POPs	persistent organic pollutants
PSP	paralytic shellfish poisoning
PST	paralytic shellfish toxin
PTWI	Provisional Tolerable Weekly Intake
PTX	pectenotoxin
QLD	Queensland
QMRA	quantitative microbial risk assessment
qPCR	quantitative polymerase chain reaction
RASFF	Rapid Alert System for Food and Feed
RACCs	Regional Algal Co-ordinating Committees
RIDOH	Rhode Island Department of Health
RNA	ribonucleic acid
RTE	ready-to-eat
RT-PCR	reverse transcription polymerase chain reaction
RT-qPCR	reverse transcription quantitative polymerase chain reaction
SA	South Australia
ST	sequence type
STX	saxitoxin
TAS	Tasmania
TCDD	tetrachlorodibenzo-p-dioxin
TDI	tolerable daily intake
TEFs	toxic equivalency factors
TTX	tetrodotoxin
UK	United Kingdom
UKHSA	United Kingdom Health Security Agency
USA	United States of America
VIC	Victoria
WA	Western Australia
WGS	whole-genome sequencing
WHO	World Health Organization
YTX	yessotoxin

Units of measurement

°C	degrees Celsius
CFU	Colony Forming Unit
g	gram
kg	kilogram
L	litre
mg	milligram
ml	millilitre
mm	millimetre
MPN	Most Probable Number
ng	nanogram
pg	picogram
ppb	parts per billion
ppm	parts per million
s	second
TEQ	total toxic equivalency
µg	microgram
µm	micrometre

Executive summary

The previous risk assessment of the seafood safety scheme was published in 2017. The 2017 risk assessment was an update of the 2012 risk assessment. Each five-year review is conducted on an alternate basis, as either a full risk assessment or an update. A full risk assessment is reported here containing new or updated information identified in an environmental scan for issues that have impacted seafood and seafood product food safety.

Information sources included:

- foodborne illness reports and recall data in Australia attributed to seafood and seafood products
- international issues arising from human illness or perceived hazards linked with seafood and seafood products
- border detections for seafood and seafood products
- risk assessments of seafood and seafood products
- emerging issues in the pre-harvest to consumer continuum for seafood and seafood products relevant to health risk
- research findings related to hazards in seafood and seafood product production and processing
- baseline surveys of microbiological and chemical hazards in seafood and seafood products
- other relevant sources if identified during the above evaluations.

Seafood supply in NSW comes from three major sources consisting of wild catch, aquaculture and imported products. Globally, a wide range of biological and chemical hazards are associated with fresh fish, shellfish and other aquatic invertebrates. The impact of climate change on food safety must also be considered, as it has been reported that the seafood industry will be disproportionately affected. Climate change has the potential of causing, enhancing or modifying the occurrence and intensity of some foodborne diseases.

Australia's seafood consumption has increased nearly twofold from 1988-1989 to 2017-2018, due to population growth and increasing household incomes. While the total seafood volume produced domestically has remained relatively constant over time, imports have been an important source to supply the increasing domestic demand for seafood. Seafood production and consumption data was sourced from the Australian Bureau of Agricultural and Resource Economics (ABARES) and the 27th Australian Total Diet Study (ATDS). Imported seafood is responsible for over 60% of total apparent seafood consumption in Australia. In NSW, by tonne, wild-caught seafood constitutes the main method of seafood production. Nationally, total seafood consumption from 2016-2017 to 2021-2022 was 13.7 ± 0.4 kg per person. Amongst the food categories surveyed in the 27th ATDS, the highest mean consumption amongst Australian consumers was reported for "*commercial crumbed, battered or coated fish (excluding salmon and tuna)*" (92 grams/day), followed by "*freshwater fish (no crumbs, batter or coating)" (54 grams/day)*, "*tuna*" (41 grams/day), "*salmon*" (31 grams/day) and "*saltwater fish (no crumbs, batter or coating)*" (23 grams/day).

The following overview summarises the update of the hazard characterisation, in relation to foodborne illness in NSW from 2016 to 2020 due to seafood and seafood products (Communicable Diseases Branch, 2017, 2018b, 2019a, 2019b, 2022):

- Seafood; alone or in a complex food(s), was identified as the responsible vehicle in 27 foodborne illness outbreaks from 2016 to 2020. Across this period, one to eight outbreaks were linked to seafood or seafood-related dishes annually.
- Where the agent responsible was identified (25/27), histamine poisoning (n = 17) was the cause of the largest number of outbreaks, followed by ciguatera toxin (n = 5), norovirus (n = 2) and *Listeria monocytogenes* (n = 1). Where there were multiple occurrences, tuna was the food vehicle responsible for the largest percentage of seafood related outbreaks (41%, 11/27), followed by Spanish mackerel (11%, 3/27), kingfish (7%, 2/27) and oysters (7%, 2/27). In all foodborne

incidents involving tuna and kingfish, histamine was the agent responsible. In all foodborne incidents involving Spanish mackerel, ciguatera toxin was the agent responsible. In all foodborne incidents involving oysters, norovirus was the agent responsible. Smoked salmon was the food vehicle responsible for an outbreak involving *L. monocytogenes*.

- Private residences were the most common outbreak setting and were implicated in 44% (12/27) of all seafood-related outbreaks. The remaining outbreaks were linked to restaurants (33%, 9/27), take-away (11%, 3/27), community settings (7%, 2/27) and a commercial caterer (4%, 1/27).

Of note, from January to March 2024, there was an outbreak of *Vibrio parahaemolyticus* linked to NSW oysters.

Several surveys have been conducted of Australian seafood, notably:

- The NSW Food Authority undertook a biotoxin survey of wild harvest shellfish in the marketplace during the 2015, 2016 and 2017 wild harvest seasons. Diarrhetic shellfish toxins (DSTs) were present in 40.6% (110/271) of sampled pipis (*Plebidonax deltoides*) (each sample was a homogenate of 15–20 individual shellfish), of which 2 samples were above the regulatory limit of 0.2 mg/kg okadaic acid (Farrell et al., 2018). In light of the results, the survey was extended to the 2018 and 2019 wild harvest seasons. During 2018-2019, DST was detected in 19% (13/70) of sampled pipis (maximum 0.18 mg/kg okadaic acid equivalent). During 2019-2020, DST was detected in 35% (10/29) of sampled pipis (0.054 - 0.54 mg/kg okadaic acid equivalent), of which three samples were above the regulatory limit. All three results above the regulatory limit for DSTs were from the same collection beach and from stock harvested within a two-day period. The beach was closed to harvest upon receipt of the high results.
- Infectious stage larvae of the zoonotic *Anisakis pegreffii* were reported in snapper (*Chrysophrys auratus*) purchased from the Sydney fish market (Hossen et al., 2021) and flathead (*Neoplatycephalus richardsoni*) purchased from a local seafood market in Melbourne (Asnoussi et al., 2017). Identification of zoonotic and/or potentially zoonotic larvae from a popular Australian table fish such as snapper, considered a suitable species for consuming raw, is of concern for human health.
- The Food Authority undertook a survey of *Vibrio parahaemolyticus* in NSW oysters at harvest. This survey ran from 2022-2024, with 725 samples collected from five NSW oyster growing areas. Modelling of the data undertaken by the University of Tasmania identified that a water temperature >20^{0}C was the primary factor determining the risk of elevated *V. parahaemolyticus* levels occurring at harvest (Hadley et al., 2025). Enhanced risk management advice has been provided to the oyster industry to assist in managing vibrio related food safety risks. Over 4,000 isolates were collected during the survey, representing the largest collection of *V. parahaemolyticus* isolates in Australia. Whole-genome sequencing (WGS) is being undertaken to determine genetic variability and elucidate the risk posed by *V. parahaemolyticus* strains currently present in NSW waters.

Analysis of consumer level recalls and imported foods which failed inspection and testing requirements at Australia's borders, provides some information on the foods and safety hazards that do or could enter the food supply from either domestic or imported food sources and pose a health risk.

National recalls and failures of imported food at border control:

- Between 13/6/2019 and 18/12/2024 there were 16 recalls of seafood and seafood products due to the presence of microbial contaminants (50%, 8/16), incorrect labelling (18.75%, 3/16), histamine (12.5%, 2/16), biotoxins (6.25%, 1/16), chemical contaminants (6.25%, 1/16) and a product with a low preservative content and the potential for microbial contamination (6.25%, 1/16). The eight recalls due to microbial contamination were due to *L. monocytogenes* (25%, 4/16), Hepatitis A virus (12.5%, 2/16), *Vibrio parahaemolyticus* (6.25%, 1/16) and an unspecified microbial contaminant (6.25%, 1/16). All recalls due to *L. monocytogenes* were associated with smoked whole fish or smoked fish pate. Both recalls due to the presence of histamine were associated with imported anchovies. Both recalls due to Hepatitis A virus were associated with imported salted or pickled clams. *Gymnodinium catenatum* was responsible for one recall of live mussels resulting in biotoxin contamination.

- Of all products that failed inspection and testing requirements at import between January 2018 to December 2022, seafood and seafood products were responsible for 22% (416/1,877) of all fail reports. In order of highest occurrence, the five most common reasons for fail reports were due to histamine (47.4%, 197/416), antibiotics (15.6%, 65/416), standard plate count (12.3%, 51/416), *Escherichia coli* (7.2%, 30/416) and *L. monocytogenes* (4.8%, 20/416).

The risk characterisation was hampered by the absence of information on the exposure pathway for each of the seafood outbreaks in NSW. Specifically, there was little or no information available on whether the seafood associated with each outbreak was purchased from a commercial premises or caught/harvested recreationally. In addition, there was little or no information on whether the seafood linked to each outbreak was produced domestically or imported. However, seafood served in hospitality settings in Australia will soon have mandatory Country of Origin Labelling (CoOL).

While the number of foodborne outbreaks associated with commercially produced seafood from NSW is unknown, there is a high rate of regulatory compliance across the sector. From 2017–2018 to 2021–2022, businesses licensed across the seafood supply chain achieved or exceeded the 95% compliance target set in the NSW Food Safety Strategy 2015–2021.

Histamine poisoning has remained the leading cause of seafood outbreaks in NSW (2005 – 2020). Histamine can be easily controlled and mitigated by applying basic good hygienic practices, such as rapidly chilling fish and maintaining appropriate time and temperature controls. Targeted educational initiatives could be warranted, if insight were gained on whether fishers are adopting high-risk practices that significantly increase the chances of histamine poisoning *for example, longlining and gillnetting, where death may occur many hours before the fish is removed from the water*.

Climate change will impact the migration and establishment of new species in NSW coastal waters. There were five ciguatera poisoning outbreaks, which accounted for the second highest number of seafood related outbreaks in NSW (2016 to 2020). This was an increase from the four ciguatera poisoning outbreaks which occurred across the previous eleven-year period (2005 to 2015). Efforts to raise awareness amongst the public, particularly in previously unaffected locations, could aid in the future management and mitigation of public health threats associated with ciguatera poisoning in NSW.

Globally, increased seawater temperatures have been associated with the spread and increased incidence of foodborne illness caused by ingesting raw seafood contaminated with pathogenic *Vibrio*. To support *Vibrio* risk management in NSW, data on the presence and prevalence of *V. parahaemolyticus* in oyster harvest areas has been modelled with high-resolution data from sensors and weather records. This has resulted in enhanced risk management advice for the oyster industry. Further work utilising WGS technologies will provide insight into the genetic variability and risk posed by *V. parahaemolyticus* strains currently present in NSW waters.

Various studies on the development and assessment of rapid methods for the detection of norovirus, pathogenic *Vibrio*, ciguatoxin and other marine biotoxins in seafood have been reported. Field methods to identify harmful algal bloom (HAB) species in seawater are also in various stages of development. Validated rapid methods could significantly aid the management and mitigation of public health threats if successfully implemented for end-product testing of seafood or during environmental monitoring, as part of either a routine surveillance program or as required on a risk assessment basis.

Finally, unlike other foods (for example, poultry), seafood is often consumed raw or prepared in ways that do not kill bacteria, parasites or inactivate viruses and toxins. The Australian population is aging and outside of facilities licensed to serve food to vulnerable persons, there will be an increasing proportion of vulnerable people in households consuming high-risk ready-to-eat (RTE) seafoods. It will therefore be important to continue raising awareness of the risks associated with certain consumption habits and types of food in risk groups.

Introduction

The Australian Seafood Industry

The Australian seafood industry is comprised of wild capture and aquaculture. The amount of seafood produced in Australia has steadily grown over the last decade, driven by the expansion of prawn and salmon aquaculture and by increased tuna catch (DAFF, 2023a). This growth differs from many other developed countries in that a significant proportion of Australian product, which could otherwise supply the domestic market, is sold to export markets. In general, Australian fisheries exports are dominated by high-value products such as rock lobster, premium tuna species and abalone.

Aquaculture production occurs throughout Australia, from the tropical north to the temperate south (DAFF, 2024b). The aquaculture industry is largely based in regional Australia. Aquaculture has overtaken commercial wild catch as Australia's leading provider of fish and seafood by value, reaching 51% of gross value of production (GVP) or $1.6 billion, compared to $1.58 billion for wild catch in 2019–2020 (Norwood, 2021). The volume of aquaculture production increased by 11% during 2019–2020, although commercial wild catch continued to provide the bulk of product by weight – 62% compared to aquaculture's 38%, or 179,261 tonnes compared to 106,139 tonnes (Norwood, 2021).

Australia is a net importer of seafood (DAFF, 2023a). It has been estimated that 62% of the edible seafood Australians consume (by weight) is imported, predominantly from Asia. New Zealand and Norway are also important sources of seafood imports to Australia. Imports largely consist of lower value products, such as canned fish and frozen fillets.

Recreational fishing has no commercial contribution in Australia and therefore, is not covered in the Scheme. However, it must be noted that recreational fishing makes a significant contribution to the Australian economy. Recreational fishing in Australia in 2018-2019 contributed an estimated $11.5 billion to Australia's gross domestic product (GDP) and supported over 100,000 full-time equivalent jobs in Australia (Moore et al., 2023).

NSW Food Regulation 2025

The NSW Food Regulation is the regulatory framework for the NSW *Food Act 2003*, which ensures food for sale in NSW is safe to eat. The NSW Food Regulation 2025 commenced on the 1st of September 2025 and remakes the previous 2015 Regulation with amendments (NSW Food Authority, 2025d). The NSW Food Authority has published a table which compares the main amendments to the 2015 Regulation, and the location of these amendments in the 2025 Regulation (NSW Food Authority, 2025b).

The NSW Food Regulation 2025 is important to the food industry as it sets minimum food safety requirements for food industry sectors that have been identified as higher risk, including the seafood industry. These businesses are subject to Food Safety Schemes because of the priority classification.

The Food Regulation 2025 lists definitions that apply in the *Seafood safety scheme*. The term "seafood" means any aquatic vertebrates or aquatic invertebrates intended for human consumption. The term "shellfish" means bivalve molluscs, including cockles, clams, mussels, oysters, pipis and scallops.

In the *Seafood safety scheme*, "seafood business" means a business involving the handling of seafood, including (but not limited to) the carrying on of any of the following activities:

- cultivating, harvesting or collecting shellfish,

- depuration or wet storage of shellfish,
- cultivating spat,
- processing seafood, including canning, cooking, filleting, gilling and gutting, high pressure processing, shucking, skinning, smoking and preserving,
- packaging seafood,
- storing seafood,
- transporting seafood, except transporting seafood from retail premises to the consumer or in a vehicle from which the seafood will be sold by retail,
- wholesaling seafood.

For the purposes of the *Seafood safety scheme*, a “seafood business”:

- does not include the act of taking or catching fin fish, crustacea or cephalopods but includes any handling of such seafood immediately after it is taken or caught, whether the handling occurs on board a vessel or otherwise, and
- does not include the handling of live lobsters, crayfish, abalone, crabs or sea urchins, and
- does not include the retail sale of seafood.

It is important to emphasise that seafood safety in the retail sector is not covered by the *Seafood safety scheme*. This is managed by local councils under the food safety standards (3.2.1, 3.2.2, 3.2.2A and 3.2.3) of the Australia New Zealand Food Standards Code (the Code).

Licensed seafood businesses must comply with the sampling and analysis provisions of the *Seafood food safety scheme* of the Food Regulation 2025. The NSW Food Authority has prepared the NSW Food Safety Schemes Manual to specify certain requirements for the Food Safety Schemes under the Food Regulation 2025 (NSW Food Authority, 2025e). The requirements referred to in the Food Safety Schemes Manual are mandatory. The Food Safety Schemes Manual specifies the sampling and analysis requirements that seafood businesses must comply with in relation to microbiological testing. In brief, the Food Safety Schemes Manual requires that:

- all seafood processors are to test non-reticulated water used for *Escherichia coli*
- processors of ready-to-eat (RTE) seafood test opened and packaged oysters for *E. coli*
- processors of RTE sliced or whole packaged cooked and/or smoked seafood test for *Listeria monocytogenes*

The NSW Food Authority licenses around 240 shellfish businesses, which include oyster farmers and shellfish wild harvesters (NSW Food Authority, 2024l). Shellfish businesses should refer to the NSW Shellfish Industry Manual for testing requirements for harvested product and environmental testing (NSW Food Authority, 2018b).

Commonwealth regulation of shellfish consists of the Code, export controls and the Australian Shellfish Quality Assurance Program (ASQAP) – which is a shellfish program operation manual. ASQAP forms the basis upon which both the administration of state- and territory-managed shellfish programs and the implementation of producer-based operational procedures are audited. The NSW Shellfish Program was established by the Food Regulation 2015 under the *Seafood food safety scheme* (NSW Food Authority, 2024l). The NSW Food Authority employs a team of professional staff who manage the NSW Shellfish Program, which is delivered under the framework provided by the ASQAP manual. Shellfish regulated under this program include farm-produced oysters and mussels, and wild harvested pipis, cockles and clams.

In NSW the Local Shellfish Program in each harvesting area is responsible for developing and implementing an effective *Marine Biotoxin Management Plan* (MBMP). Sampling marine phytoplankton and biotoxins in accordance with the requirements set out in this plan is mandatory under the legislation. This monitoring is required to manage the potential health risks posed to consumers by toxic algae. During the open harvest status, fortnightly phytoplankton (seawater) and monthly biotoxin (shellfish flesh) sampling is the minimum requirement for NSW shellfish aquaculture areas. All local shellfish programs are subject to the requirements in the NSW MBMP, however, the location and the number of sample sites in each harvest area represents the specific regional conditions. Testing of the samples is carried out in NATA accredited laboratories. Reports on fortnightly algal sampling and monthly biotoxin results are assessed within two hours of receipt. In the case that a ‘phytoplankton action limit’ (PAL) has been exceeded or a positive biotoxin test result occurs, the relevant laboratories provide verbal notification to NSW Food Authority staff who action the report immediately. The frequency of monitoring is increased to weekly following detection of phytoplankton cell concentrations above the specified trigger levels and/or reports of a positive biotoxin test result. If a PAL exceedance from seawater samples and/or a positive biotoxin result from shellfish flesh above the regulatory limit are reported, the harvest area is closed pending the outcome of subsequent testing. The status of commercial shellfish harvest aquaculture areas in NSW is available on the NSW Food Authority website (NSW Food Authority, 2025f). If a toxin event occurs in a commercial harvest area that is known to be used for recreational harvest then the NSW Food Authority will immediately contact the NSW Department of Primary Industries and Regional Development (DPIRD) (Fisheries) who have the regulatory responsibility to prohibit recreational harvest and decide appropriate sampling strategies for recreational species.

The seafood sector in NSW

The NSW Food Authority licenses around 1,900 businesses in the seafood sector (NSW Food Authority, 2024i).

This includes 150 seafood processing businesses and more than 1,000 businesses that handle wild caught seafood, cold food stores and transport vehicles.

Businesses that need to hold a Food Authority licence include seafood processing businesses and seafood transport vehicles involved in:

- handling fin fish, crustacea or cephalopods after they are taken or caught, whether the handling occurs on board a vessel or otherwise
- processing seafood, including canning, cooking, filleting, gilling and gutting, high pressure processing, shucking, skinning, smoking and preserving
- packaging seafood
- storing
- wholesale
- transporting, except from retail premises to the consumer or in a vehicle from which the seafood will be sold by retail.

Food businesses in this industry need to meet food safety and labelling requirements specific to the type of business:

- seafood processing businesses
- seafood transport vehicles.

Legislation, standards and industry guidelines applicable to seafood businesses

The Australia and New Zealand food regulatory system involves the Australian Government, New Zealand and Australian states and territories. In this system food standards are developed under the Code, which is administered by Food Standards Australia New Zealand (FSANZ) and enforced by state and territory governments. The standards in the Code are legislative instruments under the Legislation Act 2003. The NSW Food Authority enforces the Food Act 2003 (NSW) and associated regulations within NSW in respect of all food for sale. The type of seafood business will determine the Standards which apply.

The following provisions of the Code apply to a food business that is involved in seafood processing (NSW Food Authority, 2024j):

- Chapter 1, Part 1.2 - Labelling and other Information Requirements
- Standard 3.2.1 Food Safety Programs
- Standard 3.2.2, Division 4 - Health and Hygiene
- Standard 3.2.3 - Food Premises and Equipment
- Standard 4.2.1 - Primary Production and Processing Standard for Seafood

In addition, seafood processing businesses must comply with the relevant mandatory requirements of the NSW Food Safety Schemes Manual and if exporting, Department of Agriculture Fisheries and Forestry (DAFF) export certification or permit.

The following provisions of the Code apply to operators in the seafood transport industry (NSW Food Authority, 2024k):

- Chapter 1, Part 1.2 - Labelling and other Information Requirements
- Standard 3.2.2, Division 4 - Health and Hygiene
- Standard 3.2.3 - Food Premises and Equipment
- Standard 4.2.1 - Primary Production and Processing Standard for Seafood

Seafood may be contaminated by microorganisms, chemicals or foreign material that is present in the water or, may occur post-harvest (for example, during transport) or due to poor personal hygiene or ill health of seafood handlers.

Microbiological criteria that are applied to determine the safety of a food lot (food safety criteria) are included in the Code. Standard 1.6.1 of the Code lists the maximum permissible levels of food-borne microorganisms that pose a risk to human health in nominated foods or classes of foods, for example *Salmonella* in raw crustaceans and *E. coli* in some types of bivalve molluscs.

Other microbiological criteria (process hygiene criteria) can be developed and applied at various stages throughout the food chain to indicate whether the food safety controls in place are working as intended. The *Compendium of Microbiological Criteria for Food* is a compilation of process hygiene criteria that have been established for specific food commodities and microbiological guideline criteria used for RTE foods (FSANZ, 2025). For example, guideline criteria have been included for *V. parahaemolyticus* in RTE seafood.

Standard 1.4.1 contains maximum levels of specified metal and non-metal contaminants in nominated foods. Maximum levels are included for arsenic (crustacea, fish and molluscs), cadmium (molluscs), lead (fish and molluscs), mercury (fish, crustacea and molluscs) and tin (all canned foods). Maximum levels for bivalves are also included for Amnesic (Domoic acid equivalent), Diarrhetic (Okadaic acid equivalent), Neurotoxic and Paralytic (Saxitoxin dihydrochloride equivalent) shellfish poisons. A maximum level of 200 mg/kg of histamine is specified for all fish and fish products. As a general principle, regardless of whether a maximum level exists, the levels of contaminants should be kept as low as reasonably achievable.

Updating the 2017 Risk Assessment

This Risk Assessment was produced following a literature review for issues related to seafood and seafood products that have impacted food safety. Information sources included:

- foodborne illness reports and recall data in Australia attributed to seafood and seafood products
- international issues arising from human illness or perceived hazards linked with seafood and seafood products
- border detections for seafood and seafood products
- risk assessments of seafood and seafood products
- emerging issues in the pre-harvest to consumer continuum for seafood and seafood products relevant to health risk
- research findings related to hazards in seafood and seafood product production and processing
- baseline surveys of microbiological and chemical hazards in seafood and seafood products
- other relevant sources if identified during the above evaluations.

Risk Assessment

Hazard identification

Consumption of seafood and seafood products can be associated with a variety of human health hazards. Aquatic animals have a particularly intricate relationship with their environment and are prone to exposure and accumulation of a diverse range of hazards present in water, sediments and their food (Stentiford et al., 2022). Identified sources of seafood contamination have included natural and anthropogenic sources.

The FAO and WHO (2020) *Code of Practice for Fish and Fishery Products* lists possible biological, chemical and physical hazards associated with fresh fish, shellfish and other aquatic invertebrates. These hazards are discussed in the following section, with a focus on those hazards that are relevant to seafood consumed within Australia.

All seafood can be susceptible to surface or tissue contamination originating from the marine environment (Iwamoto et al., 2010). However, some seafood commodities are inherently riskier than others owing to many factors, including the nature of the environment from which they come, their mode of feeding, the season during which they are harvested, and how they are prepared and served (Iwamoto et al., 2010). This risk assessment provides information on the nature of the hazards associated with wild catch, aquaculture and imported seafood commodities.

The previous Risk Assessment of the Seafood Safety Scheme cited studies published between 1999 and 2002, that identified and ranked food safety hazards in Australian seafood (Ross & Sanderson, 2000; Ross et al., 2002; Sumner, 2002; Walsh & Grant, 1999). At the time of writing, no new or updated literature was identified which ranked food safety hazards in Australian seafood. Table 1 has been reproduced from Hussain et al. (2017) and provides a summary of NSW foodborne illness outbreaks attributed to seafood between 2005 and 2015 (Hussain et al., 2017). Where the hazard was identified, histamine accounted for the largest number of outbreaks and hospitalisations in NSW across all seafood commodities. *Salmonella* non-typhi was associated with the second largest number of seafood associated outbreaks and the highest number of cases overall. All *Salmonella* non-typhi outbreaks were attributed to finfish, apart from a single outbreak attributed to crustaceans. Ciguatoxin and norovirus respectively accounted for the third and fourth highest number of seafood associated outbreaks, with ciguatoxin responsible for the second highest number of hospitalisations overall.

Table 1: Summary of NSW foodborne illness outbreaks attributed to seafood between 2005 and 2015[1]

	Hazard	Outbreaks	Cases	Hospitalisations
Seafood total	Ciguatoxin	4	21	14
	Histamine	11	35	19
	Salmonella non-typhi[2]	9	41	9
	Norovirus	3	22	0
	Other (bacterial)	2	35	2
	Unknown	14	154	1
	Total	**43**	**308**	**45**
Finfish	Ciguatoxin	4	21	14
	Histamine	11	35	19
	Salmonella non-typhi[2]	8	37	7
	Other (bacterial)	2	35	2
	Unknown	3	10	1
	Sub-total	28	138	43
Shellfish	Norovirus	3	22	0
	Unknown	7	43	0
	Sub-total	10	65	0
Crustacean total	*Salmonella* non-typhi[2]	1	4	2
	Unknown	4	101	0
	Sub-total	5	105	2

[1] *Data from Hussain et al. (2017).*

[2] *Cross-contamination of seafood from egg when used as an ingredient. Data source: NSW OzFoodNet (a health network to enhance the surveillance of foodborne diseases in Australia).*

Commercial fishing (wild catch)

As a general principle, the risk of contamination of seafood products by chemical and biological agents is greater in freshwater, coastal ecosystems and aquaculture when compared to the open seas.

Freshwater finfish species are found in rivers and in freshwater lakes, ponds and dams. Trout and native fish such as Murray cod are present in inland waterways in NSW. In commercial terms, freshwater fish represent a very minor segment of total fisheries products in NSW. In the previous Seafood Risk Assessment it was reported that freshwater fish comprised less than 0.5% of the total commercial wild catch in NSW (NSW Food Authority, 2017b). The current literature review did not reveal an updated value on this figure. Major hazards attributed to freshwater fish include pathogenic bacteria, environmental contaminants or chemical contaminants from human activity. Considering the likely low volume of wild catch freshwater finfish from NSW inland waters and consumption, it is not regarded as a food safety threat. However, it is still important to keep recreational fishers and the public aware of the health of inland waterways and emergence of any potential contamination issue.

Recreational fishing (wild catch)

One in five adult Australians participate in recreational fishing each year (Moore et al., 2023). While most recreational fishers fish less than five days a year, a small proportion fish more than 52 days a year.

In a survey of households in which at least one resident held a recreational fishing license and had been fishing in NSW in 2021-2022, saltwater fishing represented 70% of the total fishing effort and fishing in freshwater accounting for the remaining 30% (Murphy et al., 2023). The majority of saltwater fishing occurred in estuaries (71%) and the remainder in ocean waters (29%). For freshwater fishing, the majority of effort occurred in rivers (64%), with the remainder occurring in lakes and dams (36%). Survey participants recorded the capture of a diverse range of finfish, sharks, rays, crustaceans, molluscs and other taxa, with 123 species and species groupings reported to be caught during 2021-2022.

The NSW Food Authority has produced guidance for those who catch or collect shellfish, crustacea and finfish recreationally (NSW Food Authority, 2024h).

Saltwater finfish hazards

Finfish may contain pathogenic bacteria and parasites. These microorganisms may be naturally present in the marine environment or part of the natural microflora of the fish. Fish may also become contaminated prior to harvest due to poor water quality, or by food handlers or the environment during processing. Poor water quality may occur due to contamination of the marine environment by sewage from effluent from wastewater treatment plants, combined sewer/stormwater overflows, malfunctioning septic tanks or recreational and commercial fishing vessels.

Hazards may be for specific fish species and finished product types (FDA, 2022b).

Pathogenic bacteria and parasites are killed when seafood is adequately cooked. With any seafood eaten raw, for example sashimi, it is important that guidelines for catching, handling and preparation are followed to prevent contamination. Skills and knowledge of staff in understanding the potential for and preventing contamination of raw seafood, for example preparation methods, are also essential.

Cold-smoked fish is processed at temperatures that are too low to ensure freedom from pathogens or parasites. *L. monocytogenes* may be present on the incoming product, or the product may become contaminated post-harvest in the processing facility. *L. monocytogenes* is relatively salt tolerant and could grow to significant numbers at refrigeration temperatures during prolonged storage. Controls must be in place for cold-smoked fish to prevent growth, eliminate or reduce *L. monocytogenes* to an acceptable level.

Marine toxins such as ciguatoxin may be a significant hazard, particularly in tropical reef fish. Ciguatoxins are temperature-stable, so they are not destroyed by cooking or by freezing.

Bacteria that are associated with histamine development are commonly present in the saltwater environment. They naturally exist on the gills, on external surfaces and in the gut of live saltwater fish. Histamine is a hazard in certain species of fish and high levels of histamine in the fish muscle may result when products are not immediately chilled after catching and retained in a chilled state. Histamine is not destroyed by cooking or freezing.

Shellfish hazards

Shellfish include univalve molluscs (conch, abalone, whelks) and bivalve molluscs (clams, oysters, mussels, scallop, pipi). Shellfish possess unique ecological and physiological characteristics. Therefore, the nature of hazards associated with this kind of seafood is different from finfish.

Bivalve shellfish which feed by filtering large volumes of water, can accumulate and concentrate in their digestive glands any pathogenic bacteria, viruses, toxic algae or pollution (for example, sewage runoff or industrial waste outfalls) present in harvest waters. Several bivalve molluscs are higher risk because they are filter feeders and are eaten with viscera and other organs intact. This includes oysters, clams, scallops, pipis and mussels. Additionally, some of these shellfish are commonly consumed raw or only lightly cooked.

Bacterial pathogens introduced into shellfish growing areas through pollution can multiply quickly, particularly at higher temperatures, potentially rendering shellfish unsafe. Some pathogenic bacteria, such as *Vibrio* species, naturally occur in coastal and estuarine environments and populations can depend on water depth and tidal levels. They are particularly prevalent in warm tropical waters and can be found in temperate zones during summer months.

In addition to bacterial pathogens, shellfish harvested from inshore waters that are contaminated by sewage may harbour viruses that are pathogenic to humans. These viruses are highly resistant and can retain infectivity under severe environmental conditions. Shellfish contamination with gastroenteritis viruses such as norovirus is recognised as a significant public health risk worldwide. Of particular concern, norovirus is selectively accumulated and retained within the digestive tissues of oysters, persisting long after bacterial indicators of sewage contamination are no longer detectable.

Some species of dinoflagellates and diatoms, both microalgae, produce toxins that can be harmful to humans. Through the act of feeding, bivalve molluscs such as oysters, mussels and clams can concentrate these toxins. If enough toxin is accumulated and the shellfish are subsequently consumed by humans, illness can result. Univalve molluscs, such as abalone, can also accumulate marine biotoxins (McLeod et al., 2017).

Crustacean hazards

Crustaceans are invertebrates with segmented bodies protected by chitinous shells including shrimp, lobster, crayfish, crab and krill.

Many naturally occurring bacteria, some potentially pathogenic, can be associated with crustaceans (Anantanawat et al., 2013). This includes pathogenic bacteria such as *Vibrio* spp. and *Cl. botulinum*, which may form part of the natural microbiota of crustaceans (de Souza Valente & Wan, 2021; Farag et al., 2023).

Toxic metals can be naturally occurring in the marine environment, or they can originate from polluting industries. The contamination pathway is most likely to be via the consumption of other marine animals and plants, which can lead to a direct accumulation of toxic metals. The critical metals to consider for crustaceans are arsenic (inorganic) and mercury (Anantanawat et al., 2013). In Australia, there are regulatory limits in the Code for arsenic (inorganic) and mercury in crustaceans. Prawns caught in certain parts of Australian waters have been documented to contain elevated levels of cadmium on some occasions (Dobson et al., 2014). Toxic metals, such as cadmium, also accumulate preferentially in the crustacean midintestinal gland (hepatopancreas), so processes and/or advisories to eliminate or reduce consumption of crab, lobster or prawn "mustard" are recommended (SafeFish, 2023b). While Australia does not have limits for cadmium in crustaceans, some overseas countries have requirements.

Similar to bivalve shellfish, crustaceans such as lobsters and crabs have been found to accumulate a high level of marine biotoxins (Anantanawat et al., 2013; McLeod et al., 2018).

Cephalopod and gastropod hazards

Squid, octopus and cuttlefish are the most consumed cephalopods across the world and across different food cultures (Mouritsen & Styrbæk, 2018). Although their consumption is attaining popularity in many countries, they remain culturally linked mostly to southern European countries (Portugal, Spain, Italy and Greece), some Latin American countries (Mexico, Argentina and Uruguay) and several Pacific and Asian countries, particularly Japan (Gleadall et al., 2023).

Cephalopods are mostly caught for human consumption by wild catch. As with other wild caught species, contamination of cephalopod tissues depends on taxonomy, life cycle, feeding habits and both natural and anthropogenic factors affecting the characteristics of the marine environment (Varrà et al., 2023).

Cephalopods may be a host for *Anisakis* spp. (Fiorenza et al., 2020). However, cephalopods are seldom eaten unprepared (i.e. raw) because the high amount of connective tissue leads to unpalatable conditions (i.e. tough and chewy). Heat treatment is the most common method of tenderising cephalopods, by boiling in water or sous vide, baking, frying or grilling.

Compared to other fishery products, cephalopods have been reported to bioaccumulate and bioconcentrate metals into their tissues at higher levels, even when the environmental concentrations are low (Penicaud et al., 2017). In this way, cephalopods may transfer these metals along the food chain. Varrà et al. (2023) reported that flying squid from the Italian northern Adriatic Sea had significantly higher concentrations of cadmium and mercury, leading to dietary exposure levels above the established toxicological reference values in cases of chronic consumption by children and adolescents (Varrà et al., 2023). Similarly, Sangiuliano et al. (2017) reported that common squid samples purchased in Spain contained cadmium concentrations that could lead to a health risk after prolonged consumption (Sangiuliano et al., 2017).

Gastropods include marine limpets, snails and slugs. Human poisonings from gastropods mostly occur in Asian countries such as Taiwan, Japan and China, where consumption is popular.

Tetrodotoxin (TTX) has been reported in eleven marine gastropod genera from five countries (Taiwan, Japan, China, Vietnam and Portugal), with the first detection occurring in 1980 (Biessy et al., 2019). TTX poisoning from gastropod ingestions have occurred in every decade since the 1980's. There were nine food poisoning incidents in Taiwan between 1994 to 2006, which resulted in three deaths, mainly from eating gastropods of the Nassariidae (mud snails) family. There is currently no regulation or monitoring of TTX in edible marine gastropods. The European Food Safety Authority (EFSA) has recommended that further studies on the sources and critical factors leading to the accumulation of TTX in marine gastropods (and bivalves) are needed (EFSA Panel on Contaminants in the Food Chain et al., 2017).

There have been several reports of paralytic shellfish poisoning (PSP) associated with the consumption of marine gastropods (Choi et al., 2006; Jen et al., 2014). These incidents have included the consumption of contaminated snails of *Nassarius* spp. in China (1979) and Japan (2002 and 2004). The presence of PST has since been reported in additional gastropod species worldwide, including in abalone in Australia (Homan et al., 2010; McLeod et al., 2017; Seger et al., 2020), *Concholepas concholepas* in Chile (Seguel et al., 2023) and *Natica* spp. and *Oliva* spp. in Vietnam (Jen et al., 2014).

The concentrations of trace metals in marine gastropods have been determined in a variety of contexts, including food safety (Skinner et al., 2004). In a recent Australian study, the heavy metal content of wild-harvested Australian abalone (*Haliotis* spp.) viscera was examined (Chung et al., 2024). Abalone predominantly feed on macroalgae, which are prone to accumulate heavy metals. Variation was revealed in the heavy metal content across the eleven abalone viscera samples tested.

Whilst mercury and lead levels were within the limits of all listed legislation, most of the other heavy metal pollutants, including arsenic, cadmium, copper, chromium, nickel were detected at levels exceeding domestic and/or international regulated limits. Chung et al. (2024) concluded that this result aligns with previous investigations on heavy metals in gastropods reporting significant bioaccumulation in the internal organs, suggesting unsatisfactory levels for human consumption. Abalone viscera is a by-product produced during commercial food processing of abalone and is generally discarded as waste.

Overall, the risk associated with cephalopods and gastropods is low or very low due to the very small amount consumed and cooking prior to serving. There is little information in the published literature on the food safety hazards related to these seafood products in NSW or Australia.

Commercial aquaculture

In NSW, aquaculture occurs in fresh, estuarine and marine waters (NSW DPI, 2024). Aquaculture permits are issued for the different types of aquaculture, with some farms having more than one permit (Table 2). Aquaculture makes a significant contribution to the NSW economy contributing $425.2 million to NSW economic output in 2021/22 (BDO EconSearch, 2023).

By economic value, oyster production is the main aquaculture activity in NSW. Oyster farms within the estuaries of the state utilise a range of growing infrastructure including racks, longlines, rafts, trays and in baskets.

In intensive farming systems, the species being grown is given specially prepared food. In extensive farming systems, the species grown feeds naturally from the surrounding environment.

Land based farms occur across the state and are generally divided into pond based or tank based recirculating aquaculture systems. Pond based aquaculture may be intensive or extensive farming. The location of aquaculture farms is dictated primarily by the environmental constraints of the species being grown. Some species such as silver perch and yabbies are grown widely across the state, while mussels are grown in Jervis and Twofold bays, trout on the southern and northern slopes, and Murray cod in the Riverina.

Hatcheries that produce fingerlings for aquaculture farms, stocking of farm dams and aquarium fish are located throughout NSW.

Table 2: Aquaculture in NSW

Permit class	Number of permits	Main species grown
Extensive water based	240	Sydney rock oyster
Extensive land based	13	Yabby
Fishout (fishing business)	19	Trout, silver perch
Hatchery	40	Numerous species
Intensive land based	78	Silver perch, barramundi, trout

Data from Aquaculture in New South Wales – Facts & Figures 2024 (NSW DPI, 2024).

Aquaculture products present broadly the same hazards that are present in corresponding varieties caught in the wild (FAO and WHO, 2020a). Food safety hazards will depend on the system of culture, management practices and environment. High stocking densities, compared with the natural situation, might increase the risk of cross-infection of pathogens within a population of fish and might lead to deterioration in water quality. On the other hand, farmed fish can also present a lower risk of harm. In systems where the fish receive formulated feeds, the risks associated with transmission of hazards through the food consumed by the fish could be reduced. Potential hazards that are specific to aquaculture products include residues of veterinary drugs in excess of recommended guidelines and other chemicals used in aquaculture production. Contamination of faecal origin can also occur where the facilities are close to human habitation or animal husbandry. Raising fish in cages in the marine environment poses few hazards and low risks. In closed recirculation systems, hazards are even further reduced. In such systems, the water is constantly refreshed and reused and water quality is controlled within safe measures.

Imported seafood

Data published by the ABARES estimates that over 60% of seafood consumed in Australia is imported (Tuynman et al., 2023). In NSW alone, approximately 87% of purchased seafood is reported to be imported (NSW DPI, 2024).

Imported food must meet Australian food standards as is the case with food produced domestically.

The Department of Agriculture, Fisheries and Forestry (DAFF) administers a risk-based border inspection program - the Imported Food Inspection Scheme - to ensure that food importers only import food that is safe and compliant with the Code.

As is the case with all countries, it is not practical to inspect every food item imported into Australia. FSANZ provides DAFF with advice on which foods pose a medium or high risk to public health and safety (FSANZ, 2023a). This advice helps DAFF determine which foods are regularly inspected.

FSANZ has recently completed several imported food risk statements (FSANZ, 2023a). Those imported seafood products which have been categorised as posing a medium to high risk after the time of publication of the previous Risk Assessment of the Seafood Safety Scheme (April 2017), are summarised in Table 3. Imported seafood and seafood products that failed inspection and testing requirements from 2018 to 2022, are discussed within the Hazard Characterisation section of this risk assessment.

Table 3: Imported seafood products recently assessed to pose a medium or high risk to public health and safety

Food	Microorganism / analyte / contaminant	Date of assessment (latest update)
Bivalve molluscs	Hepatitis A virus	July 2017
	Norovirus	July 2017
	Domoic acid	June 2021
	Saxitoxin-group toxins	June 2021
Crustaceans – RTE cooked crustaceans that can support growth of *L. monocytogenes*	*L. monocytogenes*	March 2020
Pufferfish (fugu) – whole or portions, fresh, frozen, dried or canned	Tetrodotoxin	June 2022

Information sourced from FSANZ (2023).

Biological hazards

The FAO and WHO (2020) *Code of Practice for Fish and Fishery Products* lists possible biological hazards associated with fresh fish, shellfish and other aquatic invertebrates (FAO and WHO, 2020a). These biological hazards are summarised in Table 4 and include pathogenic bacteria, viruses and parasites. The following section focuses on those hazards that have been implicated in food related illnesses resulting from seafood consumption in Australia.

Table 4: Possible biological hazards associated with fresh fish, shellfish and other aquatic invertebrates[1]

Biological hazard	Source	Organisms of most significance
Pathogenic bacteria	Naturally present in the aquatic environment	*Aeromonas hydrophila* *Clostridium botulinum* *Listeria monocytogenes* *Vibrio parahaemolyticus*, *V. cholerae* and *V. vulnificus*
	Occasionally isolated from fish	*Edwardsiella tarda* *Plesiomonas shigelloides* *Staphylococcus aureus* *Yersinia enterocolitica*
	Environmental contaminant	*Escherichia coli* *Salmonella* spp. *Shigella* spp.
Viruses	Environmental contaminant	*Astroviruses* *Caliciviruses* *Hepatitis A virus* *Norovirus*
Parasites	Occur worldwide and fresh and marine fish are intermediate hosts	Cestodes[2] – *Dibothriocephalus latus*
	Occur worldwide and some species of marine fish are intermediate hosts	Nematodes[3] - *Anisakis* spp. *Capillaria* spp. *Gnathostoma* spp. *Pseudoteranova* spp.
	A major public health problem endemic to approximately 20 countries around the world	Trematodes[4] – *Clonorchis* and *Opisthorchis* (liver flukes) *Heterophyes* and *Echinochasmus* (intestinal flukes) *Paragonimus* (lung flukes)

[1] *Information sourced from FAO and WHO (2020a).*

[2] *Cestodes have a ribbon-like morphology and belong to phylum Platyhelminthes (flatworms) and class Cestoda.*

[3] *Nematodes are nonsegmented roundworms that belong to the phylum Nematoda.*

[4] *Trematodes, also known as flukes, belong to the phylum Platyhelminthes (flatworms) and class Trematoda.*

Pathogenic bacteria

Table 4 lists disease-causing bacteria that may be naturally present in the aquatic environment or as part of the normal microflora of fish, or that may enter seafood as environmental contaminants via cross contamination by human or animal sources.

Bacteria that are introduced through environmental contamination by domestic and/or industrial wastes, include members of the Enterobacteriaceae such as *Salmonella* spp., *Shigella* spp. and *E. coli.* These members of the Enterobacteriaceae family are major bacterial foodborne pathogens. The infectious diseases they cause are well defined and typically characterised by diarrhoea and other gastrointestinal syndromes. Further information on each of these bacterial agents can be accessed from the NSW Health website (NSW Health, 2025a) and the USA Food and Drug Administration (FDA) website (FDA, 2022a).

Indigenous pathogenic bacteria, when present on fresh fish, are usually found in fairly low numbers, and food safety hazards are insignificant where products are adequately cooked prior to consumption (FAO and WHO, 2020a).

Fish gills and intestines can contain high numbers of *Clostridium botulinum* spores, as *Cl. botulinum* is often found in freshwater and marine environments. If environmental conditions are optimal, these spores can germinate and grow, producing a potent neurotoxin. To reduce the risk of toxin production, proper evisceration is important, as it removes the spores of *Cl. botulinum*. The evisceration process must ensure the complete removal of all internal organs in the body without cutting or puncturing them. Botulism can result from eating food that has been contaminated with the toxin (foodborne botulism) or ingesting food that contains the bacteria that produce the toxin (intestinal botulism). Botulism is a rare but serious illness that causes paralysis (NSW Health, 2018a). Children under the age of 12 months are most at risk of infection. The symptoms of infant botulism include constipation, loss of appetite, weak suck, weak cry and muscle weakness including poor head control. Early symptoms of foodborne botulism include weakness, marked fatigue and vertigo usually followed by blurred vision, dry mouth and difficulty swallowing. Nausea and vomiting may also occur. These symptoms may progress to paralysis of the arm muscles and continue down the body to the trunk and legs. Paralysis of breathing muscles can be fatal. Most cases recover if diagnosed and treated early. In foodborne botulism, symptoms may begin from a few hours to several days after eating the contaminated food.

Listeria monocytogenes is ubiquitous and occurs naturally in the terrestrial environment, as well as freshwater and saltwater environments. *L. monocytogenes* is a foodborne pathogen of particular concern for at-risk people within the community including pregnant women, infants, the elderly and adults with a lowered immunity (NSW Health, 2018b). In these people, listeriosis can result in severe illnesses, with high mortality rates. Infection during pregnancy can lead to miscarriage, stillbirth and infection of the newborn. The incubation period (between infection and symptoms) can vary from three to 70 days but on average is about three weeks. Symptoms of listeriosis include fever, muscle aches, and sometimes gastrointestinal symptoms such as nausea and diarrhoea. In the more severe form, symptoms also include collapse and shock. If infection spreads to the central nervous system, symptoms such as headache, stiff neck, confusion, loss of balance, convulsions and coma can occur. About a third of these patients may die.

Foodborne illness caused by *Vibrio* species are almost exclusively associated with seafood and most illnesses are linked to raw oyster consumption (DePaola, 2019). *Vibrio* species are naturally occurring in the estuarine and marine environments and are routinely detected in low concentrations in raw seafood, most often with no implications for human health (Harlock et al., 2022). Environmental factors can lead to increased amounts of *Vibrio* species in the water column and changes in the prevalence of pathogenic strains. *Vibrio* are usually found in warm coastal waters, especially during the summer months. Certain strains of *V. parahaemolyticus* can be pathogenic and outbreaks in Australia over summer months due to this species have been increasing, often associated with marine heatwaves (Harlock et al., 2022). *V. parahaemolyticus* became a nationally notifiable disease within Australia in January 2025 (DHAC, 2025) and illness reports are therefore likely to increase. Gastroenteritis caused by *Vibrio* species include the symptoms of watery diarrhea, stomach cramps, vomiting, fever and chills (NSW Health, 2025b). Symptoms usually appear within 12-24 hours after exposure to the bacteria and can last 1-7 days. Most people will recover on their own, however, severe illness may result in hospitalisation.

Viruses

All of the seafood-borne viruses causing illness are transmitted by the faecal–oral cycle. Enteric viruses can contaminate seafood either through contamination at source, principally through sewage pollution of the marine environment, or in association with seafood processing through inadequate hygiene practices by human handlers or exposure to unsanitary equipment etc.

Enteric viruses that have been implicated in seafood-associated illness are the hepatitis A virus, caliciviruses, astroviruses and norovirus. However, the viruses which are widely associated with seafood illness outbreaks are hepatitis A virus and norovirus.

Hepatitis A is a viral infection of the liver (NSW Health, 2022). Symptoms of hepatitis A include feeling unwell, tiredness, fever, nausea, lack of appetite, abdominal discomfort, joint pain (occasionally), dark urine, pale stools and jaundice. Jaundice, dark urine and pale stools do not occur in all cases. Symptoms of hepatitis usually show about four weeks after contact with the virus. Sometimes symptoms will appear between two and seven weeks. Illness is usually mild and lasts one to three weeks. Almost all people recover completely. Some people, particularly people with chronic liver disease, may experience more severe symptoms. Small children who become infected usually have no symptoms. Hepatitis A does not cause long-term liver disease and deaths caused by hepatitis A are very rare. Occasionally people are hospitalised for the disease and can have relapsing symptoms after the disease has seemed to clear. Hepatitis A is not common in Australia, most people acquire their infection when travelling overseas.

Norovirus is highly infectious and a leading cause of gastroenteritis in Australia and worldwide. Gastroenteritis caused by norovirus usually starts suddenly and causes vomiting and watery diarrhoea (NSW Health, 2024a). Vomiting can be frequent and is more common among children. People may also have nausea, fever, stomach pains, headache and muscle aches. People, particularly young children and the elderly, can become dehydrated. Symptoms usually begin between 24 and 48 hours after exposure to the virus and can last for one or two days.

Parasites

A wide range of parasites transmissible to humans can be found in seafood products. Human fishery product-borne parasitic diseases are caused by cestodes, trematodes and nematodes and are caused by infection following ingestion of viable parasites, or as allergic (hypersensitivity) reactions against parasite antigens. For allergy, the only parasites in fishery products implicated are nematodes of the family Anisakidae, in which sensitisation occurs via infection by live larvae (EFSA Panel on Biological Hazards (BIOHAZ), 2010).

Some parasites have a global distribution, with human infection observed on a regular basis worldwide. In Australia, there have only been two recorded parasitic outbreaks associated with seafood consumption. A husband and wife were infected with the nematode parasite *Gnathostoma* after eating a fresh water fish in remote northern Western Australia (Jeremiah et al., 2011). The fish had been pan-fried whole over a campfire, but the duration and thoroughness of cooking is unclear. A woman of Tongan descent was infected with the nematode parasite *Contracaecum* after eating raw, locally caught South Australian mackerel (Shamsi & Butcher, 2011).

The term 'anisakiosis (anisakidosis)' or 'anisakiasis' collectively defines accidental infection of humans by the third larval stage (L3) of parasitic nematodes of the family Anisakidae (genera *Anisakis*, *Pseudoterranova* and, very rarely, *Contracaecum*) (Adroher-Auroux & Benítez-Rodríguez, 2020). The terms anisakiosis or anisakidosis refer to disease caused by any member of the family Anisakidae, whereas anisakiasis is caused by members of the genus *Anisakis*. Globally, among seafood-borne parasites, members of the genus *Anisakis* are considered the most important parasites in relation to human infections. The etiological agent of 97% of human cases of anisakiasis are larvae of the complex *A. simplex sensu lato*, specifically the species *A. simplex sensu stricto* and *A. pegreffii* (Adroher-Auroux & Benítez-Rodríguez, 2020). The two species *A. simplex sensu stricto* and *A. pegreffii* are the most common zoonotic nematodes associated with the consumption of raw or mildly thermally processed seafood. The L3 larval stages are mostly located in the visceral body cavity and outside the internal organs, but they are also found in the musculature of commercially important fish species (EFSA Panel on Biological Hazards et al., 2024).

Parasitic nematodes of the genus *Anisakis*, have an indirect life cycle, using marine mammals, usually cetaceans as their definitive host (Golden et al., 2022). The first intermediate hosts of Anisakid larvae are crustaceans. Fish and cephalopods that prey on this crustacean host can then act as paratenic[1] hosts for *Anisakis* spp., which are not obligately required for the parasite's development but efficiently pass the parasite up the food web to their definitive marine mammal host. Humans are infected with *Anisakis* spp. through consumption of the L3 form of the parasite in raw, smoked, marinated, salted or undercooked fish or squid. They are accidental hosts for the parasite, so it does not mature, but on reaching the gastrointestinal tract, the larvae can cause disease (anisakiosis). The local mucosa damage caused by the larvae penetrating the gastrointestinal tract tissues results in gastric anisakiosis, the symptoms of which include nausea, vomiting and abdominal pain. After a first penetration of the gastrointestinal mucosa by live *Anisakis* larvae, the released antigens induce the production of IgE antibodies in response to the parasite infection (de Las Vecillas et al., 2020). Patients can experience both abdominal and hypersensitivity symptoms and this condition is described as gastroallergic anisakiosis. The other condition associated with *Anisakis* infection is an allergic response to fish products that contain parasite allergens. In these cases, live parasites may not be necessary to induce an allergic reaction, although it is generally believed that an initial *Anisakis* infection must occur to sensitise individuals to parasite antigens. However, it has not been possible to definitively rule out the occurrence of sensitisation through exposure to antigen alone. Sensitised individuals can develop allergic IgE-mediated symptoms some minutes to hours after the intake of parasitised fish (de Las Vecillas et al., 2020). Clinical manifestations can range from mild to severe (for example, anaphylaxis) (de Las Vecillas et al., 2020).

Marine toxins

Marine biotoxins

Marine biotoxins include chemical contaminants naturally produced by certain types of algae and bacteria. They can enter the food chain through the consumption of fish and other seafood, such as molluscs and crustaceans. Climate and temperature strongly influence their presence in marine and freshwater environments. In addition, there are a few natural toxins and harmful compounds that are specific to certain fish species.

Marine biotoxins are mostly produced by phytoplankton (algae). Phytoplankton are microscopic photosynthetic unicellular organisms, that exist solitarily or in chains. Phytoplankton are the primary producers at the base of the food chain in almost all aquatic ecosystems. Some phytoplankton produce toxic compounds that can accumulate in filter-feeding bivalve shellfish and can be harmful to humans, if consumed. Phytoplankton species that produce toxins often occur in blooms, known as harmful algal blooms (HABs). Marine HABs and associated shellfish poisoning outbreaks are more

[1] Paratenic hosts are not needed in the life cycle of the parasite, but act as reservoirs. The parasite can persist but does not develop further in the paratenic host.

common in warmer months, but can occur at any time of year. HABs are expected to become more frequent and widespread as climate change causes increases in sea temperature and changes patterns of nutrient cycling. This could increase the public health risks from shellfish poisoning.

Marine biotoxins can cause a variety of different gastrointestinal or neurological illnesses (FSANZ, 2024e; NSW Health, 2024b).

Common marine biotoxins include:

- Paralytic Shellfish Toxins (PSTs)
- Diarrhetic Shellfish Toxins (DSTs)
- Amnesic Shellfish Toxin (AST)
- Neurotoxic Shellfish Toxins (NSTs)
- Ciguatoxins (CTXs)
- Gempylotoxins (GTXs)
- Tetrodotoxin (TTX).

Additional marine toxins include Azaspiracid Shellfish Toxins (AZTs). Cyanotoxins are produced by bacteria, although they are sometimes termed “blue-green algae” and are found in freshwater (NSW DPIE, 2025).

The three main algal toxin groups found in NSW coastal waters are AST, PSTs and DSTs (NSW Food Authority, 2017a). NSTs and AZTs have not previously been detected in NSW (NSW Food Authority, 2017a). Of note, brevetoxins (neurotoxins) were detected for the first time in 2025 in Australian waters in South Australia (Anthony Zammit, *personal communication*). In Australia, the level of biotoxins in shellfish is regulated in *Standard 1.4.1 clause 3* of the Code. Schedule 19 includes maximum levels permitted per kg in bivalve molluscs for AST (domoic acid equivalent), DSTs [okadaic acid (OA) equivalent], NSTs and PSTs (saxitoxin dihydrochloride equivalent). The limits are similar to those regulated by the EU and in the USA. While a regulatory limit for AZTs is not currently defined in the Code, international standards would be applied to any positive AZT report.

Ciguatera poisoning is the most common type of marine biotoxin food poisoning worldwide (EFSA, 2025). Ciguatera poisoning is caused by the consumption of herbivorous marine species that feed on toxic microalgae (*Gambierdiscus* spp. and *Fukuyoa* spp.), or from consumption of predatory carnivorous marine species that have consumed such herbivorous marine species. Globally, over 425 species of fish have been associated with ciguatera poisoning, consisting mostly of carnivorous fish found in coral reefs (FAO and WHO, 2020b). While ciguatera poisoning is an illness commonly thought to be an issue in tropical or subtropical regions only, there has been an apparent increase in reported cases of ciguatera poisoning globally and in the geographic range of ciguatera poisoning cases along the Eastern coastline of Australia (Farrell et al., 2017). Foods at higher risk of contamination are coral fish that include Chinaman fish, red bass, some wrasse, tropical snappers and coral trout (FSANZ, 2024e). Ciguatera poisoning can be prevented by avoiding consumption of fish of unknown species and avoiding consumption of large, predatory fish species. Although ciguatera poisoning is primarily considered a fish-borne syndrome, research has revealed that marine invertebrates such as urchins, gastropods, bivalves, crab, lobster and octopus can also contain high levels of CTXs (Perkins et al., 2024). As a result, the traditional name of ciguatera fish poisoning has been changed throughout recent literature to ciguatera poisoning to reflect the broader range of sources for this toxin. The symptoms of ciguatera poisoning start between 1 and 24 hours after eating a toxic marine species and include (NSW Health, 2024b):

- tingling and numbness in fingers, toes, around lips, tongue, mouth and throat
- burning sensation or pain on contact with cold water
- joint and muscle pains with muscular weakness
- nausea, vomiting, diarrhoea and/or abdominal cramps

- headache, fatigue and fainting
- extreme itchiness, often worsened by drinking alcohol
- difficulty breathing in severe cases.

Tetrodotoxin (TTX) has been reported to be produced by bacteria from a variety of genera present in fish of the Tetraodontidae family and other aquatic animals. TTX poisoning is usually associated with the consumption of puffer fish, which are a culinary delicacy in Japan. In Japan, Government certification is required for commercial sale of pufferfish flesh (*fugu*) and significant training is necessary to enable an individual to remove the toxic organs from pufferfish without contaminating the edible portions with TTX. In addition, select pufferfish species are allowed and there is a maximum regulatory limit for TTX that is permitted in *fugu*. Nevertheless, TTX intoxications still result in serious food poisoning and death in Japan. Small quantities of pufferfish are being imported into Australia for human consumption (FSANZ, 2022). However, there is no data on *fugu* consumption amongst Australian consumers. The Code does not specify a maximum level for TTX. While TTX intoxications have occurred in Australia, these events have occurred where recreational fishers have caught and eaten pufferfish species without understanding the associated risks of toxicity. Most recently, a case of TTX poisoning from recreationally caught pufferfish occurred in South Australia (SA) (Burton et al., 2024). TTX has been detected in a variety of other marine species including globefish, toadfish, octopus and shellfish species. TTX interferes with the transmission of signals from nerves to muscles and causes an increasing paralysis of the muscles of the body. TTX poisoning can be fatal.

Gempylotoxins (GTXs) are wax esters naturally found in high concentrations in the meat of escolar (*Lepidocybium flavobrunneum*) and oilfish (*Ruvettus pretiosus*). These wax esters are indigestible and may cause diarrhea, abdominal cramps, nausea, headache, and vomiting when consumed in sufficient quantities or consumed in lower quantities by sensitive individuals. The exact quantity required to cause these purgative effects is not known and appears to vary based on individual sensitivities. No cooking or handling practices of these fish can prevent illness. The NSW Food Authority recommends that businesses warn customers buying these fish of the potential side effects (NSW Food Authority, 2025a).

Cyanotoxins are produced by true bacteria, although they are sometimes termed “blue-green algae” as they can photosynthesise due to the presence of chlorophyll. Cyanobacteria are found naturally in lakes, streams, ponds and other surface waters. Similar to other types of algae, when conditions are favourable, cyanobacteria can rapidly multiply in surface water and cause blooms. Their primary health significance is that many species of cyanobacteria produce toxins, which can be either contained intracellularly, or expressed extracellularly and therefore present in the surrounding water.

Exposure to cyanobacteria and their toxins can occur from primary contact (swimming) and secondary contact (boating, fishing) recreational activities. Toxins may also be ingested by consuming water or wild-caught foods such as shellfish and crustaceans.

The *Guidelines for Managing Risks in Recreational Water* includes an overview of cyanobacterial toxins (NHMRC, 2008). An excerpt from the *Guidelines* is provided below, describing the main groups of cyanotoxins.

The three main groups of cyanotoxins are:

- Cyclic peptides (microcystins and nodularin). Microcystins cause damage to the liver and are possibly carcinogenic. Nodularin has an identical mode of action to microcystin in animals and is considered to present at least the same risk to human health as microcystin.
- Alkaloids (neurotoxins and cylindrospermopsin). Neurotoxins produced by cyanobacteria include anatoxin a, anatoxin a-s and the saxitoxins. Only saxitoxins have been detected in Australian waters. Cylindrospermopsin is a general cytotoxin that blocks protein synthesis. The major pathological effects are damage to the liver, kidneys, lungs, heart, stomach, adrenal glands, the vascular system and the lymphatic system. Acute clinical symptoms are kidney and liver failure.

- Lipopolysaccharides (LPS). LPS are an integral component of the cell wall of all gram-negative bacteria, including cyanobacteria. LPS has been reported to elicit irritant and allergenic responses, as well as to be pyrogenic (fever-causing) and toxic. However, it is possible that cyanobacterial LPS represent a relatively minor to low hazard to human health in water contaminated with cyanobacteria.

Although the toxins listed are assumed to be the substances most significant for human health, it is unlikely that all cyanotoxins have been discovered.

Potentially toxin-producing cyanobacteria found in freshwater are listed in Table 5.

Table 5: Potentially toxin-producing cyanobacteria found in freshwater[1]

Cyanobacteria	Toxin(s) produced
Cylindrospermopsis raciborskii, *Aphanizomenon ovalisporum*, *Aphanizomenon flos-aquae*, *Raphidiopsis curvata* and *Umezakia natans*	Cylindrospermopsins *Cylindrospermopsis raciborskii* is the most common producer of cylindrospermopsins in Australian water sources.
Microcystis, *Anabaena*, *Planktothrix* (*Oscillatoria*), *Nostoc*, *Anabaenopsis* and *Radiocystis*	Microcystins *Microcystis sp.* and *M. aeruginosa* in particular is the most common producer of microcystins in Australian water sources.
Nodularia spumigena	Nodularins
Anabaena, *Lyngbya*, *Oscillatoria*, *Cylindrospermopsis*, *Cylindrospermum* and *Aphanizomenon*	Saxitoxins, anatoxin-a and anatoxin-a(s) In Australia neurotoxin production appears to be limited to saxitoxins from *Anabaena circinalis*.

[1] *Data source is The Australian Drinking Water Guidelines (NHMRC, 2011).*

Cyanotoxins are known to bioaccumulate in aquatic animals, including in finfish and shellfish. When toxins produced by cyanobacteria are present in the aquatic environment, seafood harvested from this water may present a health hazard to consumers. People should avoid the consumption of wild-caught foods from HAB impacted waters.

Blue-green algal blooms are normally associated with lakes and reservoirs, but do occur in rivers when conditions suit. The formation of algal blooms is influenced by a range of factors, including the unique adaptive capacity of cyanobacteria species, nutrient loads, temperatures and flow dynamics (DPE, 2022). The prevention of low or no-flow conditions has been demonstrated to reduce bloom formation (DPE, 2022). However, blooms may also form under high-flow conditions in response to high nutrient concentrations and water temperatures (DPE, 2022).

WaterNSW plays a central role in algae management and is responsible for testing for, and notifying about, blue-green algal blooms (WaterNSW, 2024a). WaterNSW liaise with other agencies affected by algal blooms to ensure that an integrated risk management approach is taken. WaterNSW coordinate and support Regional Algal Co-ordinating Committees (RACCs), who are responsible for local management of algal blooms and issue algal alerts. The RACCs include representatives of state and local governments, water utilities, community/tourism bodies and, where appropriate, federal and interstate governments. Each RACC maintains a contingency plan which sets out appropriate responses to alerts. One key task of the RACCs is to keep their local communities informed of hazards arising from blooms.

Alerts are declared where algal cell numbers exceed the triggers identified in the *Guidelines for Managing Risk in Recreational Waters* (WaterNSW, 2024a). This includes a traffic light system of alerts. Red alerts are issued when contact with the water should be avoided. There have been a number of recent bloom events in NSW, including red alerts for extended periods in the lower Murray River in the 2019/20 and 2020/21 summers under relatively high-flow conditions (DPE, 2022). These were composed of several different potentially toxic species (DPE, 2022).

Research is currently being undertaken by WaterNSW into emerging monitoring and remote sensing capability, including online algal and natural organics sensors, passive samplers, satellite imagery to improve management of blue-green algal risk and for calibration of water quality models (DCCEEW, 2024). WaterNSW is also undertaking joint research with Sydney Water on utilising machine learning capability to forecast short-term changes in water quality in the Greater Sydney Declared Catchment (DCCEEW, 2024).

Histamine poisoning

Histidine is found naturally in the muscles of some fish and in certain species may be present in large quantities. Histidine can be converted to histamine by bacteria that produce the enzyme histidine decarboxylase. Bacteria that are associated with histamine development are present in the marine environment and naturally exist on the gills, external surfaces and in the gut of fish (FDA, 2020). Scombridae are the family of fish such as tuna and mackerel, which are traditionally considered to present the highest risk on histamine poisoning. Hence histamine poisoning was initially referred to as Scombroid poisoning. However, other species have also been associated with histamine poisoning, including anchovies, sardines, yellowtail kingfish, amberjack, Australian salmon, mahi mahi and escolar (SafeFish, 2015). Thus, the disease is now more accurately described as histamine poisoning.

Living and immediately postmortem fish contain no histamine (DeBeer et al., 2021). Upon death, the defence mechanisms of the fish no longer inhibit bacterial growth in the muscle tissue and histamine-forming bacteria may start to grow, resulting in the production of histamine (FDA, 2020). High levels of histamine in the fish muscle may result when products are not immediately chilled after catching and retained in a chilled state. This is particularly the case if fish are caught in warm ocean waters, there is a substantial delay between fish death and chilling (for example, longlining and gillnetting, where death may occur many hours before the fish is removed from the water) and/or fish are not stored under refrigeration (QLD Government, 2021). Prevention relies on the fish being chilled, or frozen soon after being caught and then being kept refrigerated or frozen until it is cooked, preserved or consumed.

Once the enzyme histidine decarboxylase is present in the fish, it can continue to produce histamine in the fish even if the bacteria are not active (FDA, 2020). The enzyme can be active at or near refrigeration temperatures (FDA, 2020). The enzyme remains stable while in the frozen state and may be reactivated very rapidly after thawing (FDA, 2020).

Once formed, histamine is not destroyed by cooking, smoking, freezing or canning (QLD Government, 2021). Histamine does not affect the appearance, odour or taste of fish (QLD Government, 2021).

Histamine poisoning occurs very quickly after consumption of contaminated fish, usually within 30 minutes to a few hours. Symptoms may vary for different individuals, but common signs of histamine poisoning include (NSW Food Authority, 2024d):

- a peppery taste sensation
- tingling of the mouth and lips
- a skin rash
- headaches
- dizziness
- itching of the skin.

Histamine poisoning is not usually life threatening, has no sequelae and is normally of short duration. While the symptoms are self-limiting, they can cause severe discomfort. In some cases, nausea, vomiting and diarrhoea may occur. Symptoms usually last for four to six hours and rarely exceed one day. Histamine poisoning can be treated with an antihistamine.

Chemical hazards

Seafood may be harvested from coastal zones and inland habitats that are exposed to varying quantities of environmental contaminants (FAO and WHO, 2020a). Of greatest concern is seafood harvested from coastal and estuarine areas rather than seafood harvested from the open seas (FAO and WHO, 2020a). Amongst those chemical hazards of concern are organochloric compounds (for example, PCBs; polychlorinated biphenyls), heavy metals, veterinary drug residues (in aquaculture products), diesel oil, detergents and disinfectants (FAO and WHO, 2020a).

Australia has implemented controls for several persistent organic pollutants (POPs). A brief background to POPs and their management in relation to human health is provided below, with particular reference to dioxins and PFAS which have recently been surveyed as part of the Australian Total Diet Study (ATDS). The ATDS is Australia's most comprehensive monitoring survey of chemicals, nutrients and other substances in the Australian diet (FSANZ, 2024b). The ATDS is managed by FSANZ and involves measuring the levels of different chemicals and substances in a range of foods typical to the Australian diet. The resulting data is used to estimate Australian consumers' exposure to chemicals through food to ensure it is safe to eat. The 26th ATDS investigated levels of dioxins, dioxin-like compounds (DLCs) and non-dioxin-like polychlorinated biphenyls (NDL-PCBs) in the national food supply (FSANZ, 2020). The 27th ATDS investigated PFAS in the national food supply (FSANZ, 2021). The results of the 26th and 27th ATDS are discussed below and indicate that dietary exposure to these compounds from the Australian seafood supply is generally low.

A seafood monitoring program is undertaken as part of the National Residue Survey (NRS) and tests for pesticide and veterinary medicine residues, as well as a range of other environmental contaminants in Australian seafood. The aquaculture seafood and wild-caught seafood that were tested as part of the 2022-2023 monitoring program displayed a high level of compliance, the results of which are described below (DAFF, 2024a). The results of the 25th ATDS, which surveyed for a number of agricultural and veterinary chemicals and metal contaminants (FSANZ, 2019), are also discussed below. In brief, the dietary exposure to the chemicals and contaminants under study in the 25th ATDS was concluded to be acceptably low for most Australian consumers.

Persistent organic pollutants

The Stockholm Convention on Persistent Organic Pollutants (POPs) is a global treaty to protect human health and the environment from chemicals that remain intact in the environment for long periods, become widely distributed geographically, accumulate in the fatty tissue of humans and wildlife, and have harmful impacts on human health or on the environment. Australia ratified the Stockholm Convention in 2004 (DCCEEW, 2023). At this time, the Convention listed twelve POPs. Australia has placed controls on the import, manufacture, use and export of aldrin, chlordane, dieldrin, endrin, heptachlor, hexachlorobenzene (HCB), mirex, toxaphene, polychlorinated biphenyls (PCB), dichlorodiphenyltrichloroethane (DDT), dioxins and furans.

Over time, more POPs have been listed in the Stockholm Convention. This includes per- and polyfluoroalkyl substances (PFAS).

POPs are an ongoing threat as legacy contaminants persist long after their use has ceased.

In marine areas directly impacted by contamination, POPs can accumulate in the edible tissues of commercially and recreationally fished species, which creates a human exposure pathway for these contaminants through seafood consumption.

Dioxins are a group of chlorinated chemicals that are mainly byproducts of industrial practices or are generated in natural processes such as bush fires. Actions taken by the Australian government over the past few decades have led to reduced emissions of dioxins (for example, banning the manufacture and use of chemicals known to be sources of dioxins). However, dioxins are chemically stable and can last for decades in the environment. Dioxins are highly lipophilic and can accumulate in the body fat of animals and humans.

Dioxins are hydrophobic and bind strongly to sediments in aquatic habitats. In NSW, historic manufacturing of chlorinated pesticides adjacent to Homebush Bay has led to substantial dioxin contamination of aquatic sediments in Port Jackson. After detection of elevated levels of dioxins in some fish and seafood, all commercial fishing in Sydney Harbour was prohibited in 2006 as a health precaution (NSW DPI, 2023; NSW Food Authority, 2024n). The area affected includes all of Port Jackson and its tributaries. Recreational fishing has not been banned however people intending to eat their catch should follow the health advice provided on the NSW Food Authority website (NSW Food Authority, 2024n).

Per- and poly- fluoroalkyl substances (PFAS) are a group of synthetic chemicals produced since the mid-twentieth century that include perfluorooctane sulfonate (PFOS), perfluorooctanoic acid (PFOA) and perfluorohexane sulfonate (PFHxS). Due to their fire retardant, waterproofing and stain resistant qualities, these chemicals have been used extensively in a wide range of industrial and domestic products. Amongst these products are those including textiles, food packaging, mist suppressants, pesticides, polishes, electronic components and firefighting foams.

PFAS are very stable chemicals that bioaccumulate, do not easily break down and can persist in the environment. Because of the relatively high mobility of some PFAS chemicals in water, and the fact they are highly persistent, these point sources often result in contamination of nearby waterways via groundwater or surface drainage. PFAS emissions into waterways can also arise from diffuse sources such as wastewater treatment plants, landfill and stormwater.

Due to their widespread use in everyday and specialty products, almost everyone is exposed to low levels of PFAS from food, water and various consumer products (NSW EPA, 2023b). Finding PFAS in the environment does not necessarily mean there is a human health risk (NSW EPA, 2023b). However, specific contamination can lead to higher exposures through contaminated food, especially seafood, or affected drinking water (NSW EPA, 2023b).

The Australian Government Department of Health, FSANZ and the National Health and Medical Research Council (NHMRC) have developed Health Based Guidance Values (HBGVs) for PFOS, PFOA and PFHxS (Australian Government, 2019). The HBGVs indicate the amount of a chemical in food or drinking water that a person can consume on a regular basis over a lifetime without any significant risk to health. They are for use in site investigations and human health risk assessments in Australia. The health based guidance values are protective of human health; are a precautionary measure for use when conducting site investigations; and are to assist in providing advice to affected communities on how to minimise exposure to PFAS.

The NSW Environment Protection Authority (EPA) is leading an investigation program to assess the legacy of PFAS use across NSW (NSW EPA, 2023a). Investigation sites include those where the greatest usage of PFAS containing products has taken place, including firefighting training facilities, airports and some industrial sites (NSW EPA, 2023b). The NSW Department of Primary Industries and Regional Development (DPIRD) is assisting the NSW EPA by providing technical support on fisheries, agriculture, biosecurity and food safety issues (DPIRD, 2025).

Exposure of aquatic fish, crustaceans and molluscs to environmental media containing PFAS chemicals leads to bioaccumulation in their tissues. PFAS investigations have included sampling of fish and other aquatic biota in estuaries and inland waterways in NSW (NSW EPA, 2023a). At a small number of sites, the NSW Government has determined that precautionary dietary advice is required for local fishers to moderate their consumption of specific species. For those waterways, impacted residents are provided with tailored, precautionary dietary advice to help them reduce any exposure to PFAS (DPIRD, 2025). There are currently no fishing closures in place in NSW waters due to PFAS contamination (DPIRD, 2025).

In Australia, the general community's exposure to PFAS is low and declining as most people source their food from a wide variety of types and locations, and any PFAS levels that may be present in one source are diluted across the market (NSW EPA, 2023b).

Products containing PFAS are being phased out around the globe.

26th ATDS – POPs

The 26th ATDS investigated levels of compounds classified as persistent organic pollutants (POPs) by the Stockholm Convention in a broad range of foods and beverages (FSANZ, 2020). The POPs investigated included 29 dioxins and DLCs and 16 NDL-PCBs. DLCs include polychlorinated dibenzo-p-dioxins (PCDDs), polychlorinated dibenzofurans (PCDFs) and dioxin-like polychlorinated biphenyls (DL-PCBs). A total of 33 different foods and beverages were sampled from all Australian states and territories over 2 sampling periods (April 2017 and February 2018).

At the time of the 26th ATDS, there were seven PCDDs, ten PCDFs, and 12 DL-PCBs in total that had been classified as dioxins or dioxin-like compounds by the World Health Organization (WHO). Within this group, the toxicity of each congener varies according to the degree and position of chlorine substitution. To account for this, WHO developed toxic equivalency factors (TEFs) for human risk assessments of these compounds. TEFs are weighting factors applied to individual congeners indicating their toxicity relative to that of the most toxic reference congener. In this case, the reference congener is the most toxic dioxin, 2,3,7,8-tetrachlorodibenzo-p-dioxin (2,3,7,8-TCDD), which has a TEF of one. Multiplying the analytical concentration of a particular congener with its TEF gives a concentration that is toxicologically equivalent to TCDD. The total toxic equivalency (TEQ) of a combination of specific dioxins is the sum of each congener concentration multiplied by its TEF. Of note, after the time the 26th ATDS was conducted, the WHO convened an expert panel in which the 2005 WHO TEFs for chlorinated dioxin-like compounds were reevaluated. Applying these new TEFs to a limited set of dioxin-like chemical concentrations measured in human milk and seafood indicated that the total toxic equivalents will tend to be lower than when using the 2005 TEFs (DeVito et al., 2024).

In the 26th ATDS dioxins were detected in 32 of 33 foods sampled, and 190 (95%) of 200 composite samples. This result was not unexpected due to the ubiquitous nature of dioxins. Foods with the highest mean dioxin levels were salmon fillets (0.28 pg toxic equivalents per gram (TEQ/g)) and fish fillets (lower fat varieties) (0.064 pg TEQ/g). Other seafood commodities with detectable levels, included crumbed fish portions (0.059 pg TEQ/g) and canned tuna (0.027 pg TEQ/g). Whilst the Code does not specify MLs for dioxins, a comparison of analytical results with MLs set by the European Union (EU) indicated no exceedances of these European limits.

Of the 16 NDL-PCB congeners analysed, one or more were detected in 13 of the 33 sampled foods, and 21 (11%) of 200 composite samples. MLs have been set by the European Union (EU) for the sum of six indicator NDL-PCBs (PCB28, PCB52, PCB101, PCB138, PCB153 and PCB180). The highest mean lower bound (LB) levels of PCB28, PCB153 and PCB52 were reported in salmon fillets (0.061, 0.31 and 0.090 µg/kg respectively). Salmon fillets were also found to contain the highest mean LB concentration of total NDL-PCBs (i.e. the sum of 16 congeners analysed) (1.2 µg/kg). This is consistent with international data indicating that fatty fish generally contains the highest concentrations of PCBs. In Australia, the Code specifies MLs for total PCBs in fish (0.5 mg/kg). There were no exceedances of the Code or EU MLs for NDL-PCB levels detected in any samples.

The levels of dioxins and NDL-PCBs across all foods were low and did not exceed Australian or European regulatory limits. While salmon fillets had consistently higher levels than other foods owing to their high oil content, the levels were acceptably low and did not raise any concerns.

27th ATDS - PFAS

The 27th ATDS investigated a broad range of Australian foods and beverages for levels of per- and poly-fluoroalkyl substances (PFAS) (FSANZ, 2021). Composite samples were analysed for 30 different PFAS including three congeners of primary interest for food safety: perfluorooctanoic acid (PFOA), perfluorooctane sulfonic acid (PFOS) and perfluorohexane sulfonic acid (PFHxS).

There are no MLs for PFAS in the Code. To assist with site investigations and management, FSANZ developed non-regulatory trigger points to assist authorities analysing PFAS in foods in identifying when further investigation may be required.

PFOS was the only congener detected in five of the 112 food types and in less than 2% of all samples. Three of the five food types in which PFOS was detected were seafood commodities, including saltwater fish fillets (16%, 1/16; <0.050 – 0.18 µg/kg), canned tuna in brine (50%, 4/8; <0.050 – 0.19 µg/kg) and cooked prawns (19%, 3/16; <0.050 – 0.11 µg/kg). However, the range of results were well below their respective corresponding trigger point for either finfish (5.2 µg/kg) or crustaceans and molluscs (65 µg/kg). One other seafood commodity (salmon fillets, n=16) was included in the survey, but there were no detections. Overall, results from the 27th ATDS indicate PFAS levels in the general Australian seafood supply are consistently lower than overseas studies.

Overall dietary exposure to PFOS for the general Australian population was concluded to be lower than the Tolerable Daily Intake (TDI) indicating no public health and safety concerns.

National Residue Survey - pesticide and veterinary medicine residues and environmental contaminants

In Australia, the NRS is undertaken by the DAFF to test animal and plant products for pesticide and veterinary medicine residues and environmental contaminants (DAFF, 2024e). The NRS supports Australia's primary producers and agricultural industries by confirming Australia's status as a producer of clean food and facilitating access to domestic and export markets. Product testing is done through either random or specifically designed sampling protocols. In regard to seafood, residue testing datasets for aquaculture and wild caught species can be accessed from the DAFF website (DAFF, 2024f).

Results from the most recent random seafood monitoring program in 2022-2023, revealed a 100% compliance rate for aquaculture seafood (n=190) and wild-caught seafood (n=122) (DAFF, 2024a).

The aquaculture seafood commodities sampled included abalone, barramundi, cod, groper, kingfish, marron, oysters, prawns, redclaw, salmon, trout and tuna. Chemicals are tested according to the commodity to be sampled. For aquaculture seafood commodities this may include anthelmintics, antibiotics, contaminants, dyes, fungicides, herbicides, hormones, insecticides and metals. The results indicate that chemical hazards are well controlled at primary production under existing regulatory and non-regulatory measures.

The wild caught seafood commodities sampled included abalone, crab, emperor, mullet, octopus, orange roughy, scallop, sea cucumber, sea urchin, snapper, tuna and whiting. Chemicals are tested according to the commodity to be sampled. Wild caught seafood commodities are only tested for the presence of metals, which may include antimony, arsenic, cadmium, chromium, lead and mercury.

25th ATDS – metal contaminants

The 25th ATDS investigated a wide range of Australian foods for the presence of a number of agricultural and veterinary chemicals, and four metal contaminants (arsenic, cadmium, lead and mercury) (FSANZ, 2019). A summary of the ATDS results in relation to seafood and the presence of metal contaminants is provided below. Where a metal contaminant was detected in a seafood commodity, the result was compared to the corresponding ML for the commodity in Schedule 19 of Standard 1.4.1 of the Code.

The study determined the highest mean concentrations of total arsenic in prawns (2.9 mg/kg), mussels (2.7 mg/kg), takeaway fish fillets (2.2 mg/kg), canned tuna (0.92 mg/kg) and frozen fish portions (0.88 mg/kg). There were no composite sample results which exceeded their corresponding commodity-based ML as specified for total arsenic. The mean arsenic levels determined were also generally consistent with those reported in the international scientific literature, with fish and seafood having the highest levels.

Total arsenic concentrations in foods have also been used to estimate inorganic arsenic dietary exposures assuming that a proportion of total arsenic is inorganic. This method was used by FSANZ assuming a proportion (10%) of the total arsenic concentration as measured in all ATDS foods was inorganic. Inorganic arsenic was analysed in a limited number of food types including likely sources of dietary exposure. It was detected in three foods with mean concentrations in mussels of 0.28 mg/kg, white rice of 0.03 mg/kg and sushi rolls (nori) of 0.01 mg/kg. Other types of seafood including takeaway fish fillets, frozen fish portions, prawns and canned tuna had no detectable inorganic arsenic. There were no exceedances of corresponding MLs for inorganic arsenic in composite samples.

The levels of arsenic (total and inorganic) in foods sampled in the ATDS and estimates of dietary exposure for Australian consumers were generally consistent with those reported internationally.

All composite samples of mussels and canned tuna were determined to contain cadmium. The highest mean concentrations of cadmium were found in mussels (0.20 mg/kg) and prawns (0.065 mg/kg). There were no composite sample results which exceeded their corresponding ML for cadmium. The 25th ATDS foods with the highest mean concentrations of cadmium, including mussels and prawns, were also reported to have relatively higher cadmium concentrations in Europe and New Zealand. Levels of cadmium in foods sampled in the ATDS and estimates of dietary exposure for Australian consumers were generally consistent with those reported internationally.

Several foods were determined to have lead in all of their respective composite samples including mussels. Mussels also contained the highest mean concentration (0.074 mg/kg). No composite sample results exceeded the corresponding ML, indicating that dietary exposure to lead is acceptable. Mean concentrations of lead in mussels were consistently well below those reported in the previous 23rd ATDS and in the United States, Europe and New Zealand. Overall, the results indicate that dietary exposures to lead for most Australian consumers are lower than levels found to be of negligible risk of causing adverse health effects.

Foods were tested for total mercury, inorganic mercury and methylmercury. A limited number of foods were determined to contain mercury in all of their respective composite samples including takeaway fish fillets, frozen fish portions, canned tuna and mussels. This study found the highest mean concentrations of total mercury in takeaway fish fillets (0.13 mg/kg), frozen fish portions (0.048 mg/kg) and canned tuna (0.046 mg/kg). There were no composite sample results which exceeded their corresponding ML for mercury. Mean mercury levels reported in the 25th ATDS were consistent with international data, with the highest concentrations reported in fish and other seafood (particularly species high in the food chain).

FSANZ undertook estimations of dietary exposure to inorganic mercury and concluded that for most Australian consumers this is acceptably low.

Methylmercury was analysed in a limited number of seafood types, with a focus on likely sources of dietary exposure. It was detected in three foods, with mean concentrations in takeaway fish fillets (0.14 mg/kg), frozen fish portions (0.06 mg/kg) and canned tuna (0.05 mg/kg). Methylmercury was not detected in mussels and prawns. These results are consistent with the known properties of methylmercury including propensity to bioaccumulate at the higher end of the marine food chain. Methylmercury is a developmental neurotoxin, and the most sensitive developmental stage is the foetus. Exposure of pregnant women to methylmercury is therefore of greatest concern to human health. FSANZ determined that the most sensitive subgroup–women of child bearing age–had dietary exposure below the Provisional Tolerable Weekly Intake (PTWI). The only age group to exceed the PWTI, was children aged 2 to 5 years. While there is no clear evidence that prenatal vulnerability extends into postnatal exposure, the sensitivity of 2 to 5-year-olds to adverse effects of methylmercury is not clearly defined. This uncertainty must be weighed against the potential benefits of moderate fish consumption. FSANZ publishes consumer advice to manage dietary exposure to mercury through fish consumption while highlighting the health benefits of fish consumption.

Physical hazards

A physical hazard can be defined as any physical material not normally found in a food that can cause illness or injury to a person consuming the product. Amongst those physical hazards identified by the FAO and WHO (2020) in the *Code of Practice for Fish and Fishery Products*, are materials including metal or glass fragments, shell and bones. Physical hazards are less likely than chemical or biological contaminants to affect large numbers of people and, are most likely to be reported by production or by consumer complaints. Of the 16 consumer level recalls of seafood and seafood products in Australia from 13/6/2019 to 18/12/2024 (Table 12), none were due to the presence of physical objects.

Emerging hazards

Aichivirus A

Aichivirus A (AiV-A) viruses were first detected in samples from an oyster-related gastroenteritis outbreak in Aichi, Japan in 1989. AiV-1 has since been detected in many types of environmental samples, such as groundwater, river water, sewage and shellfish (Abdelqader et al., 2025). Several countries have also reported gastroenteritis outbreaks linked to AiV and oysters (Abdelqader et al., 2025; Rivadulla & Romalde, 2020). While reported outbreaks are infrequent, there is evidence that AiV may be one cause of undiagnosed gastroenteritis. In a recent Australian study, a molecular screening assay for AiV-A was developed and used to test historical clinical specimens from 650 patients submitted for norovirus testing during May 2008 (Northill et al., 2020). In total 3% (18/650) of all patients had a positive clinical sample for AiV. Of the 18 patients with positive AiV-A samples, 39% (7/18) were also co-infected with norovirus genotype 2. The authors stated that their findings were comparable to previous studies reporting viral co-infection being commonplace, raising the question of whether AiV-A viruses are passengers or pathogens. Further work is required to understand the potential role of AiA as an agent of foodborne illness.

Micro- and nanoplastics

Primary microplastics are plastics originally manufactured to be that size, while secondary microplastics originate from fragmentation. Nanoplastics can originate from engineered material or can be produced during fragmentation of microplastic debris. Microplastics (5 mm–0.1 μm) and to a lesser extent nanoplastics (< 0.1 μm), have received considerable attention in food safety discussions because of their potential transfer along the food chain and their subsequent probable impact on human health (Garrido Gamarro & Costanzo, 2022). Of most concern, microplastics with a size <150 µm and nanoplastics may translocate across the gut epithelium causing systemic exposure.

Microplastics have been detected in fishery products and other food commodities. However, it has been concluded that levels of microplastics in foods and their level of exposure to humans are generally low (Garrido Gamarro & Costanzo, 2022). While this may be the case, much less is known about the nature and extent of the adverse health effects of microplastics; as well as their associated additives and contaminants, on the human body following exposure. The ability to make definitive conclusions on the public health implications of microplastic exposure would be enhanced by collection of missing data on exposure through certain food commodities and an increased knowledge of the toxicity of microplastics (Garrido Gamarro & Costanzo, 2022). In addition, standardised analytical methods are required (Garrido Gamarro & Costanzo, 2022). Whereas researchers were often limited to larger-sized microplastics (for example, > 300 μm), working with microscopes and visual inspection of particles alone, methods have evolved to enable work with much smaller particles, albeit with more costly analytical instruments and stricter contamination control procedures (Garrido Gamarro & Costanzo, 2022).

Commercial aquatic species have been widely investigated, as microplastics may be ingested by fish, crustaceans and bivalves. The composition of plastic polymers found in marine organisms generally reflect the types of plastic that are used in aquaculture or fishing gear, whether to breed or collect these organisms (Garrido Gamarro & Costanzo, 2022). Historically, food safety considerations of aquatic organisms typically involve those that are eaten whole, as microplastic particles were generally believed not be absorbed by the intestine and that they would mostly be retained in the digestive tract. However, some particles have been detected in the edible muscle tissues of fish, squid, crab and prawn (Garrido Gamarro & Costanzo, 2022). These results suggest that considering the digestive tract the only reservoir of plastic could lead to an underestimation of the actual amount that may be ingested.

Studies investigating microplastic contamination in fish mainly focus on the analysis of gut content, removing the gastrointestinal tract and either digesting it or simply opening for a visual identification of the particles. Studies involving visual inspection only may focus on the frequency of occurrence (number of organisms with microplastics present) and microplastic load (for example, particles per individual or particles per gram). If a digestion step is undertaken, a density separation step can be carried out to separate and collect the lighter microplastics from water, sediment or organic matter. The supernatant solution may then be filtered, so that polymeric particles can be identified. Chemicals associated with microplastics may also be analysed and quantified through chemical separation techniques based on their molecular characteristics.

A review was recently published on the sources, impacts and mitigation strategies for microplastics pollution in Australia (Hossain et al., 2025). Different sources, fates, and entry routes of microplastics into the terrestrial and aquatic environments were described (Hossain et al., 2025).

Microplastic surveys have been conducted on aquatic species purchased from domestic seafood markets and collected from freshwater and marine environments around Australia. Comparison of results from surveys published within Australia or to international studies is difficult, as there is no uniformity in the methods of plastic identification and quantification, or how these results are reported (for example, particles per individual, particles per gram). While the surveys have reported differences in the frequencies of occurrence and plastic load between states and species, the results have all generally been equivalent, or lower than, results of comparable international studies for related species.

A recent survey supported by the Fisheries Research and Development Corporation (FRDC), was the most comprehensive Australian survey to date of microplastics across a broad range of commercially important aquatic species (Gillanders et al., 2021). The survey included fish and invertebrates from 25 different species (15 finfish, 6 crustacea, 3 bivalves, 1 cephalopod) sourced from commercial fishers, seafood processors or sales outlets throughout Australia. Microplastics were found in all species examined, however less than half of all organisms contained microplastics and in general microplastic loads were low. Overall, the frequency of occurrence was 43.9% for all finfish, crustacean and mollusc samples combined. The frequency of occurrence ranged from 39.4% in finfish to 45.5% in crustaceans and 50.9% in molluscs. There were 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). Variation in frequency of occurrence in finfish, crustaceans and filter feeding molluscs was found among the states. The microplastic load varied from zero to 29 pieces among samples, with the maximum microplastic loads reported to be 17 pieces in finfish, 9 pieces in crustaceans, 29 pieces in filter feeding molluscs and 2 pieces in other molluscs. In comparing their results to international studies, the authors reported that the Australian seafood surveyed contained a median level of frequency of occurrence of microplastics and that the average microplastic load was at the lower end of the range reported internationally.

In a study by Ogunola et al. (2022), the microplastic load in three species of prawns (king, banana and tiger prawns) and two species of crabs (blue-swimmer and mud crabs) from Australia was reported to be 48%. The authors stated that this result was in the lower range of microplastics in decapod crustaceans worldwide (Ogunola et al., 2022).

Microplastic concentrations were found at low to moderate levels in a global context amongst wild mussels (*Mytilus* spp.) (Klein et al., 2022).

Microplastics were present in 49.4% of all commercially farmed oysters (*Crassostrea gigas* and *Saccostrea glomerata*) sampled across a broad spatial scale (Wootton et al., 2022). In comparison, microplastics were found in all oysters collected from six major seaports of NSW (Port Jackson, Botany, Kembla, Newcastle, Yamba and Eden) (Jahan et al., 2019).

In a survey of microplastic abundance in nine commercially important, wild-caught fish species (Australian herring, Australian salmon, Australian sardine, snapper, dusky flathead, southern garfish, King George whiting, sea mullet, tiger flathead), an average of 35.5% of fish samples across all states had at least one piece of microplastic in their gastro-intestinal tract (Wootton et al., 2021). The average microplastic load was 0.94 of a piece per fish but ranged from zero to 17 pieces. The average plastic ingestion was less than other similar global studies.

Microplastic contamination was detected in the edible portion of every species of five high-commercial-value Australian seafood products surveyed (oysters, prawns, squid, crabs and sardines) (Ribeiro et al., 2020). Sardines contained the highest total plastic mass concentration.

There are currently no regulations set for micro or nanoplastics in seafood products. However, preventing the release of microplastics from appropriate primary and secondary sources can reduce microplastic contamination. This has led to several countries implementing environmental legislation to manage microplastic-related waste (Hossain et al., 2025). A number of Federal Government initiatives to reduce plastic pollution in Australia have been implemented (SafeFish, 2023c).

International risk assessments and reviews to assess food safety hazards in the seafood supply chain

New Zealand

Pectenotoxins

Pectenotoxins (PTXs) are produced by *Dinophysis* spp., along with OA, dinophysistoxin 1 (DTX1) and dinophysistoxin 2 (DTX2). The OA group toxins cause diarrhetic shellfish poisoning (DSP) and are therefore regulated. Historically, due to the co-production and co-occurrence of PTXs and OA group toxins by *Dinophysis* spp., PTXs have been included in DSP regulation (Boundy et al., 2020a).

DSP toxins are not defined within the FSC Standard 1.4.1. Within the NSW MBMP, DSP toxins are defined to include OA, DTX1, DTX2, DTX3, PTX, PTX2, (PTX2-sa is currently regarded as non-toxic), yessotoxin (YTX), 45-OH YTX and azaspiracids (NSW Food Authority, 2015a). However, as stated in the NSW MBMP, there is debate about the human toxicity of some of these compounds (NSW Food Authority, 2015a). Any change to their regulation would require further toxicology studies, to allow more appropriate levels to be set (NSW Food Authority, 2015a).

In New Zealand, maximum permissible levels for marine biotoxins in Bivalve Molluscan Shellfish are regulated under the Animal Products Notice: Regulated Control Scheme - Bivalve Molluscan Shellfish for Human Consumption.

The food safety risk presented by PTX in shellfish in New Zealand was assessed using data collected from 2009-2019 (Boundy et al., 2020b). The risk assessment included review of both PTX and DSP groups, as at the time they were regulated together. However, pectenotoxins and OA have a different mechanism of action, meaning that their toxicities are not additive, which is the fundamental principle of grouping toxins (Boundy et al., 2020a). Furthermore, evaluation of the available toxicity data suggested that pectenotoxins have very low oral toxicity, with studies showing no oral toxicity in mice dosed with the PTX analogue PTX2 at 5000 µg/kg (Boundy et al., 2020a). No known human illnesses had been reported due to exposure to pectenotoxins in shellfish, a fact which combined with the toxicity data indicated that they pose negligible risk to humans (Boundy et al., 2020a).

The main PTX analogue observed in shellfish, PTX2, was detected in 1.3% of New Zealand shellfish samples analysed over the 2009-2019 period, with a maximum concentration of 0.079 mg/kg. However, over this time period there was no evidence that PTX has resulted in any human illness. DSP was detected in 4.2% of New Zealand shellfish samples, with a maximum concentration of 1.4 mg/kg, and 0.4% of samples over the current maximum permissible level of 0.16 mg OA eq/kg. Pre-dating the risk management programme of routine monitoring, a few historic cases of suspected DSP intoxication had been reported from non-commercial shellfish.

The risk assessment concluded that the food safety risk presented by PTX in New Zealand shellfish was low and that the PTX-group should be removed from regulation in New Zealand. However, the risk assessment recommended that the current maximum permissible level of 0.16 mg OA eq/kg for DSP is retained.

As of December 2024, maximum permissible levels for the DSP toxin group in bivalve molluscan shellfish in New Zealand are specified for OA (edible portion must not exceed 0.16 mg of OA equivalent per kg), which includes OA and dinophysistoxins (DTX1 and DTX2).

Pectenotoxins were deregulated in the European Union (EU) in 2021 with Regulation (EC) No 2021/1374 due to unproven adverse effects on humans (European Commission, 2021).

UK

Norovirus

In the United Kingdom (UK), an assessment was undertaken to determine the contribution made by the food chain to the burden of norovirus infection (Williams & O'Brien, 2019). A novel microsimulation-based method of performing a Quantitative Microbial Risk Assessment (QMRA) was developed, alongside an Individual-Based Model, to estimate the foodborne component of norovirus infection in the UK. Four food groups were chosen that historically are the most common food sources of norovirus infection, comprising oysters, lettuce, raspberries and catered food prepared in a commercial kitchen. New data acquired during the project was incorporated into the models where possible. This data included results of a one year (March 2015 – March 2016) survey of oysters collected from the point-of-sale to the consumer. In addition, the prevalence of environmental contamination with norovirus in outbreak and non-outbreak catering premises was determined. In total 256 catering premises were sampled, including 247 premises sampled for surveillance purposes and 16 premises sampled as part of outbreak investigations. Overall, it was estimated that the proportion of norovirus transmission that is foodborne was 16% (range 2.1% to 22.9%) in a QMRA and 35% (range 11% to 55%) in an Individual-Based Model. The authors of the report concluded that this indicated that between a fifth and a third of all norovirus illnesses could be attributed to the foodborne route. From the QMRA analyses, nearly 75% of foodborne infections occurred through contaminated catered food (a proxy for food handling), with contaminated lettuce accounting for around 20% of illness burden, followed by berries at 3% and oysters at 3%.

Europe

Analysis of the hazards in seafood notified in the Rapid Alert System for Food and Feed (RASFF) in 1996–2020

Pigłowski et al. (2023) undertook an analysis of the hazards in seafood notified in the Rapid Alert System for Food and Feed (RASFF) (Pigłowski, 2023). Between 1979 and 2020 seafood products accounted for 16.8% of the notifications from all food products, which comprised the seafood categories of fish (10%), crustaceans (3.4%), molluscs (2.6%) and cephalopods (0.7%).

A more detailed analysis was undertaken of the notifications over a 25 year period from 1996–2020. Due to the diverse nature of the hazards (252 hazard types), only hazards with more than 100 notifications were selected for further analysis. This resulted in the assessment of 25 hazards, covering a total of 10,551 (83%) notifications. The most frequently notified seafood products were shrimps (13.0%), tuna (10.0%), swordfish (9.6%), salmon (5.5%), mussels (4.7%) and also prawns, calms, squid, mackerel, oysters, shark, hake and panga. Microbiological hazards (27.6%) were responsible for the largest number of notifications between 1996–2020, followed by heavy metals (19.8%), veterinary products (8.3%), insufficient controls (for example, temperature and hygiene; 7.6%), parasites (specifically Anisakis; 4.7%) and additives/allergens (specifically sulphite; 4.2%). Heavy metals responsible for more than 100 notifications were mercury (13.9%) and cadmium (5.9%). The veterinary products responsible for more than 100 notifications were nitrofuran (5.4%), chloramphenicol (2%) and leucomalachite green (0.9%). The remaining 10.9% of hazards with more than 100 notifications were due to carbon monoxide (2.2%), benzo(a)pyrene (1.6%), DSP toxins (1.5%), organoleptic characteristics (1.4%), spoilage (0.8%), health certificate(s) (adulteration/fraud; 1.3%) and packaging (defective/incorrect packaging; 1.1%) and due to foodborne outbreaks by an undetermined agent (1%).

Of the microbiological hazards, *Listeria* (6.4%) was the most frequently reported followed by *Salmonella* (4.1%), *E. coli* (3.9%), *Vibrio* (3.6%), norovirus (2.2%), mesophiles (1%), Enterobacteriaceae (0.8%) and histamine (5.6%). In the case of *Listeria*, almost all notifications concerned *L. monocytogenes*. Half of the notifications regarding *Vibrio* were due to the presence of *V. parahaemolyticus*. Also reported were *V. cholerae*, including NON O:1 and NON O:1/NON O:139, and in much smaller numbers *V. vulnificus* and *V. alginolyticus*.

Listeria was reported primarily in salmon. *Salmonella* reported products were much more varied and were due mostly to mussels, but also clams, octopus, perch and shrimps. Notifications related to *E. coli* involved mussels and clams. Norovirus was found in oysters and clams. Histamine was reported mainly in tuna, but also in sardines. Notifications on Anisakis were mainly due to mackerel and hake, but also for anchovies, anglerfish and squid in products originating from European countries (Croatia, Denmark, France, Norway, Spain, the United Kingdom) and also from New Zealand.

V. parahaemolyticus and *V. vulnificus*

The FAO and WHO (2020c) undertook a review of risk assessment tools for *V. parahaemolyticus* and *V. vulnificus* in oysters and different bivalve molluscan species (FAO and WHO, 2020c). It was concluded that monitoring seawater for *V. parahaemolyticus* and *V. vulnificus* in bivalve growth and harvest areas has limited value in terms of predicting the presence of these pathogens in bivalves. Monitoring of seafood for these pathogenic vibrios was considered the most appropriate way to get insight into the levels of the pathogens in these commodities at the time of harvest. As monitoring on an ongoing basis could be expensive, it was recommended that consideration be given to undertaking a study over the course of a year and using this to establish a relationship between total and pathogenic *V. parahaemolyticus* and *V. vulnificus* in the seafood and abiotic factors such as water temperature and salinity. It was proposed that if a relationship could be established for the harvest area of interest, measuring these abiotic factors may be a more cost-effective way of monitoring. The review also acknowledged that the development of microbiological monitoring methods, particularly molecular methods for *V. parahaemolyticus* and *V. vulnificus* is evolving rapidly. Additionally, molecular detection assays are targeting an ever-growing list of genes. Regarding *V. parahaemolyticus*, the *tdh* and *trh* genes were stated to be the most suitable virulence markers at the time of the review. It was concluded that the international shellfish safety community needs to calibrate molecular methods for detection and quantification of pathogens and that it would be helpful if laboratories were using common materials to evaluate method performance.

Parasites in fishery products

The EFSA (2024) undertook a re-evaluation of certain aspects of the EFSA Scientific Opinion of April 2010 on risk assessment of parasites in fishery products, based on new scientific data (EFSA Panel on Biological Hazards et al., 2024). In a review of RASFF notifications of zoonotic parasites in fish and fishery products from 2010 to the end of 2023, there were 544 notifications of infection of the fish/fishery products reported by 21 European Union (EU) member states. The origin of the notified products included Spain (114 cases), Morocco (95 cases), France (92 cases) and Norway (18 cases). In addition, 29 cases originated from New Zealand, of which 21 were notified by Greece in 2011 due to a parasitic infection with Anisakis of frozen squids. *Anisakis* was the parasite reported in most (85%) of the notifications. In total, 95.59% of the notifications were attributed to ‘fish and fishery products’, but notably 4.04% were assigned to ‘cephalopods and products thereof’ and

0.38% to ‘bivalve molluscs and products thereof’. The most reported fish species were hake (20.22% of the total 544 notifications), mackerel (18%), monkfish/angler (13.60%), scabbardfish (6.43%) and codfish (5.70%). These five species together account for almost two-thirds of the total number of the notifications. As the notifications do not include information on whether the product originated from wild fisheries or aquaculture production, the infected cod could potentially have been sourced from wild caught fish. The Panel considered it to be 99%–100% certain that fish produced in recirculating aquaculture systems, or indoor or roofed facilities with filtered and/or treated water intake are not exposed to parasites provided the fish is exclusively fed heat-treated feed. Fish farmed in open marine offshore cages or open flow-through freshwater ponds or tanks can be exposed to zoonotic parasites.

The Panel also noted that there had been technical developments and new scientific data available in relation to killing viable parasites of public health importance in fishery products. However, most studies target nematodes of the family Anisakidae, with less information on the trematodes and cestodes. The review included information and data on treatments including freezing, heating (conventional and microwave), high-pressure processing (HPP), pulsed electric fields (PEF), drying, ultrasounds, salting, marinating and the use of natural products. Of note, HPP employing specific pressure–time combinations that maintain the sensory characteristics can be applied for some products. Traditional dry salting processes of anchovies were reported to successfully inactivate *Anisakis*. Studies on other traditional preservation and processing methods such as air-drying of Arctic migrating cod (‘stockfish’), double salting (salting in brine plus dry salting) of anchovies and cod (‘baccalà’) were also reported to indicate that anisakids are successfully inactivated. However, it was concluded that more data covering these and other parasites in more fish species and products are required to determine if these processes are always effective.

Chemical hazards in seafood

A hazard identification was recently undertaken which focused on potential chemical hazards in seafood, both regulated and emerging / non-regulated compounds in the EU (Diogène et al., 2023). This included an overview of and critical view on EU regulations. A summary of the main findings of the review is provided below.

EU legislation specifying the requirements for compliance with criteria of seafood safety are regularly being revised and are contained within Regulations (EU) 2023/915, (EC) No 852/2004, (EC) No853/2004 and (EC) 2017/625. All the regulated contaminants, whatever their nature (toxins, toxic metals, organic compounds), are associated with a maximum permitted level and an official method, except for CTXs. However, Regulation (EC) No 853/2004 stipulates that fishery products must not be placed on the market if they contain CTXs. Maximum permitted levels and analytical methods for CTXs are not defined and not harmonized between laboratories in the EU or worldwide. The challenges associated with the analysis of CTXs (limited availability of standards and of contaminated, characterised material; limited method validation due to limitations in sample material and standards) hinder understanding of CTXs dynamics in the marine food web.

Among regulated compounds, maximum levels have been set for organic and inorganic arsenic, cadmium, mercury, PCBs and PFAS in fish and seafood. Maximum levels have also been set for marine biotoxins in live bivalve mollusks, echinoderms, tunicates and marine gastropods. The review found that as reports of acute cases of poisoning within the population are scarce, it was assumed that the current maximum levels protect seafood consumers from acute intoxications. However, the review found little on the chronic effects which might occur from regular intake of contaminants via seafood consumption, including marine biotoxins such as neurotoxins of the group of cyclic imines which are not regulated.

In case of heavy metals, current EU legislation does not provide maximum levels for all seafood groups. While mercury is regulated for all mollusks species, maximum levels for cadmium and lead refer to bivalve mollusks only. Maximum levels for arsenic in bivalve species were not considered in the latest Commission Regulation (EU) 2023/465.

PFAS were non-regulated compounds until the end of 2022. Since 1st January 2023 four PFAS compounds, namely PFOS, PFOA, perfluorononanoic acid (PFNA) and PFHxS, have been regulated in the EU with maximum levels for both the individual and the sum of the four compounds in food of animal origin including fish meat and fishery products, bivalve mollusks and crustaceans. Seafood and fish are among the main dietary sources of human intake of these compounds and maximum levels are listed in Commission Regulation (EC) No 2023/915.

Part of the EU regulations dealing with marine biotoxins were published almost 20 years ago. Since this time, the regulatory limits of certain toxins have been raised (for example, YTX) or eliminated (for example, PTXs).

Among the non-regulated compounds, the marine biotoxins TTX, CTXs, MCs, and mycotoxins are of particular importance for seafood safety.

In regard to TTX, fish species of certain families (for example, *Tetraodontidae*) are prohibited from being placed on the market according to Regulation (EC) No 853/2004. Bivalve mollusks and gastropods from European waters have recently been reported to contain TTX. Shellfish and gastropod species are not currently covered by EU legislation and there are no maximum levels for TTX.

Microcystins (MCs) are produced by cyanobacteria such as *Microcystis aeruginosa*. Producers and toxins are mainly found in freshwater ecosystems, but have been detected and quantified at some coastal sampling points in France. The review proposed that consumption of contaminated aquatic food may be a potential route of exposure to humans. However, detection methodologies for complex food matrices are not harmonised, with a different recovery and efficiency for MC variants (endowed with different toxicity potential).

The review reported that mycotoxins have gained more relevance and interest with the use of plant-based fish feed in aquaculture and the fact that mycotoxins may occur in dried fish depending on storage conditions. Currently, only Fumonisin B1+B2 guidance level is mentioned in Commission Recommendation 2006/576/EC in relation to fish feed.

Exposure assessment

Production and consumption of seafood and seafood products

A summary of fisheries and aquaculture production statistics in NSW published by ABARES (Tuynman et al., 2023) is summarised in Table 6. The production statistics provide an insight into the volume of production of seafood by aquaculture, compared to wild caught. As can be seen in Table 6, by tonne, wild-caught constitutes the main method of seafood production in NSW. However, total fisheries and aquaculture production by value in 2021-2022 was $189,704,000, of which aquaculture was the largest contributor ($94,995,000) followed by wild-caught ($94,709,000).

Table 6: Fisheries and aquaculture production (tonnes) in NSW

Commodity	Species included	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022[10]
		Wild-caught					
Crustaceans[1]	Rock Lobster King Prawns School Prawns Other Prawns [2] Crabs	2,083	1,698	1,813	2,046	2,356	1,908

Commodity	Species included	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022 [10]
	Other Crustaceans [3]						
Molluscs	Scallops Blacklip Abalones Cuttlefishes Pipis Octopus Squids Other Molluscs [4]	630	490	604	605	563	497
Finfish	Golden Perch Sea Mullet Silver Trevallies Yellowtail Kingfish Jack Mackerels Black Bream and Yellowfin Bream Eastern Australian Salmon Snapper Grey Morwong Mulloway Sand Whiting Luderick Eastern School Whiting Dusky Flathead Other Finfish [5]	7,771	9,028	9,948	10,110	8,471	6,546
Other (not elsewhere included) [6]		89.9	96.5	86.5	126	157	146
Total wild-caught		10,574	11,312	12,451	12,886	11,548	9,098
			Aquaculture				
Total aquaculture [7]	Prawns Yabbies Oysters [8]	4,851	4,599	4,694	4,827	5,007	5,089

Commodity	Species included	2016-2017	2017-2018	2018-2019	2019-2020	2020-2021	2021-2022 [10]
	Silver Perch						
	Trouts						
	Mussels						
	Snapper						
	Barramundi						
	Ornamental species						
	Other aquaculture [9]						

[1] *Excludes catches in the Commonwealth and other jurisdiction fisheries landed into New South Wales.*

[2] *Mainly includes Tiger Prawns, Royal Red Prawn and Bay Prawns.*

[3] *Mainly includes Balmain Bugs, Yabbies and Nippers.*

[4] *Mainly includes Cockles, Periwinkles, Whelk and Blue Mussel.*

[5] *Mainly includes Australian Sardine, Blue Mackerel, Leatherjackets, Flathead, Bonitos, Yellowtail Scad, Sandy Sprat, Tailor, Silver Biddy and Eels.*

[6] *Mainly includes Beachworms and Sea Urchin.*

[7] *Excludes hatchery production.*

[8] *The 2019–20 conversion ratio for Oysters in New South Wales is approximately 1.7 kgs to the dozen; this differs between years.*

[9] *Mainly includes Longfin Eel, Golden Perch, Murray Cod, Mulloway and Pearls.*

[10] *Preliminary.*

In an analysis of 30 years of ABARES data from 1988-1989 to 2017-2018, it was reported that Australia’s seafood consumption has increased nearly twofold during this time due to population growth and increasing household incomes (Schrobback et al., 2022). While the total seafood volume produced domestically was reported to have remained relatively constant over time, imports were an important source to supply the increasing domestic demand for seafood (Schrobback et al., 2022). Data published by the ABARES on the apparent consumption of seafood in Australia from 2016-2017 to 2021-2022, is summarised in Table 7 (Tuynman et al., 2023). The apparent consumption is the sum of edible production and edible imports, less edible exports. As can be seen in Table 7, from 2016-17 to 2021-22, imported seafood is responsible for over 60% of total apparent consumption in Australia.

Australian seafood consumption data from the 27th Australian Total Diet Study (ATDS) (FSANZ, 2021) is summarised in Table 8. Mean food consumption for consumers and respondents is shown for those two years and above. Amongst the food categories surveyed in the 27th ATDS, the highest mean consumption amongst consumers was reported for “*commercial crumbed, battered or coated fish (excluding salmon and tuna)*” (92 grams/day), followed by “*freshwater fish (no crumbs, batter or coating)*” (54 grams/day), “*tuna*” (41 grams/day), “*salmon*” (31 grams/day) and “*saltwater fish (no crumbs, batter or coating)*” (23 grams/day). Consumption data reported in the 27th ATDS cannot be compared with data reported in the 26th ATDS, due to differences in the categorisation of food groups and what has been reported.

Table 7: Apparent consumption of seafood in Australia

		Units	2016–17	2017–18	2018–19	2019–20	2020–21	2021-22 [2]
Total	Production of edible seafood [1]	tonne	165,860	170,522	178,619	176,318	195,996	191,735
	Imports of edible seafood	tonne	226,386	221,589	221,466	207,047	222,290	225,806
	Exports of edible seafood	tonne	51,371	50,741	45,763	55,914	62,960	67,534
	Total apparent consumption of seafood	tonne	340,875	341,369	354,322	327,451	355,326	350,006
	Import share of apparent seafood consumption	%	66.4	64.9	62.5	63.2	62.6	64.5
By commodity	Salmons [1]	kg per person	2.1	2.0	1.9	2.0	2.1	1.8
	Tunas [1]	kg per person	2.0	1.9	1.9	1.9	1.7	1.8
	Prawns	kg per person	2.0	2.1	2.0	1.8	2.1	2.2
	Oysters	kg per person	0.5	0.4	0.4	0.4	0.5	0.5
	Scallops	kg per person	0.4	0.4	0.3	0.3	0.3	0.3
	Lobster	kg per person	0.1	0.1	0.1	0.1	0.1	0.2
	Crab	kg per person	0.2	0.2	0.2	0.2	0.2	0.2
	Other seafood	kg per person	6.5	6.6	7.1	6.2	6.9	7.0
	Total seafood	kg per person	13.9	13.7	14.0	12.8	13.8	13.8

[1] *Wild-caught and aquaculture finfish production volumes are expressed on an edible weight basis, estimated using FRDC species-specific conversion rates from fishfiles.com.au.*

[2] *Preliminary.*

Table 8: Product consumption data for Australian consumers

	Mean food consumption (grams per day)	
Food category	Consumer [1]	Respondent [2]
Commercial crumbed, battered or coated fish (excluding salmon and tuna)	92	5
Crustacea	17	2.3
Freshwater fish (no crumbs, batter or coating)	54	0.68
Molluscs	5.3	0.63
Salmon	31	2.9
Saltwater fish (no crumbs, batter or coating)	23	5.6
Squid and octopus	16	0.52
Tuna	41	4.5

[1] *Consumer – A respondent in a nutrition survey who reports consuming a particular food within the previous 24 hours.*

[2] *Respondent – Any person included in a nutrition survey, irrespective of whether they are reported consuming a particular food of interest or not.*

Hazard characterisation

Overview of foodborne illness and seafood products in NSW from 2016 to 2020

The previous seafood risk assessment (NSW Food Authority, 2017b) provided an overview of all foodborne illness outbreaks associated with seafood in NSW between 2005 to 2015. The current risk assessment includes discussion of foodborne illness outbreaks associated with seafood in NSW from 2016 to 2020.

Table 9 displays a summary of the total number of foodborne or potentially foodborne disease outbreaks investigated in NSW from 2016 to 2020, as well as the number of these outbreaks in which seafood; alone or in a complex food(s), was specifically identified as the responsible vehicle (Communicable Diseases Branch, 2017, 2018b, 2019a, 2019b, 2022). As can be seen in Table 9, the suspected/responsible food vehicle was identified in only a minority of the total outbreaks (43% ± 17%). A possible explanation for this is the delay between consumption of foods and reporting of illness, which impairs case recall of foods and ingredients consumed. This also reduces the ability of the NSW Food Authority to obtain specimens of implicated foods and timely environmental samples. In addition, not all reported outbreaks can be properly investigated due to factors such as lack of cooperation from cases (an outbreak is often reported by one case, representing many cases who may not want to collaborate) and prioritisation of resources. It is therefore acknowledged that the role of various food commodities as vehicles of foodborne disease may be underestimated.

Table 9: Summary of foodborne or potentially foodborne disease outbreaks reported in NSW from 2016 to 2020

	2016	2017	2018	2019	2020
Total number of foodborne or potentially foodborne disease outbreaks	70	38	50	58	31
Number of people affected in all outbreaks	> 1,625	> 437	> 560	> 604	> 443
Percentage of all outbreaks in which the suspected/responsible vehicle was known	36% (25/70)	26% (10/38)	32% (16/50)	67% (39/58)	55% (17/31)
Total number of outbreaks in which seafood; alone or in a complex food(s), was specifically identified as the suspected/responsible vehicle	6	1	7	8	5

Seafood; alone or in a complex food(s), was specifically identified as the responsible vehicle in 27 outbreaks from 2016 to 2020 (Table 9). One to eight outbreaks were linked to seafood or seafood-related dishes each year from 2016 to 2020 (Table 9).

Information on each of the 27 outbreaks is summarised in Table 10. The 27 outbreaks were due to histamine poisoning (n = 17), ciguatera toxin (n = 5), norovirus (n = 2), *L. monocytogenes* (n = 1) and unknown agents (n = 2). Where there were multiple occurrences, tuna was the food vehicle responsible for the majority (11/27; 41%) of seafood related outbreaks, followed by Spanish mackerel (n = 3), kingfish (n = 2) and oysters (n = 2). In all foodborne incidents involving tuna (n = 11) and kingfish (n =2), histamine was the agent responsible. In all foodborne incidents involving Spanish mackerel (n = 3), ciguatera toxin was the agent responsible. In all foodborne incidents involving oysters (n = 2), norovirus was the agent responsible. Smoked salmon was the food vehicle responsible for the outbreak involving *L. monocytogenes*.

In one of the 27 outbreaks, the suspected or responsible vehicle could be confidently assumed to have been consumed raw. This outbreak involved tuna sashimi in 2016. Sashimi (unknown fish type) was also listed as a suspected or responsible vehicle in an outbreak in 2020, however seafood and vegetable tempura were also reported to be an alternate suspected or responsible vehicle.

Private residences' were the most common outbreak setting and were implicated in 44% (12/27) of all seafood-related outbreaks. The other outbreaks were linked to restaurants (9/27), take-away establishments (3/27), community settings (2/27) and a commercial caterer (1/27).

Table 10: Foodborne disease outbreaks reported in NSW between 2016 and 2020, in which seafood; alone or in a complex food(s), was specifically identified as the responsible vehicle

Year	Month of onset	Setting	Pathogen	No. affected	No. hospitalised	Suspected or responsible vehicle
2020	November	Restaurant	Histamine	2	0	Kingfish
	September	Restaurant	Unknown	2	0	Either seafood and vegetable tempura or Sashimi (unknown fish type)
	July	Private Residence	Histamine	3	1	Tuna steaks
	February	Restaurant	Unknown	3	0	Calamari
	January	Take-away	Histamine	3	0	Kingfish steak
2019	December	Commercial caterer	Histamine	12	0	Tuna
	November	Restaurant	Histamine	6	1	Mahi mahi
	October	Community	Histamine	5	1	Marlin
	July	Community	*Listeria monocytogenes*	2	2	Smoked salmon
	July	Private Residence	Ciguatera toxin	5	0	Redthroat emperor fish
	May	Restaurant	Histamine	2	0	Tuna burger patties
	March	Private Residence	Histamine	2	0	Tuna steaks
	January	Restaurant	Histamine	2	2	Tuna steaks
2018	November	Take-away	Histamine	1	0	Fish
	November	Private Residence	Histamine	1	0	Tuna steaks
	May	Private Residence	Histamine	1	Unknown	Tuna steaks

Year	Month of onset	Setting	Pathogen	No. affected	No. hospitalised	Suspected or responsible vehicle
	March	Take-away	Histamine	2	2	Canned tuna
	March	Private Residence	Histamine	2	0	Tuna steaks
	March	Private Residence	Ciguatera toxin	4	0	Mackerel
	February	Private Residence	Histamine	6	3	Tuna (yellow fin)
2017	February	Restaurant	Ciguatera toxin	4	4	Grouper fish
2016	April	Private Residence	Ciguatera toxin	5	2	Spanish mackerel
	April	Private Residence	Ciguatera toxin	4	0	Spanish mackerel
	January	Restaurant	Histamine	2	2	Tuna sashimi
	January	Private Residence	Histamine	3	1	Tilapia fish
	January	Private Residence	Norovirus	7	0	Oysters
	January	Restaurant	Norovirus	4	0	Oysters

Other notable foodborne disease outbreaks associated with seafood in NSW

The following section describes notable outbreaks that occurred in NSW, some of which were not reported in the 2016 – 2020 annual NSW reports of the Communicable Diseases Branch (Table 10).

The OzFoodNet network publishes annual reports of foodborne disease at the national level. At the time of writing, annual national reports from 2001 to 2017 could be accessed online (DHAC, 2023). The OzFoodNet annual reports contain further information on a select number of significant outbreaks. As a situation evolves, new findings may lead to differing conclusions over time.

Additional information on the select outbreaks described below, was sourced from the published meeting outcomes of the NSW Shellfish Committee and peer-reviewed journal articles.

An outbreak in NSW involving Hepatitis A and imported clams was reported by the Communicable Diseases Branch (Communicable Diseases Branch, 2019b), however the suspected / responsible vehicle was initially reported as imported products / unknown.

Vibrio and oysters

Documented foodborne outbreaks associated with non-choleragenic *Vibrio* are rare in Australia (Harlock et al., 2022). In an overview of non-cholera vibriosis outbreaks recorded in Australia between 2002 and 2019, where *Vibrio* species were confirmed from clinical specimens, five outbreaks were identified (Harlock et al., 2022). Two *V. parahaemolyticus* outbreaks were recorded, both with an unknown source (unidentified source in New South Wales in 2002 and Tasmania in 2005). Subsequently, two *V. parahaemolyticus* outbreaks were recorded in 2016, originating from oysters from Tasmania (TAS) and SA. An outbreak in NSW in February 2017 occurred due to oysters from TAS contaminated with *Vibrio albensis*, which resulted in three cases and one hospitalisation (OzFoodNet Working Group, 2022).

Significant events have since been recorded in SA (2021/2022) and NSW (2024). An overview of a *V. parahaemolyticus* outbreak was provided at the meeting of the NSW Shellfish Committee in May 2024 (NSW Food Authority, 2024g). In February 2024 the NSW Food Authority were made aware of three interstate cases of *V. parahaemolyticus* illnesses associated with NSW oysters. Further investigation by NSW Health and the NSW Food Authority identified 35 cases of *V. parahaemolyticus* illness from January to March 2024, with 30 cases associated with the consumption of NSW oysters. The marine heat wave experienced along the Australian east coast during the summer of 2023/24 created environmental conditions that significantly increased vibriosis risk factors. Enhanced *Vibrio* risk management guidance material was developed to assist industry to manage this risk and the Food Authority continued to work with the NSW shellfish industry to develop and implement best practice requirements.

Hepatitis A and imported clams

Hepatitis A is spread through contact with people infected with the disease, their fluids or waste. Hepatitis A is not common in Australia and most people acquire their infection when travelling overseas (NSW Health, 2022). Vaccination can protect against hepatitis A.

In 2019 between July and August, a genetic cluster of locally acquired hepatitis A cases was identified amid a rise in other cases imported from South Korea (Communicable Diseases Branch, 2019b). There was a total of four local cases, all which were hospitalised. All cases were South Korean born residents of NSW. Cases had no recent travel, except one case who spent approximately 20% of the 50-day incubation period in South Korea. All cases reporting buying their groceries from Korean grocery stores.

Phylogenetic analysis indicated the sequences seen in these cases matched a sequence seen in previous travellers to South Korea. At the time South Korea was experiencing a Hepatitis A epidemic, with over 12,000 cases reported from year to date in South Korea as of September 2019. Reports indicated possible links with salt clams (jeotgal). The sequence also matched a historical (2016) NSW case who was also a South Korean national who had not travelled outside of NSW during their incubation period.

A Korean specific food questionnaire was developed to capture imported Korean foods that had the potential to be contaminated with hepatitis A virus. The NSW Food Authority conducted an investigation cross-checking implicated food brands sold at the grocery stores visited by each case. The investigation resulted in a consumer recall of two imported salted clam brands.

Methemoglobinemia and prawns

On 13 November 2019, a public health unit in Sydney was notified of two unrelated patients who presented on the previous day to different emergency departments with methaemoglobinaemia (O'Neill et al., 2021). Both had sudden symptom onset after dining at the same restaurant, raising suspicion that these presentations were linked to contaminated food, prompting an investigation (O'Neill et al., 2021). Subsequent review by the NSW Poisons Information Centre found that both patients had ingested the same prawn dish at a restaurant, developing symptoms 15–30 minutes after consumption (O'Neill et al., 2021).

Methemoglobinemia is a sporadic, potentially fatal disease of poor tissue oxygenation in which ferrous haemoglobin (Fe^{2+}) is oxidized to the ferric (Fe^{3+}) state, rendering it incapable of binding oxygen (O_2) (McNulty et al., 2022). Fortunately, methaemoglobinaemia is diagnosable and treatable.

The first signs of methaemoglobinemia may be cyanosis[2] and mild shortness of breath, progressing through to cardiovascular and neurological sequelae of profound tissue hypoxia[3], culminating in coma and death from cardiac arrest (McNulty et al., 2022). Hereditary causes of methaemoglobinaemia are well described but rare (Maric et al., 2008). Reported clinical cases are mostly acquired and arise from exposure to an array of oxidants found in industrial chemicals, recreational and therapeutic drugs, well water and foods (McNulty et al., 2022). In food-related methemoglobinemia cases, nitrites and nitrates are the most common oxidizing agents found in food and patient tissue samples (McNulty et al., 2022).

The investigation undertaken identified that sodium nitrate was being used as a colour preservative for prawns and that it was likely present in the dish consumed by the patients (O'Neill et al., 2021). Others who consumed the contaminated prawns were unable to be confirmed. No leftover prawns were available for testing.

In Australia, nitrate and nitrite use in commercial premises must comply with the Code. Schedule 15 of the Code permits the addition of these additives to select dairy and processed meat products, to a maximum level specific to the food type. Addition of either nitrate or nitrite to prawns is a breach of the Code. The breach resulted in enforcement action and the establishment was fined.

Foodborne disease outbreaks in other Australian states and jurisdictions

The previous seafood risk assessment provided a summary of Australian foodborne illness outbreaks attributed to seafood and seafood products from 1995 to 2008 (NSW Food Authority, 2017b). During this period, histamine poisoning (n = 11) was the reported cause of the largest number of outbreaks. The remaining outbreaks, for which the specific agent responsible was identified, were due to *Salmonella* non-typhi (n = 9), ciguatoxin (n = 4) and norovirus (n = 3). All *Salmonella* outbreaks were reported to be due to cross-contamination from egg or when egg was used as an ingredient. There were no fatalities for any outbreak attributed to fish and seafood products from 1995 to 2008.

The following section provides an update on national foodborne illness outbreaks attributed to seafood and seafood products, as reported in the OzFoodNet Annual Reports from 2009 to 2017 (DHAC, 2023). It should be noted that there are limitations on the data used in the Annual Reports, due to variation amongst states and territories in which enteric pathogens are notifiable and how outbreaks are categorised and reported (Communicable Diseases Branch, 2018a).

In total, there were 121 seafood related outbreaks nationally from 2009 to 2017, with an average of 13 outbreaks each year (Table 11). The highest number of seafood associated outbreaks were due to ciguatera toxin (n = 67), followed by histamine (n = 24) (Table 11). The remaining outbreaks, for which the specific agent responsible was identified, were due to norovirus (n = 6), fish wax ester (n = 3), *V. parahaemolyticus* (n = 2), *V. albensis* (n = 1), *Salmonella* (n = 1), PST poisoning (n = 1) and *Campylobacter jejuni* (n = 1).

Ciguatera toxin was responsible for a total of 67 foodborne illness outbreaks nationally from 2009 to 2017. From 2009 to 2013, all outbreaks reported were in Queensland (QLD) (n = 24). While the majority of the 43 outbreaks reported from 2014 to 2017 occurred in QLD (n = 35), outbreaks were also reported in NSW (n = 7) and Victoria (VIC) (n = 1). From 2009 to 2017, the majority of outbreaks were associated with consumption of coral trout (n = 22). The remaining outbreaks were attributed to consumption of Spanish mackerel (n = 20), mackerel (n = 4), cod (n = 3), red throat emperor (n = 2), blue spot coral trout (n = 1), red coral trout (n = 1), coral perch (n = 1), red bass (n = 1), grouper (n = 1), passionfruit trout (n = 1), mangrove jack fish (n = 1), yellow tailed kingfish (n = 1) and flowery cod (n = 1). Four outbreaks were due to an unspecified fish species and three outbreaks were reported to be due to consumption of multiple fish species. From 2016, the OzFoodNet network annual reports started providing specific information on whether the fish consumed was caught by recreational

[2] Cyanosis is a bluish colour of mucous membranes and/or skin. While cyanosis is most frequently attributable to increased amounts of unoxygenated haemoglobin, there are other causes of bluish skin colour.

[3] Hypoxia is a deficiency in the amount of oxygen in tissue.

fisherman or purchased at retail. In 2016, nine outbreaks were due to the consumption of fish caught by recreational fisherman and five were associated with fish purchased from retail premises. In 2017, seven outbreaks were due to the consumption of fish caught by recreational fisherman, one outbreak was due to consumption of fish at a restaurant and one outbreak was due to consumption of a fish that had been purchased at a market in Fiji by an individual and transported to Australia (where it was consumed).

In total there were 24 histamine foodborne illness outbreaks nationally from 2009 to 2017, with outbreaks occurring in every year apart from 2017. Outbreaks were reported in four jurisdictions, including NSW (n = 8), QLD (n = 8), VIC (n = 6) and the Australian Capital Territory (ACT) (n = 2). The majority of outbreaks were associated with consumption of tuna (n = 11). The remaining outbreaks were attributed to consumption of mahi mahi (n = 3), mackerel (n = 1), butterfish (n = 1), tilapia (n = 1), yellow-tail kingfish (n = 1), mullet (n = 1) and bonito (n = 1). An outbreak in 2009 in NSW was attributed to imported tinned anchovies from Morocco. Three outbreaks were reported for which a specific fish type was not identified as the responsible vehicle.

Norovirus was responsible for six outbreaks, all of which were due to the consumption of contaminated oysters. Three outbreaks originated from oysters in NSW (1 outbreak in 2012 and 2 outbreaks in 2016). Two outbreaks in 2012 were linked to oysters from QLD. Tasmanian oysters resulted in 525 cases in 2013.

Fish wax ester was responsible for foodborne illness outbreaks in 2009 (n = 2) and 2013 (n = 1). Further detail was provided for two of the outbreaks, both of which occurred in VIC. The outbreak that occurred in 2013 was due to consumption of rudderfish. Further detail was also provided on one of the two outbreaks which occurred in 2009, in which 27 people were affected after consuming escolar.

In 2016 there were two separate *V. parahaemolyticus* outbreaks linked to oysters, both outbreaks were previously briefly described. Tasmanian oysters were the source of one outbreak affecting 11 people. South Australian oysters were implicated in a second outbreak affecting nine people. The 2017 outbreak of *V. albensis* in NSW associated with oysters, was also described in the previous section.

In 2014, there was one outbreak in SA of *Campylobacter jejuni* in which prawns served at a restaurant were the responsible vehicle. The prawns were believed to be cross contaminated from other raw ingredients.

In 2015, there was one outbreak in TAS of PST poisoning in which mussels were the responsible vehicle.

In 2017, a *Salmonella* outbreak was attributed to the consumption of seafood and the responsible vehicle was reported to be a green turtle (i.e. a reptile). It should be noted that the definition of seafood stated in clause 123 of Food Regulation 2025 includes aquatic vertebrates and aquatic invertebrates intended for human consumption, but specifically excludes amphibians, mammals or reptiles and aquatic plants.

There were no fatalities for any outbreak attributed to the consumption of seafood from 2009 to 2017.

Table 11: Summary of Australian foodborne outbreaks attributed to seafood from 2009 to 2017 (c = cases, h = hospitalisations)

Agent	2009	2010	2011	2012	2013	2014	2015	2016	2017
Ciguatoxin	2 (c = 5, h = 4)	6 (c = 22, h = 4)	5 (c = 17, h = 0)	2 (c = 4, h = 0)	9 (c = 26, h = 7[1])	15 (c = 80, h = 12[1])	5 (c = 18, h = 2)	14 (c = 56, h = 5)	9 (c = 32, h = 5)
Histamine	3 (c = 10, h = 2)	1 (c = 4, h = 0)	2 (c = 6, h = 3)	6 (c = 21, h = 0)	2 (c = 7, h = 0)	3 (c = 12, h = 2)	3 (c = 12, h = 2)	4 (c = 9, h = 3)	-
Norovirus	-	-	-	3 (c = 18, h = 0)	1 (c = 525, h = 1)	-	-	2 (c = 11, h = 0)	-
Vibrio parahaemolyticus	-	-	-	-	-	-	-	2 (c = 20, h = 4)	-
Salmonella	-	-	-	-	-	-	-	-	1 (c = 20, h = 2) (*S. Muenchen* / green turtle meat)
Vibrio albensis	-	-	-	-	-	-	-	-	1 (c = 3, h = 1)
Fish wax ester	2 (c = 30, h = 0)	-	-	-	1 (c = 4, h = 0)	-	-	-	-
Paralytic shellfish poisoning	-	-	-	-	-	-	1 (c = 4, h = 2)	-	-
Campylobacter jejuni	-	-	-	-	-	1 (c = 22, h =2)	-	-	-
Unknown	2 (c = 5, h = 1)	2 (c = 8, h = 0)	1 (c = 4, h = 4)	2 (c = 8, h = 0)	1 (c = 4, h = 0)	2 (c = 4, h = 0)	-	3 (c = 27, h = 0)	2 (c = 23, h = 0)

Agent	2009	2010	2011	2012	2013	2014	2015	2016	2017
TOTAL	9 (c = 50, h = 7)	9 (c = 34, h = 4)	8 (c = 27, h = 7)	13 (c = 51, h = 0)	14 (c = 566, h = 8[1])	21 (c = 118, h = 16[1])	9 (c = 34, h = 6)	25 (c = 123, h = 12)	13 (c = 78, h = 8)

[1] *The exact number of hospitalisations were reported to be unknown.*

International outbreaks and recall data related to seafood products

The following section contains an overview of foodborne illness, outbreak and recall data associated with seafood and seafood products compiled by various international agencies.

New Zealand

Annual reports concerning foodborne disease in New Zealand can be accessed on the website of the Ministry for Primary Industries (Ministry for Primary Industries, 2024). The annual reports include data from the New Zealand notifiable disease surveillance system (EpiSurv), as well as data on patient admission and discharge from publicly funded hospitals from the National Minimum Dataset (NMDS). It should be noted that EpiSurv and the NMDS database are separate systems and hospital admission can occur without cases being notified in EpiSurv.

The following section contains an overview of foodborne outbreaks in New Zealand from 2017 to 2023, in which the suspected vehicle was seafood. Consumption of contaminated seafood is a recognised transmission route for ciguatera poisoning, histamine poisoning and toxic shellfish poisoning. Therefore, as well as providing information on outbreaks, individual cases of ciguatera poisoning, histamine poisoning and toxic shellfish poisoning are described in the following section. However, it should be noted that in addition to fish and fish products, ripened cheeses may also be a source of histamine poisoning.

Histamine poisoning outbreaks were reported annually in 2017 (n = 2), 2018 (n = 2), 2019 (n = 3), 2020 (n = 1), 2021 (n = 1), 2022 (n = 1) and 2023 (n = 1). A single fish type was identified as the suspected vehicle in 46% (5/11) of outbreaks and included tuna (n = 2), gurnet (n = 1), trevally (n = 1) and kahawai (n = 1). Individual cases (reported in EpiSurv) and hospitalisations (reported in the NMDS database) were also reported in 2017 (cases = 9, hospitalisations = 8), 2018 (cases = 9, hospitalisations = 5), 2019 (cases = 10, hospitalisations = 9), 2020 (cases = 0, hospitalisations = 10), 2021 (cases = 6, hospitalisations = 10), 2022 (cases = 0, hospitalisations = 14) and 2023 (cases = 4, hospitalisations = 10).

Ciguatera poisoning outbreaks were reported in 2017 (n = 2), 2019 (n = 1) and 2020 (n = 1). A fish type was identified as the suspected vehicle in two of the four outbreaks and in both cases this was kawakawa (n = 2). Individual cases (reported in EpiSurv) and hospitalisations (reported in the NMDS database) were also reported in 2017 (cases = 1, hospitalisations = 6), 2018 (cases = 0, hospitalisations = 4), 2019 (cases = 10, hospitalisations = 14), 2020 (cases = 0, hospitalisations = 2), 2021 (cases = 1, hospitalisations = 2), 2022 (cases = 0, hospitalisations = 2) and 2023 (cases = 0, hospitalisations = 3).

The first recorded *V. parahaemolyticus* outbreak in New Zealand since 2009 occurred in 2019 and was due to the consumption of mussels. *V. parahaemolyticus* outbreaks were also reported in 2020 (n = 1) and 2021 (n =2). Raw mussels were the suspected vehicle in outbreaks in 2020 and 2021, while raw oysters were the suspected vehicle in a later outbreak in 2021.

Salmonella Weltevreden was responsible for an outbreak in 2018, in which the suspected vehicle was raw sea cucumber from Samoa. *Salmonella* Typhimurium was responsible for an outbreak in 2020 in which the suspected vehicle was retail purchased raw fish, raw mussels and kina.

In each year a single *Shigella* outbreak was reported in 2017, 2019, 2022 and 2023. In each case the suspected vehicle was imported and included raw fish/shellfish from Tonga (2017), fish from Tonga (2019), dried tuna from the Pacific Islands (2022) and imported raw kina.

Hepatitis A virus was responsible for an outbreak involving four confirmed cases associated with the consumption of shellfish in a home setting in 2018.

Norovirus outbreaks occurred in 2017 (n = 4), 2020 (n = 1), 2021 (n = 1), 2022 (n = 1), 2023 (n = 1). Oysters were responsible for all four outbreaks in 2017 and the outbreak that occurred in 2022. Crayfish sandwiches were identified as the responsible vehicle in the 2023 outbreak. Oysters were also the suspected vehicle in the outbreak that occurred in 2021, with possible contamination from oyster harvesting worker(s). Food handlers were also identified as the source of the outbreak in 2020, in which the suspected vehicle responsible was marinated fish entrees.

There were no outbreaks of toxic shellfish poisoning reported in EpiSurv from 2017 to 2023. The last outbreaks in New Zealand were in 2014 (13 cases) and 2012 (29 cases). Individual cases (reported in EpiSurv) and hospitalisations (reported in the NMDS database) were reported for toxic shellfish poisoning in 2017 (five cases), 2018 (3 cases), 2019 (2 cases), 2021 (3 cases, 4 hospitalisations), 2022 (2 cases, 4 hospitalisations) and 2023 (7 hospitalisations). For some cases, further information was provided on the suspected vehicle responsible and / or whether it was a recreational catch or a retail purchase. All three cases in 2018 reported eating recreationally collected seafood. In 2019, one case was linked to cooked squid from a food outlet and the second case was linked to raw and cooked recreationally collected tuatua. In 2022 it was reported that one case consumed raw recreationally gathered kina, while the other case consumed prawns, clams and scampi. While no toxic shellfish poisoning outbreaks were reported in EpiSurv in 2023, two suspected shellfish poisoning outbreaks in the Auckland Public Health Service region were referred to New Zealand Food Safety (NZFS). The two cases associated with the first outbreak had consumed steamed mussels from a food service outlet as the suspected source. The seven cases associated with the second outbreak had consumed oysters as the suspected source, however, case symptoms were more consistent with a bacterial or viral infection than shellfish poisoning. Cases consumed oysters just prior to a trade level recall of oysters due to the detection of paralytic shellfish poison in the growing area.

Canada

The Canadian Food Inspection Agency (CFIA) reports on food safety incidents that have caused serious illnesses in Canada or have otherwise significant interest to the Canadian public (CFIA, 2024). At the time of writing, there were no reports published on food safety incidents associated with seafood between 2012 and November 2024. However, 56 recalls and safety alerts had been issued for fish and seafood products between the 29/10/2021 and 19/11/2024 (Government of Canada, 2024).

The majority of the recalls were due to the presence of undeclared allergens (n = 32). Recalls also resulted from the presence of norovirus (n = 8), *Cl. botulinum* (n = 3), histamine (n = 2), PSP (n = 1), *V. parahaemolyticus* (n = 1) and *L. monocytogenes* (n = 1).

Oysters were the commodity responsible for all recalls involving norovirus (n = 8), PSP (n = 1) and *V. parahaemolyticus* (n = 1). Both recalls due to histamine were from dried fish, including silver fish and anchovies. Recalls due to the presence of *Cl. botulinum* involved bottled clams (n = 2) and cold smoked salmon (n = 1). *L. monocytogenes* resulted in a recall of smoked salmon.

In addition, there were three cases of oysters being recalled due to generic *E. coli*, one case of oysters being recalled due to improper harvest authorisation and one case of sardines being recalled due to container integrity defects. Presence of the synthetic, broad-spectrum antibacterial drug nitrofuran was responsible for recalls involving frozen white shrimp (n = 2) and frozen tilapia fish (n = 1).

USA

The Centers for Disease Control and Prevention (CDC) established the National Outbreak Reporting System (NORS) to capture data on foodborne, waterborne and enteric illness outbreaks in the United States (CDC, 2024). NORS is a web-based platform that relies on voluntary reporting by state, local, and territorial public health agencies to detect, investigate and report outbreaks. Therefore, the NORS outbreak data likely represents a small proportion of actual cases of foodborne illness, with many outbreaks unrecognised and/or unreported.

Data was downloaded from the NORS dashboard on the 10/7/2024 for all foodborne outbreaks that occurred during 2017 to 2021 with the Interagency Food Safety Analytics Collaboration (IFSAC) Food Category of “fish” and “shellfish”. In total, the 150 outbreaks resulted in 549 illnesses and 46 hospitalisations. No fatalities were reported. The agent responsible was unspecified for a minority of the outbreaks (5%, 7/150). Only one outbreak was reported to be multistate and was due to *Salmonella enterica* contaminated smoked fish, which resulted in 7 illnesses and 1 hospitalisation.

The food vehicle responsible for each outbreak is described in the section below as reported in data downloaded from the NORS dashboard. However, it should be noted that broader categorisations for fish species have been adopted in published studies reporting on foodborne outbreak data collected from NORS for tuna (tuna, ahi, albacore, yellowfin, yellowtail and skipjack), mahi mahi (mahi mahi and roi) and jack (jack, amberjack, almaco jack, hamachi, ulua and papio) (Sheng & Wang, 2021).

Ciguatoxin was responsible for the majority of outbreaks due to fish and shellfish (54%, 81/150). The type of fish responsible was specified in 89% (72/81) of ciguatoxin outbreaks. Of these, multiple ciguatoxin outbreaks were associated with baraccuda (n = 27), grouper (n = 6), hogfish (n = 6), king mackerel (n = 5), mutton snapper (n = 4), amberjack (n = 3), jack (n = 2), snapper (n = 2), kingfish (n = 2), kole (n = 2) and ulua (n = 2). A single ciguatoxin outbreak was associated with consumption of each of roi, triggerfish, palani/surgeon, crevalle jack, almaco jack, red grouper, seabass, sheepshead, yellowtail snapper, red snapper and silk snapper.

Histamine poisoning was the second most common agent responsible for foodborne outbreaks due to fish and shellfish (31%, 46/150). Of these, the type of fish responsible was specified in 93% (43/46) of histamine outbreaks. Multiple histamine outbreaks were reported due to consumption of tuna (n = 21), mahi mahi (n = 8), ahi tuna (n = 6) and amberjack (n = 2). One histamine food poisoning outbreak was attributed to each of escolar, salmon, snapper, wahoo, marlin and tilapia.

Norovirus was responsible for six outbreaks (6/150), associated with consumption of either seafood nachos, fish tacos, fried basa fish, sole fish, baked flounder and tuna fish sandwiches.

V. parahaemolyticus was listed as a confirmed (n = 2) or suspected (n = 1) agent in a total of three outbreaks, of which crawfish/crayfish were responsible for two outbreaks and the remaining outbreak was due to consumption of raw oysters.

Giardia was responsible for one outbreak involving oysters.

There was one outbreak each in which the suspected agent was *V. vulnificus* in tilapia fish, *Bacillus cereus* in fish and *Cl. botulinum* in white fish.

Outbreaks were also reported for an unspecified chemical/toxin in buffalo fish (n = 1) and paralytic shellfish poison in pufferfish (n = 1).

The following section describes two notable outbreaks not captured in the data downloaded from the NORS database.

Other notable foodborne disease outbreaks associated with seafood in the USA

Salmonella and finfish

Salmonella Thompson is a relatively uncommon serotype not typically associated with seafood. A multistate outbreak of *Salmonella* Thompson was linked to seafood exposure in the USA in 2021 (Shen et al., 2023). The outbreak resulted in a total of 115 cases from 15 states. Twenty (26%) patients were hospitalised, no deaths were reported. Implicated seafood products were traced to a single seafood distributor, in which the outbreak strain was identified through environmental sampling in 13 (9.8%) of 132 environmental swabs of the facility’s floor and floor drains. The inspection identified several opportunities for cross-contamination of raw fish, including the use of high-pressure hoses that produced backsplash onto fresh product. Other substantial findings included insufficient sanitiser concentration, condensation dripping onto product contact surfaces and using gloved hands to remove water from floor drains without changing gloves after contact with the drains. The distributor issued a voluntary recall of 16 seafood items with high potential for contamination and completed remediation actions. This outbreak illustrated the importance of effective cleaning and sanitising procedures and implementation of controls.

Campylobacter and oysters

From September to November 2021, the Rhode Island Department of Health (RIDOH) detected and responded to an outbreak of eight *Campylobacter* cases linked to the consumption of raw oysters from a farm-to-table restaurant (Caron et al., 2023). This was the first *Campylobacter* outbreak linked to oysters on Rhode Island. Oysters and other shellfish are not foods that are commonly highlighted as high risk for *Campylobacter* contamination. Caron et al. (2023) reported that analysis of the CDC's NORS data revealed that only 1.2% (12/996) of all 996 *Campylobacter* outbreaks detected in the USA since the 1970s were confirmed or suspected of having shellfish as a source of the outbreak.

A review of the growing area conditions during the summer and fall of 2021 found no evidence of widespread elevated faecal coliform in the water, based on growing area water sample monitoring results. A shoreline survey update found no large faecal coliform shoreline sources flowing or potentially flowing into the growing area. There were no failed onsite wastewater treatment systems and there were no complaints about malfunctioning systems adjacent to the growing area throughout all of 2021. Investigation of nearby agricultural operations showed no potential farm animal sources of bacterial contamination. Phytoplankton data showed the absence of potentially harmful blooms. Water temperature and air temperatures were similar to those typically observed during prior years.

The single prevailing issue identified during the environmental assessment of the oyster farm was the presence of flocks of wild birds. *Campylobacter* is known to reside in the gastrointestinal tracts of wild and domesticated birds. Flocks of wild cormorants and gulls had frequently been observed at the oyster farm and were observed to land on the floating gear. Contamination of the growing area waters on the lease by flocks of birds roosting on floating gear and defecating in the lease was therefore the presumed mechanism for *Campylobacter* contamination of the oysters.

As a result of the outbreak response, several investigative processes and best practice recommendations were made in the hope that increased awareness and mitigation of risk factors would help prevent future similar outbreaks of illness. To begin, RIDOH included exposure to raw shellfish as a question on their case report forms to better identify future oyster-related *Campylobacter* clusters. The outbreak also highlighted that increased awareness was required at shellfish aquaculture farms around the risks of using floating gear to hold oyster cages and of the importance of using bird abatement to keep birds off floating aquaculture gear to prevent contamination of oysters from bird faeces. It was also made evident that it was important to communicate the findings of the investigation and that faecal coliform water samples collected near an oyster aquaculture farm may not act as an adequate indicator for the presence of *Campylobacter*. Finally, at the time of the outbreak there were no national guidelines available for closing or reopening shellfish harvest areas due to *Campylobacter* contamination by the USA FDA's National Shellfish Sanitation Program (NSSP). This resulted in the development of guidelines for the closure and reopening of oyster harvest areas due to contamination with *Campylobacter* in Rhode Island. The reopening criteria included a 2-week natural depuration time, successful bird abatement, three rounds of negative *Campylobacter* samples, three rounds of faecal coliform levels below 230 MPN/100 g in the oysters and, water samples that met faecal coliform guidelines.

The outbreak illustrated the need to consider the risk of contamination and the ability for *Campylobacter* to survive, given the characteristics of the water (for example, salinity, temperature, etc.) in a particular aquaculture harvest location.

Europe

The European monitoring system for foodborne diseases and zoonoses from animals, food and feed relies on the annual collection of information from EU member states. The European Commission (EC) has directed the EFSA and the European Centre for Disease Control and Prevention (ECDC) to collect and analyse data from EU member states. Annually, these data sets are jointly published in the One Health zoonoses report (EFSA and ECDC, 2019, 2021a, 2021b, 2022, 2023). An overview of the data and related statistics is also provided on EFSA's interactive foodborne outbreak dashboard (EFSA, 2024).

Outbreaks are categorised as having ‘strong evidence’ or ‘weak evidence’ based on the strength of evidence implicating a suspected food vehicle. The evaluation of the strength of evidence implicating a suspected food vehicle is based on the assessment of all available types of evidence (that is, microbiological, epidemiological, descriptive environmental, trace-back of the investigated foodstuffs). The following overview focuses on foodborne outbreaks reported between 2018 and 2022 where the evidence implicating a particular food vehicle was strong. Strong evidence outbreaks represent a minority of all reported outbreaks and therefore the role of various food commodities as vehicles of foodborne disease may be underestimated.

Information was obtained from EFSA’s foodborne outbreak dashboard (EFSA, 2024) on the annual number of strong evidence foodborne outbreaks between 2018 and 2022 related to fish and fishery products and the resulting number of cases, hospitalisations and deaths. It is important to note that monitoring and surveillance schemes for most zoonotic agents are not harmonised among European member states and the interpretation of pooled data requires caution. In addition, the number of reporting member and non-member EU states fluctuated across 2018 (n = 30), 2019 (n = 30), 2020 (n = 25), 2021 (n = 26) and 2022 (n = 30).

The total number of strong evidence outbreaks from all food vehicles fluctuated from over 800 in 2018 (n = 807) and 2019 (n = 811), dipping in 2020 (n = 276), 2021 (n = 383) and 2022 (n = 525). Of these, outbreaks linked specifically to fish and fishery products were reported in 2018 (n = 120), 2019 (n = 199), 2020 (n = 70), 2021 (n = 55) and 2022 (n = 76). Fish and fishery product-related outbreaks accounted for between 14% and 25% of all strong evidence outbreaks from all food vehicles in 2018 (15%, 120/807), 2019 (25%, 199/811), 2020 (25%, 70/276), 2021 (14%, 55/383) and 2022 (14%, 76/525).

Information on the causative agents of ‘strong evidence’ foodborne outbreaks linked to fish and fishery products from 2018 to 2022 was accessed from EFSA’s foodborne outbreak dashboard (EFSA, 2024). In some instances, further descriptive information on various foodborne outbreaks was provided in the One Health zoonoses reports (EFSA and ECDC, 2019, 2021a, 2021b, 2022, 2023).

Of all foodborne outbreaks linked to fish and fishery products, no fatalities were reported in 2018 or 2019. All fatalities reported in 2020 (n = 10), 2021 (n = 4) and 2022 (n = 3) were due to *L. monocytogenes*. *L. monocytogenes* outbreaks were reported in 2018 (n = 1), 2019 (n = 1), 2020 (n = 8), 2021 (n = 4) and 2022 (n = 6). In those years in which multiple *L. monocytogenes* outbreaks were reported, *L. monocytogenes* was also responsible for the greatest number of hospitalisations of any causative agent in 2020 (81%, 57/70), 2021 (24%, 13/54) and 2022 (42%, 24/57).

The annual reports provide further descriptive detail on various *L. monocytogenes* outbreaks.

The 2018 annual report provided an update on a prolonged multi-country outbreak of listeriosis cases caused by *L. monocytogenes* sequence type (ST) 8 (EFSA and ECDC, 2019). In total, WGS-based analysis identified 12 patients with onset of symptoms between October 2015 and May 2018 and isolates matching the outbreak strain: six in Denmark, one in France and five in Germany (ECDC and EFSA, 2018). Four of these cases died due to or with the disease (ECDC and EFSA, 2018). It was concluded that the extent of the outbreak was underestimated, as the outbreak was identified through sequencing and only a subset of the EU/EEA countries routinely use this advanced technique to characterise *L. monocytogenes* isolates (ECDC and EFSA, 2018). The consumption of RTE cold-smoked salmon was implicated in the outbreak (EFSA and ECDC, 2019). At the time of investigation, no concluding evidence was available on whether the contamination had taken place at the primary production level or at the salmon processing factory (EFSA and ECDC, 2019).

The 2019 annual report provided an update on a prolonged multi-country outbreak of listeriosis cases caused by *L. monocytogenes* sequence type (ST) 1247, clonal complex (CC) 8 (EFSA and ECDC, 2021a). The outbreak included 22 notified cases in five EU countries (Denmark, Estonia, Finland, France and Sweden). Cases had occurred between July 2014 and February 2019. Cold-smoked fished products (cold-smoked salmon and cold-smoked trout) manufactured by an Estonian processing company were identified as the suspected source of the outbreak.

In 2020, fish and fish products had the highest number of deaths among strong-evidence outbreaks reported for this foodstuff since 2010 (EFSA and ECDC, 2021b). The most severe outbreaks caused by *L. monocytogenes* in 2020 were reported by the Netherlands and Germany. Two outbreaks were linked to the consumption of trout fillet and involved a total of 46 cases, 41 hospitalisations and seven deaths. A third outbreak caused by eel involved eight cases, all hospitalised, with one death. In the UK two deaths were also reported among cases involved in an outbreak linked to smoked salmon caused by *L. monocytogenes*.

In 2021, fish and fish products had the highest number of deaths of all strong evidence outbreaks (EFSA and ECDC, 2022). All four deaths concerned two listeriosis foodborne outbreaks identified in the Netherlands and associated with the consumption of different smoked fishes (smoked salmon, eel and mackerel).

Norovirus and other calicivirus accounted for the highest number of outbreaks of any causative agent in 2018 (40%, 48/120), 2019 (74%, 147/199), 2020 (41%, 29/70) and 2021 (35%, 19/55). Norovirus and other calicivirus also accounted for the highest number of cases of any causative agent in 2018 (64%, 849/1327), 2019 (73%, 1304/1787), 2020 (70%, 768/1094) and 2021 (41%, 147/361). In 2022, norovirus and other calicivirus accounted for the highest number of cases of any causative agent (32%, 210/652) and the second highest number of outbreaks of any causative agent (20%, 15/76) after histamine. Caliciviruses include two genus, *Norovirus* and *Sapovirus*, associated with disease in humans. Norovirus is a major cause of gastroenteritis globally and is often considered the most frequent cause of foodborne outbreaks in developed countries, while Sapovirus is less prevalent (Franck et al., 2014). It is assumed that the majority of outbreaks and cases reported were due to norovirus.

Histamine outbreaks were responsible for the second largest number of outbreaks of any causative agent in 2018 (20%, 24/120), 2019 (11%, 21/199), 2020 (20%, 14/70) and 2021 (26%, 14/55). Histamine outbreaks were also responsible for the second largest total number of human cases of any causative agent in 2018 (9%, 117/1327), 2019 (6%, 104/1787), 2020 (7%, 73/1094) and 2021 (21%, 77/361). In 2022, histamine outbreaks were responsible for the highest number of outbreaks of any causative agent (32%, 24/76) and the second highest number of cases of any causative agent (16%, 106/652).

Across each year outbreaks due to marine biotoxins were reported in 2018 (20 outbreaks, 64 cases), 2019 (10 outbreaks, 41 cases, 3 hospitalisations), 2020 (1 outbreak, 5 cases), 2021 (5 outbreaks, 17 cases) and 2022 (3 outbreaks, 11 cases, 1 hospitalisation). Marine biotoxins include ciguatoxin, saxitoxin and OA.

Where a specific causative agent was identified, the remaining outbreaks in each year were variously attributed to *Salmonella*, *Staphylococcus aureus* toxins, *Bacillus* toxins, *Cl. botulinum*, *Clostridium perfringens, Campylobacter* and *Aeromonas caviae*.

Apart from 2020, there was at least one *Salmonella* outbreak in 2018 (5 outbreaks, 100 cases), 2019 (4 outbreaks, 41 cases), 2021 (1 outbreak, 44 cases) and 2022 (8 outbreaks, 84 cases, 10 hospitalisations).

Apart from 2020, there was at least one outbreak linked to *Staphylococcus aureus* toxins in 2018 (1 outbreak, 16 cases, 2 hospitalisations), 2019 (1 outbreak, 43 cases), 2021 (2 outbreaks, 7 cases) and 2022 (2 outbreaks, 35 cases, 5 hospitalisations).

Bacillus toxins were attributed to at least one outbreak in every year: in 2018 (1 outbreak, 16 cases), 2019 (3 outbreaks, 12 cases), 2020 (1 outbreak, 3 cases), 2021 (2 outbreaks, 8 cases, 1 hospitalisation) and 2022 (1 outbreak, 16 cases, 1 hospitalisation).

Cl. botulinum was responsible for outbreaks reported in 2020 (2 outbreaks, 5 cases, 5 hospitalisations) and 2021 (1 outbreak, 5 cases, 5 hospitalisations).

Cl. perfringens was responsible for outbreaks reported in 2019 (94 cases) and 2020 (26 cases).

Campylobacter was responsible for a single outbreak reported in each year of 2019 (13 cases) and 2020 (3 cases, 1 hospitalisation).

Aeromonas caviae was responsible for a single outbreak in 2022 (3 cases, 1 hospitalisation).

Anisakis caused two outbreaks in 2020, both reported by Spain, involving six individuals (EFSA and ECDC, 2021b).

Domestic Surveys

NSW Food Authority seafood verification program

As part of the Food Safety Schemes verification program for RTE products, RTE seafood products are purchased from retail outlets or directly from manufacturers and tested against the requirements set out in the NSW Food Safety Schemes Manual (NSW Food Authority, 2025e). The results of the Food Safety Schemes verification program are published in the Annual Food Testing Reports available on the NSW Food Authority website (NSW Food Authority, 2019a, 2020a, 2020b, 2021a, 2022a, 2023a, 2024a).

All RTE seafood samples tested in 2017 – 2018 (n = 4), 2018 - 2019 (n = 1), 2019 – 2020 (n = 5), 2021 – 2022 (n = 2) and 2022 – 2023 (n = 4) were compliant.

In 2020 – 2021, no RTE seafood samples were collected for testing, as sampling was suspended on several occasions due to COVID-19 movement restrictions during the year.

In 2023 – 2024, 15% (3/20) of the RTE seafood samples collected for testing were non-compliant. The three samples were opened oysters from three different manufacturers. All three samples contained *E. coli* greater than the regulatory limit of 2.3 cfu/g. All businesses responsible for sale of non-compliant RTE products were notified and provided with guidance on control measures.

Research and targeted projects conducted by the NSW Food Authority

Algal biotoxins in wild harvest shellfish

The Food Authority undertook a biotoxin survey of wild harvest shellfish in the marketplace during the 2015, 2016 and 2017 wild harvest seasons (Farrell et al., 2018). The results of the market survey found that 99% of samples tested were below the regulatory limit for biotoxins. When toxin was detected, the predominant toxin group was DSTs (34.06 % of 323 samples were positive). Pipis were the main shellfish group sampled and DSTs were detected only in pipis (40.6 %, 110 of 271 samples), of which 2 samples were above the regulatory limit of 0.2 mg/kg OA. Each sample was a homogenate of the soft tissue of 15–20 individual shellfish.

In order to gain more data to develop a risk assessment, the survey was extended to the 2018 and 2019 wild harvest seasons (NSW Food Authority, 2020b). During 2018-2019, biotoxin testing was conducted on 76 shellfish samples consisting of five cockle, one clam and 70 pipi samples. Of these, DST was detected in 19% (13/70) of sampled pipis (maximum 0.18 mg/kg OA equivalent). During 2019-2020, biotoxin testing was conducted on 37 shellfish samples consisting of five cockle, three clam and 29 pipi samples. DST was detected in 35% (10/29) of sampled pipis (0.054 - 0.54 mg/kg OA equivalent), of which three samples were above the regulatory limit. All three results above the regulatory limit for DSTs were from the same collection beach and from stock harvest within a two-day period. The beach was closed to harvest upon receipt of the high results. In addition, the 2019-2020 survey results revealed two cockle samples positive for AST. The positive results were 2.4 and 4.8 mg/kg domoic acid (regulatory limit 20 mg/kg domoic acid). One (bait only) cockle sample was also positive for gymnodimne (0.044 mg/kg). While this sample was not from a batch of shellfish intended for human consumption, it should be noted that this toxin is not regulated in shellfish and has not been linked to human illness cases.

Vibrio parahaemolyticus in NSW oysters survey (2022-2024)

A survey commenced in April 2022 to determine the prevalence and level of total and pathogenic *V. parahaemolyticus* in five major NSW oyster growing areas located in geographically diverse regions of the state. Project survey sampling was completed in April 2024. Test methods include determining total *V. parahaemolyticus* present in samples and PCR analysis for virulence markers. There are no regulatory limits for *V. parahaemolyticus* in the Code. Where specified limits or guidance levels have been set by other countries there is a very wide range, likely due to the weak relationship between *Vibrio* levels and illness outbreaks.

Between 26 April 2022 and 27 June 2022, 70 samples were collected across the five estuaries. All test results were either "not detected" or low level detections of *V. parahaemolyticus*.

Between 11 July 2022 and 26 June 2023, 342 samples were collected. All test results were either "not detected" or low level detections of *V. parahaemolyticus*.

Between 3 July 2023 and 15 April 2024, 313 samples were collected.

Modelling of the data undertaken by the University of Tasmania identified that water temperature >20^{0}C was the primary factor determining the risk of elevated *Vibrio parahaemolyticus* levels occurring at harvest (Hadley et al., 2025). Enhanced risk management advice has been provided to the oyster industry to assist in managing vibrio related food safety risks. Over 4000 isolates were collected during the survey, representing the largest collection of *Vibrio parahaemolyticus* isolates in Australia. Whole genome sequencing is being undertaken to determine genetic variability and elucidate the risk posed by *Vibrio parahaemolyticus* strains currently present in NSW waters.

Published domestic surveys of seafood products

Norovirus and hepatitis A virus in Australian oysters

Torok et al. (2018) undertook a national prevalence survey between July 2014 and August 2015 for norovirus and hepatitis A virus in mature Australian oysters taken from harvest areas which were open for harvest (Torok et al., 2018). Two different types of oysters were sampled. In SA, TAS and NSW, Pacific oysters (*Crassostrea gigas*) were sampled. Sydney rock oysters (*Saccostrea glomerata*) were also sampled in NSW and QLD. The sampling plan and total number of samples to be collected per state was informed by national and state production data. To determine baseline levels of these viruses, the survey design called for a total of 300 oyster samples to be collected over 13 months between July 2014 and August 2015 in two sampling periods, representing a winter/spring (round 1) and a summer/autumn (round 2) period. Commercial Australian growing areas, represented by 33 oyster production regions in NSW, SA, TAS and QLD, were included in the survey. A total of 149 and 148 samples were collected during round one and two of sampling, respectively, and tested for norovirus and hepatitis A virus by quantitative RT-PCR. The method used for testing for norovirus genotype I (GI), norovirus genotype II (GII) and hepatitis A virus in oysters was as outlined within the IOS/TS 15216 method "*Microbiology of food and animal feed - horizontal method for determination of HAV and NoV in food using real-time RT-PCR*" with the exception that murine norovirus (MNV-1) was used instead of Mengo virus as the process control virus (ISO/CEN, 2013). Norovirus and hepatitis A virus were not detected in oysters collected in either sampling round, indicating an estimated prevalence for these viruses in Australian oysters of <2% with a 95% confidence interval based on the survey design. The low estimated prevalence of foodborne viruses in Australian oysters was consistent with epidemiological evidence, with no oyster-related foodborne viral illness reported during the survey period.

Zoonotic nematode parasites infecting selected edible fish off the Australian and NZ coast

A number of Australian studies have investigated for the presence of zoonotic nematode parasites in fish species that are used whole (for example, consumption of visceral organs may occur), raw or undercooked (Hossen & Shamsi, 2019; Hossen et al., 2021).

Hossen et al. (2021) undertook a study to survey nematodes in Australian and New Zealand snapper (*Chrysophrys auratus*) (Hossen et al., 2021). Snapper is a favoured species to serve raw as sashimi or in sushi. A total of 112 *Chrysophrys auratus* snapper were purchased from the Sydney fish market in NSW. The fish had been sourced from three separate localities: off the coast of NSW, off the coast of NZ and an unknown location. Fish were dissected and only the visceral content and digestive tract were examined for nematode infection. Fish were dissected and examined for the presence of nematodes using both visual examination and an incubation method to ensure maximum recovery of nematodes. Snapper sourced from the waters of Australia and NZ were identified as infected with zoonotic (*Anisakis pegreffii*), potentially zoonotic (*Anisakis brevispiculata*, *Terranova* type II) and non-zoonotic (*Dichelyne* spp.) nematodes. This study was the first to identify infectious stage larvae of the zoonotic *A. pegreffii* and potentially zoonotic *Terranova* type II in this species of snapper. Of the 44 samples from off the coast of NSW (Date: 11/10/2018), 7% (3/44) were infected with *Anisakis pegreffii*, 2% (1/44) with *Anisakis brevispiculata* and 9% (4/44) with *Dichelyne* cf. *pleuronectidis*. Of the 20 samples bought from the Sydney Fish Markets in NSW, 15% (3/20) were infected with *Anisakis pegreffii*, 20% (4/20) with *Dichelyne* cf.*pleuronectidis* and 5% (1/20) with *Dichelyne* sp. 1. Of the 20 samples from off the coast of NZ (Date: 28/07/2018), 10% (2/20) were infected with *Anisakis pegreffii*, 15% (3/20) with *D*. cf. *pleuronectidis* (3/20) and 5% (1/20) with *Terranova* type II. Of the 28 samples from off the coast of NZ (Date: 16/09/2019), 32% (9/28) were infected with *Anisakis pegreffii*, 11% (3/28) were infected with *D*. cf. *pleuronectidis* and 4% (1/28) with *Terranova* type II. The overall prevalence of zoonotic *A. pegrefii* was 15% (17/112).

Hossen and Shamsi (2019) examined retail purchased Australian pilchard (*Sardinops sagax*), Australian anchovy (*Engraulis australis*) and Eastern school whiting (*Sillago flindersi*) for the presence of nematode parasites (Hossen & Shamsi, 2019). In some dishes, these fish may be raw or undercooked. In addition, small fish such as anchovy and pilchard may be consumed whole. All fish were purchased from a fish market in Sydney on the same day in August 2017. For each fish sample, the surfaces of all inner organs were thoroughly inspected for the presence of nematodes. The alimentary canal, from mouth to anus, was then examined under a dissecting microscope for the presence of parasites and this was followed by overnight incubation of internal organs at room temperature, to allow deeply embedded and encysted larvae to emerge from the tissue. All nematodes were found alive. All nematode larvae were collected from the digestive system, gonad and liver and were preserved in 70% ethanol for further analysis. Nematode parasites found in the present study were all in larval stages belonging to three genera, *Contracaecum*, *Terranova* and *Hysterothylacium*. Nematodes were in the larval stage and, therefore, classified by morphotype, followed by specific identification through sequencing of their internal transcribed spacer (ITS) regions. Seven different larval types with zoonotic potential, belonging to the families Anisakidae (*Contracaecum* type II and *Terranova* type II) and Raphidascarididae (*Hysterothylacium* types IV [genotypes A and B], VIII, XIV and XVIII), were found. The number of each type of fish found to be infected with at least one type of nematode larvae with zoonotic potential, ranged from 100% (19/19) of the Australian pilchards, followed by 70% (14/20) of Eastern school whiting and 56% (39/70) of Australian anchovy. The maximum number of parasites were found in the Australian pilchard (151 larvae in 19 fish) followed by the Australian anchovy (98 larvae in 70 fish) and the Eastern school whiting (21 larvae in 20 fish). Australian anchovies were infected with the most diverse group of nematode larvae (seven different larval types) followed by the Australian pilchard (three different larval types) and Eastern school whiting (two different larval types). Nematode larvae were isolated from the digestive system, gonad and liver of each tested fish species. While muscle tissue was not tested for the presence of nematode larvae in the present study, these larvae are capable of post-mortem migration, from visceral organs to fish musculature.

Published international microbiological surveys of seafood products

UK survey of *L. monocytogenes* in smoked salmon

Results from sampling of smoked fish by the UK Health Security Agency (UKHSA) Food Water and Environmental Microbiology (FWEM) laboratories can be accessed on the UKHSA website (UKHSA, 2023b). UKHSA note that while smoked salmon products tested by FWEM may not be representative of all smoked salmon products on the market, samples microbiologically linked to incidents of human listeriosis are removed from the analysis to improve representativeness. Across the sampling period there was a continual detection of *L. monocytogenes* among smoked salmon tested, with detections in 2013 (1.7%, 2/118), 2014 (7.6%, 8/105), 2015 (4.6%, 8/173), 2016 (13.8%, 18/130), 2017 (4.6%, 5/107) and 2018 (6.4%, 5/77).

In addition, a survey led by UKHSA FWEM testing smoked fish products collected at retail shops was conducted from November 2022 to March 2023 (UKHSA, 2023b). *L. monocytogenes* was detected in 3.6% (28/786) of the smoked fish samples tested during the survey. Three of the *L. monocytogenes* isolates were the CC217 strain, previously linked to 19 cases of listeriosis between November 2020 and June 2023 (UKHSA, 2023a). The confirmed cases had all consumed smoked fish (predominantly smoked salmon) and were residents of England, Scotland or Wales. All 19 cases were hospitalised and there were four fatalities.

USA survey of RTE ceviche, poke and sushi

Marquis et al. (2023) undertook a study to determine the prevalence of *E. coli* / coliforms, *Salmonella* and *Listeria* in ceviche, poke and sushi dishes sold at the retail level (Marquis et al., 2023). A total of 105 raw, RTE samples of ceviche (n = 35), poke (n = 35) and sushi (n = 35) were collected from restaurants and grocery stores in Orange County, CA. Two samples (1.9%, 2/105) were positive for generic *E. coli*, including one sample of fish ceviche (5 CFU/g) and one sample of spicy tuna poke (35 CFU/g). Marquis et al. (2023) compared *E. coli* levels to guidelines published by the Health Protection Agency for microbiological safety of RTE foods and stated that they are satisfactory (<20 CFU/g) or borderline (20 to <100 CFU/g). Coliforms were detected in 81% of samples (85/105), with a range of 5–1710 CFU/g. Marquis et al. (2023) evaluated coliform levels using the method adapted by Kim et al. (2017) to assess the microbiological quality of RTE seafood products in South Korea (Kim et al., 2017). Overall, 66.7% of products sampled had satisfactory levels of coliforms ($<10^2$ CFU/g) and 33.3% were considered acceptable ($10^2 \leq 10^4$ CFU/g). When the results were separated by dish type, the greatest rate of coliform detection was found in ceviche (85.7%, 30/35), followed by sushi (80.0%, 28/35) and poke (77.1%, 27/35). Ceviche also had the highest average number of coliforms per sample (259 CFU/g), followed by poke (196 CFU/g) and sushi (95 CFU/g). The average coliform levels in ceviche samples (259 CFU/g) were significantly ($p < 0.05$) higher than the levels in sushi samples (95 CFU/g). The coliform levels in poke samples (196 CFU/g) were not significantly different from those in ceviche or sushi. None of the samples tested positive for *Salmonella* or *L. monocytogenes*. Marquis et al. (2023) proposed several reasons for ceviche having the greatest rate of coliform detections and the highest average number of coliforms per sample. While sushi and poke can also be made with acidic ingredients (for example, acidified rice and sauces), the fish in ceviche is soaked in a citrus marinade. The acidic conditions of ceviche are not considered sufficient to reduce the microbial population in the product. Ceviche also often includes other raw ingredients that could introduce coliforms, such as cilantro and tomatoes, both of which were found in the sampled dishes. An additional contributing factor to the relatively high levels of coliforms in ceviche could be differences in the handling and preparation of ceviche dishes as compared to sushi and poke dishes. Unlike sushi or poke restaurants, where a signification portion of the dishes are raw and RTE, ceviche was typically sold at restaurants that primarily serve heat-treated main dishes. Marquis et al. (2023) conclude that it is possible that ceviche may have been exposed to additional sources of cross-contamination and/or different storage conditions as compared to poke and sushi.

USA survey of domestic and imported frozen shrimp, catfish and tilapia

Elbashir et al. (2023) undertook a microbiological survey of shrimp, catfish and tilapia obtained from retail stores in Maryland (Elbashir et al., 2023). A total of 440 samples of domestic and imported frozen shrimp (n = 142), catfish (n = 142) and tilapia (n = 156) were analysed for aerobic plate count (APC), total coliforms, *E. coli* and seafood-borne-pathogens (*V. parahaemolyticus*, *V. vulnificus*, *Salmonella*, *Campylobacter jejuni*). All imported tilapia (n = 84) were from China while all imported catfish (n = 60) were from Vietnam. Imported shrimp originated from India (n = 20), Indonesia (n = 33) and Thailand (n = 29). The prevalence of APC, coliforms and *E. coli* positive samples was 100%, 43% and 9.3%, respectively. Based on the acceptable limits established by the International Commission on Microbiological Specifications for Foods (ICMSF), the APC for four domestic shrimp (5.6%, 4/71) and four domestic catfish (4.2%, 4/82) samples were microbiologically unacceptable. While approximately 10% of the samples positive for coliforms and *E. coli* were considered unacceptable for human consumption based on ICMSF standards. With respect to type and source of seafood, a few statistically significant differences ($p < 0.05$) were observed. This included a higher prevalence of samples positive for total coliforms among imported shrimp (63.3%) compared to domestic shrimp (8.2%) and a higher prevalence of samples positive for *E. coli* in imported tilapia (10.7%) than domestic tilapia (2.8%). Approximately 3.2%, 1.4%, 28.9% and 3.6% of the samples were positive for *V. parahaemolyticus*, *V. vulnificus*, *Salmonella* and *C. jejuni*, respectively. All vibrios were isolated from shrimp samples only. Comparing bacterial prevalence by type or source of seafood, the only significant differences identified were between domestic and imported products in the prevalence of *C. jejuni* in catfish (2.4% of domestic and 8.3% of imported) and *Salmonella* in tilapia (19.4% of domestic and 33.3% of imported). All *Salmonella* isolates (n = 127) were serotyped as *S*. Typhimurium var 5. For *Vibrio*, *Salmonella* and *Campylobacter* the MPN ranged from 75 to 1100/g. Elbashir et al. (2023) stated that they were not able to compare the quantitative results of their study with previous studies on shrimp, tilapia and catfish due to lack of pathogen-specific quantitative data. In addition, Elbashir et al. (2023) were not able to find information on microbiological acceptability based on the level of specific pathogen (*Vibrio* spp., *Salmonella* and/or *Campylobacter*). None of the marginally acceptable and unacceptable samples for APC were *V. parahaemolyticus*, *V. vulnificus* and/or *C. jejuni* positive. In contrast, only three samples from the marginally acceptable and none of the unacceptable were *Salmonella* positive. Based on APC, all *Salmonella* positive samples were acceptable for human consumption. The authors concluded that the findings of their study suggests that seafood should not be considered as safe for human consumption based only on APC levels.

Recalls and import border failures for seafood and seafood products

Recalls

Analysis of consumer level recalls and imported foods which failed inspection and testing requirements at Australia's borders, provides some information on the foods and safety hazards that do or could enter the food supply from either domestic or imported food sources and pose a health risk. Foods may be recalled due to issues associated with contamination (for example, microbial, biological toxins, chemical, foreign matter), non-compliant labelling, undeclared allergens, faulty packaging and for a variety of other reasons (for example, unsafe levels of additives) (FSANZ, 2024a). Information on consumer level recalls of seafood and seafood products in Australian States and Territories can be accessed on the FSANZ website (FSANZ, 2024a). At the time of writing, records were accessible for consumer level recalls that occurred from 13/6/2019 onwards. Recalls due to the presence of allergens were excluded from the following discussion and from Table 12. In total, there were 16 consumer level recalls of seafood and seafood products between 13/6/2019 and 18/12/2024 (Table 12). The recalls were due to the presence of microbial contaminants (50%, 8/16), incorrect labelling (18.75%, 3/16), histamine (12.5%, 2/16), biotoxins (6.25%, 1/16), chemical contaminants (6.25%, 1/16) and a product with a low preservative content and the potential for microbial contamination (6.25%, 1/16). The eight recalls due to microbial contamination were due to *L. monocytogenes* (25%, 4/16), Hepatitis A virus (12.5%, 2/16), *V. parahaemolyticus* (6.25%, 1/16) and an unspecified microbial contaminant (6.25%, 1/16). All recalls due to *L. monocytogenes* were associated with smoked whole fish or smoked fish pate. Both recalls due to the presence of histamine were associated with imported anchovies. Both recalls due to Hepatitis A virus were associated with imported salted or pickled clams. *Gymnodinium catenatum* was responsible for one recall of live mussels resulting in biotoxin contamination.

Table 12: Consumer level recalls of seafood and seafood products in Australia from 13/6/2019 to 18/12/2024

Date	Location	Product	Outlet type	Reason
30/7/2024	NSW, ACT and QLD	Paradise Beach Purveyors - Smoked Trout and Chive Dip	Supermarkets and retailers	Microbial contamination (*Listeria monocytogenes*)
17/5/2024	VIC	Live Flinders Mussels	Carrum Big Fish market and from Flinders Mussels in VIC	Biotoxin contamination (*Gymnodinium catenatum*)
9/11/2023	NSW and ACT	Sydney City Oysters Pacific Oysters	Supermarkets and online	Incorrect labelling (incorrect use by date)
29/5/2023	National	OceanRise Anchovy Fillets in Olive Oil and OceanRise Anchovy Fillets in Olive Oil with Chilli	Supermarkets	Histamine
17/7/2022	QLD, NSW, ACT, VIC, NT, SA and WA	Harris Smokehouse Hot Smoked Barramundi, Hot Smoked Trout Blackening Spice, Everyday Smashed Smoked Salmon, Premium Smoked Salmon and Smoked Salmon Trimmings	Retailers	Microbial contamination (*Listeria monocytogenes*)
6/7/2022	SA	Harris Smokehouse Smoked Salmon Pate and Harris Smokehouse Everyday	Retailers	Microbial contamination (*Listeria monocytogenes*)

Date	Location	Product	Outlet type	Reason
		Smoked Salmon Pate		
19/11/2021	SA, NSW, ACT, QLD, VIC, NT and WA	Pacific oysters (*Magallana gigas*) produced in Coffin Bay, SA, including fresh and frozen products	Direct from farms, seafood outlets, grocery stores and supermarkets	Microbial contamination (*Vibrio parahaemolyticus*)
20/4/2021	VIC, WA and TAS	Coles Tasmanian Smoked Salmon	Supermarkets and online	Incorrect labelling (incorrect use by date)
12/1/2021	VIC	Bellarine Smoked Barramundi Pâté and Bellarine Smoked Salmon Pâté	Bellarine Smokehouse and retailers	Microbial contamination (*Listeria monocytogenes*)
23/12/2020	NSW, VIC, SA, NT, TAS, ACT and WA	Woolworths Cooked and Peeled Cocktail Prawns	Supermarkets	Potential microbial contamination
22/10/2020	QLD	Golden Horse Dried Anchovy Kho Ca Com	Retailers	Histamine
18/9/2019	NSW	Byul Mi Kim Chi Salted Clams	Retailers	Possible microbial (Hepatitis A virus) contamination
17/9/2019	NSW	Koryo Food Pickled clams	Retailers	Possible microbial (Hepatitis A virus) contamination
23/8/2019	WA	Talley's Mussels Garlic	Supermarkets and retailers	Low preservative content in the marinade which may pose a food safety risk. Potential for microbial contamination.

Date	Location	Product	Outlet type	Reason
25/6/2019	NSW and SA	Chan's Yum Cha at Home Prawn Hargow and Chan's Yum Cha at Home Sesame Prawn Toast	Supermarket	Incorrect labelling (incorrect use by date)
13/6/2019	WA	Red Drago Dried Mud Fish	Retailer	Chemical residue contamination

Import border failures

DAFF monitor and test food imported into Australia under the Imported Food Inspection Scheme (IFIS) (DAFF, 2023b). This ensures all imports comply with Australian food standards and requirements for safety. All biosecurity requirements must be met before IFIS requirements apply. Imported food that presents a potential medium or high risk to public health is classified as risk food. The tests that DAFF apply depend on the food type and whether the food is a risk or surveillance food.

Requirements apply to seafood imports including:

- Bivalve molluscs and bivalve mollusc products
- Cooked crustaceans
- Fish and crustaceans from aquaculture production
- Histamine susceptible fish
- Processed finfish

A full list of import requirements by food type can be found on the DAFF website (DAFF, 2024d).

Of all products that failed inspection and testing requirements between January 2018 to December 2022 at import (n = 1,877), seafood and seafood products were responsible for 22% (416/1,877) of all fail reports.

Histamine was responsible for the most fail reports (47.4%, 197/416). DAFF have set a maximum level of 200 mg/kg for histamine susceptible fish of the families Carangidae (for example, trevallies, jacks and pompanos), Clupeidae (for example, herrings, sardines), Coryphaenidae (for example, mahi-mahi), Engraulidae (for example, anchovy), Pomatomidae (for example, bluefish), Scomberesocidae (for example, king gars and saury) and Scombridae (for example, tuna, mackerel and bonito) (DAFF, 2024c).

After histamine, the highest number of failed reports were due to antibiotics (fluoroquinolones, quinolones and nitrofurans / nitrofurazone) (15.6%, 65/416), followed by standard plate count (12.3%, 51/416), *E. coli* (7.2%, 30/416), *L. monocytogenes* (4.8%, 20/416), carbon monoxide (2.9%, 12/416), additives (annatto, erythrosine and canthaxanthin) (2.2%, 9/416), *V. cholerae* (1.7%, 7/416), Malachite green / Leucomalachite green (1.4%, 6/416), Vitamins (1.2%, 5/416), irradiated cayenne pepper (1.0%, 4/416), *Salmonella* (0.7%, 3/416), aflatoxin (0.5%, 2/416), Coagulase-positive staphylococci (0.5%, 2/416), *V. alginolyticus* (0.2%, 1/416), presence of prohibited plant (*Amanita muscaria*) (0.2%, 1/416), Semicarbazide (0.2%, 1/416), mould (0.2%, 1/416), insect and debris (0.2%, 1/416) and insect infestation (0.2%, 1/416).

In order of highest occurrence, fail reports were associated with seafood and seafood products imported from Sri Lanka (18%, 75/416), Vietnam (18%, 74/416), Indonesia (8%, 33/416), China (7%, 29/416), the Philippines (7%, 28/416), Myanmar (6%, 26/416), Thailand (6%, 24/416), Japan (5%, 20/416), Maldives (4%, 18/416), Taiwan (4%, 18/416), Italy (3%, 11/416), South Korea (2%, 8/416), Chile (2%, 7/416), Fiji (1%, 5/416), Bangladesh (1%, 4/416), Iran (1%, 4/416), Malaysia (1%, 4/416), Brazil (0.7%, 3/416), Denmark (0.7%, 3/416), India (0.7%, 3/416), Latvia (0.7%, 3/416), South Africa (0.7%, 3/416), Spain (0.7%, 3/416), Argentina (0.5%, 2/416), Tanzania (0.5%, 2/416), Ghana (0.2%, 1/416), Malta (0.2%, 1/416), Namibia (0.2%, 1/416), Poland (0.2%, 1/416), Turkey (0.2%, 1/416) and Zambia (0.2%, 1/416).

Risk characterisation

Seafood; alone or in a complex food(s), was specifically identified as the suspected/responsible vehicle in 3 to 16% of all foodborne outbreaks across NSW from 2016 to 2020. However, it is important to note that the suspected/responsible food vehicle was identified in only a minority of all foodborne outbreaks in NSW during this time (43% ± 17%). In total there were 27 outbreaks in which domestic or imported seafood was identified as the responsible vehicle. This equates to approximately five outbreaks per year (27/5), which is slightly above the four outbreaks per year across the period from 2005-2015 (43/11) covered in the previous seafood risk assessment (NSW Food Authority, 2017b).

Private residences were the most common outbreak setting and were implicated in 44% (12/27) of all seafood-related outbreaks. Information is not available to indicate whether the seafood associated with each outbreak was purchased from a commercial premises or caught/harvested recreationally. This information could aid in identifying where further promotion of specific consumer education may be warranted.

After private residences, restaurants (33%, 9/27) and take-away (11%, 3/27) were the most common setting for seafood-related outbreaks. The majority of seafood consumed within Australia is imported (62% by weight) (DAFF, 2023a) and currently there is not consistent access to country of origin information for seafood sold in hospitality settings. However, this is set to change as the Australian Government announced in November 2023 that it would introduce mandatory Country of Origin Labelling (CoOL) for seafood in hospitality (DISR, 2023; NSW Food Authority, 2024e). The change will mean restaurants, cafes and similar businesses will need to show where their seafood is from, as either Australian, imported or mixed origin. Work is currently underway to help the hospitality industry adopt the new seafood CoOL requirements.

The exact percentage of foodborne outbreaks associated with seafood from NSW is unknown. However, it is important to note that licensees operating across the seafood supply chain in NSW display a high level of regulatory compliance. The *NSW Food Safety Strategy 2015–21* included the goal of increasing all NSW businesses' compliance with food safety requirements to 95% (NSW Food Authority, 2015b). Compliance with food safety program requirements across the seafood sector was above 95% during 2017–18 (95%), 2018–19 (96%), 2019–20 (97%), 2020-21 (95%) and 2021–22 (95%) (NSW Food Authority, 2018a, 2019b, 2020c, 2021b, 2022b). Compliance across the sector with food safety program requirements for the 2022-23 financial period was 92%, a 3% drop on the average compliance rate over the previous two financial years (NSW Food Authority, 2023b). However, compliance across the sector increased to 95% in 2023-24 (NSW Food Authority, 2024b). Also of note, as of December 2023, Australian businesses in food service, catering and retail sectors that handle unpackaged, potentially hazardous food that is RTE need to meet new food safety requirements (FSANZ, 2024d). Standard 3.2.2.A is a national food safety standard and an extension of Standard 3.2.2 requirements. The requirements for seafood retailers are dependent on the business's food handling activities and will require implementation of either two or three food safety management tools (NSW Food Authority, 2024c). The three tools are "having a food safety supervisor", "food handler training" and "substantiation of critical food safety controls". An online quiz is available on the NSW Food Authority website to help businesses determine which requirements apply to their business (NSW Food Authority, 2024m). In addition, a *Guideline for seafood retailers* has been published to help businesses in complying with the Code (NSW Food Authority, 2024f).

Where there were multiple occurrences, tuna was the food vehicle responsible for the majority (41%, 11/27) of seafood related outbreaks, followed by Spanish mackerel (n = 3), kingfish (n = 2) and oysters (n = 2). In all foodborne incidents involving tuna (n = 11) and kingfish (n =2), histamine was the agent responsible. In all foodborne incidents involving Spanish mackerel (n = 3), ciguatera toxin was the agent responsible. In all foodborne incidents involving oysters (n = 2), norovirus was the agent responsible. There was only one outbreak (1/27) in which the suspected or responsible vehicle could be confidently assumed to have been consumed raw. This outbreak involved tuna sashimi in 2016. However, unlike other foods (for example, poultry), seafood is often consumed raw or prepared in ways that do not kill bacteria, parasites or inactivate viruses and toxins.

The majority of the outbreaks for which the agent responsible was identified, were due to histamine (n = 17), followed by ciguatera (n = 5), norovirus (n = 2) and *L. monocytogenes* (n = 1). The following section describes developments domestically and internationally in the management of these agents of foodborne illness. *Vibrio* is also discussed in light of recent significant events in SA (2021/2022) and NSW (2024). Parasites and shellfish toxins are discussed in reference to relevant seafood survey results and advancements made domestically and/or internationally in their management.

Finally, climate change is affecting many weather and climate extremes in every region across the globe (IPCC, 2023). The eighth biennial *State of the Climate 2024* report outlines how Australia's weather and climate has continued to change, with an increase in extreme heat events, longer fire seasons, more intense heavy rainfall and increased sea surface temperatures (CSIRO and BOM, 2024). The multiple pathways through which climate related factors may directly or indirectly impact food safety have been extensively reviewed (EFSA et al., 2020; FAO, 2020; Tirado et al., 2010). Climate change has the potential of causing, enhancing or modifying the occurrence and intensity of some foodborne diseases. Globally, increased seawater temperatures have been associated with the geographical spread and increased frequency of HABs, as well as the spread and increased incidence of foodborne illness caused by ingesting raw seafood contaminated with pathogenic *Vibrio*. The migration and establishment of new and emergent toxin-producing organisms, typically from warmer waters into more temperate areas, has added a new level of uncertainty to many seafood safety monitoring programmes globally.

Histamine

Histamine poisoning was the leading cause of seafood outbreaks in NSW from 2005 – 2020 (Table 1 and Table 10). Between 1995 and 2008 histamine poisoning was also responsible for the highest number of outbreaks nationally, moving into second place (after ciguatoxin) between 2009 and 2017 (Table 11). However, the true extent of histamine poisoning is unknown as it is not a nationally notifiable disease (DHAC, 2024). Public health data collected on histamine poisoning is usually derived from outbreak investigations in those jurisdictions in which the incidence of two or more cases of suspected foodborne illness is notifiable (Knope et al., 2014). Internationally, histamine was also the leading cause of seafood outbreaks in New Zealand from 2017 to 2023 and responsible for the second highest number of seafood related outbreaks in the USA between 2017 to 2021 (after ciguatoxin) and Europe between 2018 and 2021 (after norovirus and other calicivirus).

Globally, many regulatory organisations have adopted maximum limits for histamine in fish and fishery products. Australia, New Zealand, the EU and USA have adopted the maximum limit of 200 mg/kg (200 ppm) of histamine in raw fish, as determined by the FAO/WHO. The FAO/WHO based the limit on their determination of a no-observed-adverse-effect level (NOAEL) for healthy individuals of a total consumption of 50 mg of histamine and a maximum serving size of seafood of 250 g.

Of note, recent published compliance policy guidance in the USA includes a lowered level of histamine at which the FDA may take action during surveillance sampling and testing of fish (FDA, 2024). The histamine criteria in fish and fishery products for decomposition was lowered from two or more sample units at 50 ppm or greater to one or more sample unit at 35 ppm or greater (FDA, 2024). The FDA considers histamine at this level to indicate significant decomposition and mishandling of the fish.

While the regulations for actionable histamine levels and sampling methods may differ around the world, the goal is always rapid refrigeration after catching and high standards of handling during processing to prevent the formation of histamine. These messages are reinforced in seafood food safety resource materials developed by the NSW Food Authority and distributed to more than 600 fishers and co-ops. Both bespoke seafood safety Z-cards and posters are distributed to licensees upon licence renewal and are available on the NSW Food Authority website (NSW Food Authority, 2023c, 2023d). Aside from further promotion of seafood food safety resource materials already developed by the NSW Food Authority, more targeted initiatives could be warranted if insight were gained on the level of adoption amongst fishers of high-risk practices that significantly increase the chances of histamine poisoning *for example, longlining and gillnetting, where death may occur many hours before the fish is removed from the water.*

Ciguatera toxin

Ciguatera poisoning was responsible for the second highest number of seafood related outbreaks in NSW between 2016 and 2020 (Table 10) and was the leading cause nationally between 2009 and 2017 (Table 11). Aligning with the association of ciguatera poisoning with the consumption of warm water finfish, tropical QLD recorded the highest number of ciguatera outbreaks nationally between 2009 and 2017 (88%, 59/67).

In NSW ciguatera poisoning was responsible for four outbreaks across an eleven-year period (2005 to 2015). This increased to five ciguatera poisoning outbreaks across a five-year period from 2016 to 2020. The increase in ciguatera poisoning outbreaks within a short time period indicates that this is an emerging issue in NSW. As ciguatera poisoning incidents extend further south along the eastern Australian coast, further assessment of the potential for ciguatoxins to occur in previously unaffected locations need to be considered in terms of food safety. An increase in reports of ciguatera poisoning outbreaks in NSW in recent years could be due to several reasons, including increasing ocean temperatures leading to changes in the distribution and migration patterns of fish species and the geographic range of ciguatoxin-producing microalgae (Farrell et al., 2017). Globally there has been a geographical expansion of ciguatera poisoning. For example, ciguatera poisoning has been reported with increasing frequency in Europe, in particular on the Spanish and Portuguese islands in the Atlantic but also in Germany (BfR, 2017). The EFSA (2025) report that climate change and globalisation of trade are the main drivers of the spread of ciguatera fish poisoning, which is intensified by travel to tropical areas (EFSA, 2025).

Regulatory criteria for ciguatoxins have not been established and fish captured and sold domestically or imported into Australia are not tested for ciguatoxins (DAFF, 2024d). This is due largely to the limited availability of certified reference material, which in turn has limited the development of cost-effective routine testing (Farrell et al., 2017). More than 30 ciguatoxin analogues have been reported (Pottier et al., 2023). The availability of ciguatoxin reference standards is dependent on the amount that can be extracted from fish and/or produced by dinoflagellate cultures (Pottier et al., 2023). However, the isolated amounts are extremely low, concentrations are in the ppb range, which is a major drawback for the development and validation of biological and analytical detection methods for ciguatoxins (Pottier et al., 2023). However, ciguatera identification kits are currently under development, with preliminary testing indicating that the kits could provide results within several hours (NSW Seafood Industry Forum, 2023). Discussions are taking place between industry and the Sydney Seafood Market to determine how these kits can be incorporated into the supply chain (NSW Seafood Industry Forum, 2023).

The visual appearance, taste or odours of fish are not affected by the presence of ciguatoxins. There is no process that will remove ciguatoxins from fish prior to consumption and cooking or freezing fish will not destroy the toxins. Pending development of commercial test methods for ciguatoxins, management of ciguatera toxin poisoning risk is currently limited to the avoidance of high-risk species caught in high-risk locations. The Sydney Fish Market's *Seafood Handling Guidelines* contains a Schedule of ciguatera high-risk areas and species size limits (Sydney Fish Market Pty Ltd, 2024). The NSW Food Authority template food safety program published for seafood processors, contains information regarding ciguatera control, which refers to these industry controls (NSW Food Authority, 2024j). Of the five outbreaks which occurred in NSW between 2016 and 2020, three were due to consumption of Spanish mackerel. Spanish mackerel are a high-risk species for ciguatoxin and maximum size limits have been set for fish caught in NSW, QLD and Pacific countries (Sydney Fish Market Pty Ltd, 2024). Redthroat emperor fish and Grouper fish were responsible for the remaining two ciguatera toxin poisoning incidents. Redthroat emperor fish and Grouper fish are not listed as high-risk species for ciguatoxin, but it is unknown whether they were caught from a ciguatera high-risk area (Sydney Fish Market Pty Ltd, 2024). It is unknown whether the fish were recreationally captured or commercially purchased. The NSW Food Authority provides advice on how the risk of exposure to ciguatera toxins can be reduced (NSW Food Authority, 2025c).

Despite the strategies listed above, the response process to ciguatera poisoning incidents is limited for several reasons aside from the limited capability for chemical detection of ciguatoxins (Farrell et al., 2019). Ciguatera poisoning is a clinical diagnosis because there is as yet no confirmatory diagnostic test. Human cases of ciguatera poisoning can be easily misdiagnosed given the wide range of associated symptoms, with more than 175 gastrointestinal, cardiovascular and neurological symptoms reported (FAO and WHO, 2020b). In addition, there is a lack of public awareness particularly in previously unaffected locations. As a result, despite the large number of cases worldwide, ciguatera poisoning is grossly underreported. These factors have led to a number of recommendations to improve collection of samples from reported cases domestically (Farrell et al., 2019).

In Europe, Regulations (EU) 2017/625 and (EU) 2019/627 require that no products of animal origin including fish and other seafood including crustaceans and molluscs containing ciguatoxins are placed on the market. To better understand the risks of ciguatera poisoning in Europe, EFSA and the Spanish Food Safety Authority (AESAN) jointly funded the EuroCigua project between June 2016 and January 2021 (EFSA, 2025). The project defined the main health impacts of ciguatera in Europe. In addition, microalgae and fish were analysed for the presence of ciguatoxins and analytical methods were developed to identify and quantify the presence of ciguatoxins. The results of the first EuroCigua project and the lack of harmonised ciguatoxin methodologies or limits needed to fulfil regulatory requirements, encouraged EFSA and the Spanish Ministry of Health to jointly fund a follow-up three-year project. The second EuroCigua project is running from 2022 to 2025 and aims to prepare for future assessments and help predict future scenarios for ciguatera in Europe (EFSA, 2025). It covers several areas, including capacity building (for example, laboratories), harmonisation of methods, development of predictive modelling under climate change and identification of other major drivers influencing ciguatera and ciguatoxins' toxicity. The assessments will also take account of risks from imported fish. The work of several international organisations, including EuroCigua, was consulted in the development of a Code of Practice (CoP) for the prevention or reduction of ciguatera poisoning (FAO and WHO, 2024a). The CoP provides guidance on recommended practices to prevent or reduce ciguatera poisoning for different types of stakeholders including competent authorities, fish sector operators (fishers, seafood processors and seafood retail workers), health care professionals and consumers. An additional goal is to develop standards based on science and Codex risk-analysis principles. Australia is a participant in this work, which is expected to be completed by 2026 or earlier (FAO/WHO, 2023b).

Norovirus

Norovirus was responsible for two separate outbreaks associated with oysters in NSW in 2016. A norovirus outbreak was also linked to Wallis Lake in 2023 (Anthony Zammit, *personal communication*).

Bivalve molluscan shellfish, in particular oysters, are a consistent reservoir for norovirus transmission. Once the virus has attached to the digestive tract, it is difficult to remove and depuration may not be effective in safeguarding against viral contamination. The risk of foodborne norovirus infection is also higher for oysters specifically as they are routinely consumed raw. Thermal treatments can inactivate norovirus but they also change the organoleptic characteristics of shellfish which makes them unacceptable to some consumers. Other types of bivalve molluscs, including mussels, cockles, clams and scallops, are also consumed but most of these will tend to be cooked before consumption. Although thorough cooking should eliminate the risk of norovirus, methods such as steaming can result in incomplete inactivation. Although they are less frequent than oysters, norovirus outbreaks resulting from the consumption of other bivalve molluscs do occur.

The most effective risk management strategy for norovirus and other enteric viruses in bivalve shellfish is to prevent contamination in production areas. Indicator bacteria, coliforms and *E. coli*, have been used to detect faecal pollution in growing waters and shellfish and are internationally used in shellfish management programs (Torok et al., 2021).

The NSW Shellfish Industry Manual includes environmental sampling requirements for shellfish harvest areas (NSW Food Authority, 2018b). These requirements include testing water for faecal coliforms and testing shellfish for *E. coli*. In addition, seafood processing businesses must also test opened and packaged oysters for *E. coli* under the requirements of the NSW Food Safety Schemes Manual (NSW Food Authority, 2025e). Monitoring bacterial levels in oysters is used as a surrogate indicator for viral risk (for example, norovirus and hepatitis A) (NSW Food Authority, 2018c). The recently completed Food Agility CRC project *Transforming Australian Shellfish Production*, resulted in estuary-specific models relating to oyster growth, disease risk, harmful algal bloom risk, sources of contamination and other factors influencing industry productivity (Ajani et al., 2024). This led to revised regulatory procedures for the NSW Shellfish Program, in which salinity sensor data can be used to determine in real-time whether shellfish are safe for harvest or not and the rapid communication of this information to growers.

In NSW, following a sewage spill, the harvest area is closed for 21 days and only reopened if the parameters of the harvest area management plan are met. The NSW Food Authority Shellfish Program relies on communication with local councils and water utilities to notify them of sewage spills or discharges (NSW Food Authority, 2018c). Not reporting spills promptly creates a serious risk for contamination of shellfish. While coliforms and *E. coli* are good indicators of recent faecal contamination of growing waters by warm blooded animals, they are not good indicators of the presence of human enteric viruses (Torok et al., 2018). *E. coli* contamination of shellfish is also not always a good indicator of viral contamination, because of the ability of shellfish to isolate virus in their blood cells (NSW Food Authority, 2018c). Of particular concern and as noted previously, norovirus is selectively accumulated and retained within the digestive tissues of oysters, persisting long after bacterial indicators of sewage contamination are no longer detectable. In the evaluation of the NSW Shellfish Program conducted in 2018, it was recommended that the Food Authority considers some form of viral surveillance in NSW (NSW Food Authority, 2018c). However, it was acknowledged at the time that virus testing was not a requirement under the program due to high cost, time delays and the lack of an established acceptable limit for virus levels in live bivalves (NSW Food Authority, 2018c).

The introduction of regulatory thresholds and microbiological criteria for norovirus in shellfish has been recommended by EFSA. The International Standards organisation published a laboratory protocol for determination of hepatitis A virus and norovirus using real-time RT-PCR in 2017 (ISO 15216–1:2017). Validation of the ISO method was conducted on a variety of food matrices, including oysters (Lowther et al., 2019). RNA is extracted from the digestive glands of pooled oysters and quantified by reverse transcription quantitative PCR (RT-qPCR), enabling the enumeration of norovirus genome copies in shellfish flesh. However, a main limitation is that PCR based methods cannot distinguish intact and infectious copies from those that are damaged or deactivated.

In the previously discussed national survey undertaken by Torok et al. (2018), Australian oysters destined for market were reported to have an estimated prevalence of norovirus and hepatitis A virus of <2%, with no virus positive samples detected and no related foodborne illnesses reported. The authors of this survey concluded that for the period of the study the food safety risk related to enteric foodborne viruses in Australian shellfish was low and that in countries or regions with a demonstrated low risk of viral contamination, mandatory virus monitoring as being proposed in the

EU could be considered unnecessary, excessive and costly. However, as noted by the authors, end-product viral limits should be applied on a risk assessment basis, as there will always be a risk of foodborne viral illness associated with oysters when product is eaten raw, especially if grown in water that can be impacted by sewage and environmental run-off.

The Codex Committee on Food Hygiene (CCFH) is currently reviewing recent scientific developments, data and evidence associated with foodborne viruses, to provide recommendations for updating the existing Guidelines on the Application of General Principles of Food Hygiene to the Control of Viruses in Foods (CXG 79-2012) (FAO/WHO, 2024b). Areas of the guidance highlighted as needing updating included (FAO/WHO, 2023a):

- revision of interventions in the food chain focusing on process-specific control systems, surface disinfection as well as hand disinfection and food handler hygiene according to available evidence;
- possible inclusion of additional information on testing of foods for foodborne viruses taking into account technical advancements in viral detection in specific commodities and in assessing potential infectivity of viruses; and
- consideration of new scientific findings to control HAV and norovirus in bivalve molluscs made available since the publication of CXG 79-2012 including indicators to monitor seawater quality of molluscs growing areas and risk assessment models.

L. monocytogenes

Fortunately, listeriosis outbreaks associated with seafood in Australia are relatively rare. In NSW in 2019 two cases of listeriosis (Table 10) were linked to a national multijurisdictional outbreak associated with smoked salmon (NSW Health, 2019). In total there were four cases of listeriosis across VIC, QLD and NSW (Hodgson & Pahl, 2024). All cases were over 70 years of age with underlying health conditions and there were two fatalities (Hodgson & Pahl, 2024). Tasmanian smoked salmon was implicated, however Biosecurity Tasmania (the regulator and controlling authority) found no breaches in relation to this product following the outbreak investigation (DPIPWE, 2020). The outbreak triggered a review across Tasmania's smoked salmon producers of the regulatory system as applied to monitor *Listeria* management and the implementation appropriate controls. This resulted in the development of Guidelines to provide risk-based tools for food safety and *Listeria* management in the production of smoked salmon (and trout) with clear scientific underpinning for industry practices. The Guidelines list three Critical Control Points (CCPs) that a business must first validate and then monitor for each batch of production of cold or hot smoked product. For cold smoked fish, CCPs must include addition of acidity regulator or use of biopreservative cultures. In addition, instructions are included for businesses to validate whether their product will support the growth of *L. monocytogenes* (for example, predictive modelling using the Food Safety and Spoilage Predictor). The Guidelines are incorporated into Tasmania's Primary Produce Safety regulatory framework, to facilitate compliance and mitigate potential non-compliance with the Code.

Within NSW, seafood processing businesses need to develop and implement a documented food safety program (FSP) to ensure that all potential food safety hazards are identified and controlled (NSW Food Authority, 2024j). However, the template FSP for seafood processing only mentions smoked seafood in reference to the testing requirements for *L. monocytogenes* listed in the NSW Food Safety Schemes Manual. Guidance material for NSW licensees producing RTE seafood products could be updated to reflect the updated information and guidance now available and currently under development. SafeFish recently published a technical report consolidating current *Listeria* controls and risk management for seafood products (Hodgson & Pahl, 2024). In addition, the CCFH is currently revising the existing Guidelines on the Application of General Principles of Food Hygiene to the Control of *Listeria monocytogenes* in Foods (CXG 61-2007) (FAO/WHO, 2024a). A full farm to table risk assessment will be developed for *L. monocytogenes* in foods. Recommendations will be made at the primary production, processing and product information and consumer awareness level. The assessment will include, but will not be limited to, RTE seafood that allows for the growth of *L. monocytogenes* for example, hot- and cold-smoked fish and gravad (sugar-salt marinated) salmon/halibut. The proposed risk assessment will be flexible to accommodate other RTE fish products in the future (for example, sashimi, ceviche). Factors for consideration in the risk assessment include, but are not limited to, cross-contamination, lactic acid bacteria cultures for biocontrol, WGS/strain typing data, raw input materials with varying levels of contamination and the effect of different time/temperature profiles throughout the food supply chain (FAO/WHO, 2022a).

Foodborne illness is known to affect vulnerable populations, including the aged, more severely (FSANZ, 2024c). Although the overall risk to the general population remains low, smoked fish is a high-risk product for invasive listeriosis in vulnerable groups. This was reflected in the high mortality rate (50%), advanced age (>70) and increased susceptibility (for example, underlying health conditions) of all four cases associated with the Tasmanian smoked salmon outbreak. Similar findings have also been reported from analysis of outbreak data in the UK, where a total of eight outbreaks have been linked to smoked fish between 2015 to June 2023 and the majority (58.1%, 18/31) of human cases were individuals 75 years and over (UKHSA, 2023b).

NSW businesses that serve food to vulnerable persons (for example, hospitals, aged care facilities) need to meet specific additional food standards set out in the Food Regulation 2025 Vulnerable Persons Food Safety Scheme (NSW Food Authority, 2025g). The Australian population is aging, with both the number of people at an older age (65+) growing and older people representing an increasing share of the total population (AIHW, 2024). This means that more people are entering the high-risk categories for severe forms of *Listeria* infections. Outside of facilities licensed to serve food to vulnerable persons, there will be an increasing proportion of vulnerable people in households consuming high-risk RTE foods (for example, cold smoked salmon). Older adults frequently do not perceive themselves as being at higher risk of contracting a foodborne illness (Thorsen et al., 2025). Older adults' sense of smell, taste and eyesight also diminish with age, potentially impacting their ability to judge whether a food is safe to consume (Thorsen et al., 2025). It will therefore be important to continue raising awareness of listeriosis and its risks associated with certain consumption habits and types of food in risk groups.

Vibrio

Recorded cases of vibriosis associated with oysters in NSW in 2017 and 2024 were linked to outbreaks occurring in February (NSW Food Authority, 2024g; OzFoodNet Working Group, 2022). This is in keeping with increased reports of vibriosis outbreaks in recent years across Australia over summer months, often associated with marine heatwaves.

Although the cause and effect relationships of climate change are complex and can lead to multi-directional effects, the rise of seawater temperature and altered salinity of the seas are the two most visible effects of climate change in coastal areas (Trinanes & Martinez-Urtaza, 2021). These two environmental factors have been identified as the main components governing the distribution and abundance of *Vibrio* in coastal waters.

Globally, *V. parahaemolyticus* is the leading cause of bacterial gastroenteritis associated with the consumption of seafood products (FAO and WHO, 2021). Warmer waters and longer seasonal periods of warm waters, allows *V. parahaemolyticus* to move further south in southern hemisphere waters, broadening the number of locations commonly affected. As discussed previously, the NSW Food Authority has undertaken a two-year survey to determine the prevalence and level of total and pathogenic *V. parahaemolyticus* in oyster growing areas across the state to support *Vibrio* risk management. Data on the presence and prevalence of *V. parahaemolyticus* was collected monthly across five study estuaries and was modelled with high-resolution data from sensors and weather records. Enhanced risk management advice has been provided to the oyster industry to assist in managing vibrio related food safety risks, particularly when water temperatures are >20ºC.

Currently FSANZ provide recommendations on the interpretation of *V. parahaemolyticus* test results in RTE foods, however they only serve as a guideline (FSANZ, 2025). Questions have also been raised about the suitability of currently recommended methodologies for the detection and enumeration of both total and pathogenic *V. parahaemolyticus* in food (Hedges, 2022). Identifying pathogenic *V. parahaemolyticus* strains in samples is difficult and several test methods are available. To assist industry, SafeFish have published basic guidance on the different test methods and application of the different techniques (SafeFish, 2023d). SafeFish are also currently undertaking a project which includes a review of available international testing methods for *Vibrio* detection to highlight which would be appropriate for implementation in Australia (SafeFish, 2025b).

Several factors hinder *Vibrio* risk management for seafood, including unknowns about the virulence of different strains and their infectious dose. There is a high degree of genetic diversity among *V. parahaemolyticus* strains and importantly, not all strains are pathogenic. This has led to difficulties in identifying pathogenicity targets for use in identifying pathogenic strains and test development. To this end, SafeFish are coordinating a project that began in 2024 and will run through 2025, to gain a deeper understanding of *V. parahaemolyticus* serotypes present in Australian seafood and clinical samples (SafeFish, 2025a). Researchers and public health departments across Australia will contribute isolates or whole genome sequences that will be compared to identify the serotypes that are causing illness and search for specific marker genes (SafeFish, 2025a).

While *Vibrio* is generally associated with bivalve shellfish, other seafood can be impacted. In comparison to other countries, in recent years outbreaks of *V. parahaemolyticus* in New Zealand have been associated with mussels and a range of other seafood (not just bivalve shellfish) (NZFSSRC, 2021, 2022). This indicates that *V. parahaemolyticus* may be a risk in other seafood species within Australia. For all seafood commodities, the most important factor to reduce *Vibrio* risk is following best practice temperature control procedures from the moment of harvest and through the supply chain. Fishers should ensure that they follow their food safety plans and place harvested product under temperature control (ice or refrigeration) as soon as possible. Shellfish harvesters must follow the time/temperature protocols in the NSW Shellfish Industry Manual (NSW Food Authority, 2018b) and *Vibrio* risk management for NSW oyster farmers factsheet (NSW Food Authority, 2024o).

Of note, the CCFH agreed to revise the existing *Guidelines on the Application of General Principles of Food Hygiene to the Control of Pathogenic Vibrio Species in Seafood (CXG 73-2010)* (FAO/WHO, 2022b). In 2024, a draft revision was proposed, with technical comments addressed relating to water type, storage temperature recommendations and amendments to definitions (FAO and WHO, 2024b).

Parasites

Nematode larvae with zoonotic potential were detected in retail purchased Australian pilchard (*Sardinops sagax*), Australian anchovy (*Engraulis australis*) and Eastern school whiting (*Sillago flindersi*) (Hossen & Shamsi, 2019). The presence of the infective stage of a range of zoonotic parasites in fish commonly consumed in NSW is concerning, as these fish may be consumed whole, raw or partially cooked (Hossen & Shamsi, 2019; Hossen et al., 2021).

There has been worldwide adoption of different cuisine and an increase in the consumption of fish products that are untreated (neither frozen nor cooked) (Garcia-Sanchez et al., 2024). Raw or lightly cooked fish is consumed by the public in a variety of forms including sushi, sashimi, gravlax, ceviche, boquerones en vinagre and lomi-lomi salmon.

Many international jurisdictions have recommendations for the freezing of fish intended to be consumed raw, including cured, salted and pickled fish products (EFSA Panel on Biological Hazards (BIOHAZ), 2010; FDA, 2022b). The effectiveness of killing parasites by freezing varies with the type of fish, type of parasite and time/temperature profile of freezing.

In Europe, Regulation (EC) No 853/2004 Annex III, Section VIII, Chapter III, Part D contains a requirement that certain fishery products must be frozen at a temperature of not more than -20ºC in all parts of the product for not less than 24 hours. The treatment must be applied to the raw product or the finished product. The regulation applies to fishery products to be consumed raw or almost raw, cold smoked herring; mackerel; sprat; (wild) Atlantic and Pacific salmon; and marinated and/or salted fishery products, if the processing is insufficient to destroy nematode larvae. Some exemptions to the freezing requirements apply to food business operators, for example in instances where epidemiological data are available indicating that the fishing grounds of origin do not present a health hazard with regard to the presence of parasites.

Spain, as a member state of the European Union, established a national law to achieve the objectives of Regulation (EC) No 853/2004. However, the national law includes treatment of the specified fishery products at a minimum of 15 hours of freezing at −35°C, the inclusion of live bivalves, the exclusion of fishery products from inland waters, and marine aquaculture in which fish are not fed with food that may contain live larvae.

In the UK, the Food Standards Agency (FSA) applied freezing requirements to all food businesses that place fish and fishery products on the market such as restaurants, fish suppliers and fish buyers (FSA, 2024). Under food hygiene legislation, certain fishery products intended to be eaten raw need to be frozen before use. The fishery products include sushi, sashimi and cold smoked fish where the smoking process does not achieve a core temperature of 60°C for at least one minute. Any treated products where the processing treatment doesn't kill the parasites must also be frozen before consumption. These fishery products include gravlax, carpaccio, some pickled herring products, some marinated fish products and salted fishery products. For parasites other than trematodes the freezing treatment must consist of lowering the temperature in all parts of the product to at least either freezing at –20°C for not less than 24 hours or freezing at –35°C for not less than 15 hours. Some exemptions to the freezing requirements apply to fish reared under certain conditions with minimal risk of parasite infection. For example, exemptions apply to farmed fish derived from embryos that have been exclusively reared in an environment that is free from parasites.

Globally, among seafood-borne parasites, members of the genus *Anisakis* are considered the most important parasites in relation to human infections. Despite the popularity of consuming seafood in Australia as well as the multicultural environment of the country in which different cuisines use raw or undercooked seafoods, to date there has only been one report of human anisakidosis acquired in Australia (Shamsi & Butcher, 2011). The proportion of sensitised individuals within the Australian population is unknown. Very recently, the first human anisakiasis, caused by *Anisakis* spp. larvae was diagnosed in New Zealand after consumption of sushi rolls (Beig et al., 2019). Of particular concern is the potential effect of climate change on fish-parasite systems (Shamsi, 2020). Climate change alters the prerequisites for parasite transfer, most likely to favour zoonotic parasites. Increased water temperature, for example, usually results in parasites spreading more rapidly and higher infection rates in fish.

In the most recent report of raw finfish consumption in Australia, it was estimated that 1259 tonnes of raw finfish are consumed annually with 115.6 million servings per annum used for sushi and sashimi fish meal preparation (Sumner et al., 2015). In Australia, sushi and sashimi are based predominantly on salmon and tuna, with other high-value species such as kingfish, snappers and reef fish comprising a small proportion (Sumner et al., 2015). In Australia, infectious stage larvae of the zoonotic *Anisakis pegreffii* was recently reported in snapper (*Chrysophrys auratus*) purchased from the Sydney fish market (Hossen et al., 2021) and flathead (*Neoplatycephalus richardsoni*) purchased from a local seafood market in Melbourne (Asnoussi et al., 2017). Identification of zoonotic and/or potentially zoonotic larvae from a popular Australian table fish such as snapper, considered a suitable species for consuming raw, is of concern for human health. Given the popularity of seafood in Australia and the occurrence of infectious stages of *Anisakis* spp. in edible fish, there would be benefit in raising awareness of this parasite and its association with seafood amongst the general public and health professionals. It is possible that anisakidosis is under diagnosed in Australia due to the non-specific symptoms and limited diagnostic tests, as well as probable low-level knowledge of seafood parasitology among medical experts (Shamsi, 2014).

Those preparing raw or undercooked seafood for consumption must be aware of the risk of parasites. Food safety is improved by using high-value marine fish that is suitable and safe to eat raw, checking the intestinal cavity for parasites and candling fish muscle. However, adoption of these steps alone is not a guarantee that the seafood will be free of parasites. Aside from cooking seafood prior to consumption, a validated method to freeze seafood will ensure inactivation of parasites.

Marine biotoxins and bivalve shellfish

In Australia four of the most serious toxin groups are regulated in bivalve shellfish. Regulatory limits for biotoxins in bivalve molluscs are contained within Standard 1.4.1 of the Code for the Amnesic (Domoic acid equivalent), Diarrhetic (OA equivalent), Neurotoxic and Paralytic (STX dihydrochloride equivalent) shellfish toxins.

A commercial biotoxin analytical service started in Australia in 2012 and all states with commercial bivalve production have been monitoring for marine biotoxins since that date (FSANZ, 2023b). Since 2012, there have been no confirmed cases of PSP or DSP in commercially produced bivalves where routine biotoxin monitoring has been conducted (FSANZ, 2023b). In 2023, FSANZ concluded that current risk management strategies for commercially produced bivalve molluscs are effective measures for protecting public health and safety from PST and DST (FSANZ, 2023b). In Australia the known causative agent of Amnesic Shellfish Poisoning (ASP) are diatoms from the *Pseudo-nitzschia seriata* group (*P. multiseries* and *P. australis*) and the *P. delicatissima* group, which produce the neurotoxin domoic acid (SafeFish, 2023a). There have been no reports of illness attributable to domoic acid poisoning in Australia (SafeFish, 2023a). As noted previously, NSTs (brevetoxins) were detected for the first time in 2025 in Australian waters (Anthony Zammit, *personal communication*).

Three types of biotoxins are currently known to occur in NSW (AST, DSTs and PSTs). In NSW, these toxin groups are routinely monitored (biotoxin testing of shellfish flesh and microscopic analysis of water samples for causative phytoplankton) in locations where shellfish are cultivated and harvested (or collected in terms of wild shellfish) for human consumption. In NSW shellfish aquaculture production areas, significant phytoplankton blooms have been infrequent and biotoxin exceedances are relatively rare (NSW Food Authority, 2017a, 2018c). The majority of harvest area closures have been due to rainfall and/or salinity exceeding the management plan limits used as indicators of microbial and viral water quality (NSW Food Authority, 2017a). Since the establishment of the current phytoplankton and biotoxin monitoring program by the NSW Food Authority in 2005, all three of the major toxin groups (AST, DSTs, PSTs) have been detected in shellfish tissue in NSW (NSW Food Authority, 2017a). In commercial oyster and mussel aquaculture areas, regulatory biotoxin exceedances were reported to have occurred during only 3 occasions, including twice for AST (2010 and 2017) and once for PST (2016) (Hallegraeff et al., 2021). More recently, regulatory exceedances have occurred three times for DSTs (during two events in 2022 and one in 2023) and three times for PSTs (during two events in 2022 and one in 2024) (NSW Food Authority, *unpublished data*). One event of note was during late 2022, when an unprecedented bloom of *Alexandrium pacificum* along the mid-north and southern NSW coastline, resulted in regulatory exceedances of PSTs at Broken Bay and Twofold Bay (NSW DPI, 2022a, 2022b). Further information on this event is in preparation to be published (Vig et al., *in preparation*).

Biotoxin regulatory guidance levels have been designed primarily to prevent acute toxic effects from single exposures. Enforcement of these regulations cannot prevent low-dose exposures because they only protect against consumption of doses higher than the regulatory limit. People who consume high quantities of seafood are at a heightened risk for marine biotoxin exposure. Repeated exposure to a single biotoxin or multiple biotoxins at doses below their regulatory limits may also have health consequences, but the available evidence is limited (Lee et al., 2024). This may be particularly relevant to specific bivalve species and toxins, as the uptake and depuration of toxins varies substantially between bivalve species. For example, depuration of biotoxins from pipis tends to be slower than oysters and mussels, which may result in prolonged periods where positive toxins are detected (Farrell et al., 2018). DSTs have been a major food safety challenge for the NSW pipi industry, with up to 40% (110/271) of pipis in an end-product market survey between 2015 and 2017 returning positive results for DTX, and two market place samples above the regulatory limit (Farrell et al., 2018). DSTs are produced by the dinoflagellates *Dinophysis* and less commonly

Prorocentrum. *Dinophysis* is common in Australian waters (Hallegraeff et al., 2022). Comparison of the market survey data to samples (phytoplankton in water and biotoxins in shellfish tissue) collected during the same period at wild harvest beaches demonstrated that, while elevated concentrations of *Dinophysis* were detected, a lag in detecting bloom events on two occasions meant that wild harvest shellfish with DSTs above the regulatory limit entered the marketplace. The survey highlighted a need for distinct management strategies for different shellfish species, particularly during *Dinophysis* bloom events (Farrell et al., 2018). Subsequent to completion of the market survey, Ajani et al. (2022) designed a quantitative real-time PCR assay for *Dinophysis* spp. to detect species belonging to this genus. Novel molecular tools such as this have the potential to be used on-site, be automated and provide an early warning for the management of harmful algal blooms (Ajani et al., 2022). Rapid methods for the detection of biotoxins in shellfish could also assist the seafood industry and safeguard public health. However, a comparison of five commercially available rapid test kits for the detection of DSTs in shellfish tissues against the bench mark methods of LC-MS/MS and LC-MS, led to the conclusion that the rapid test kits may not be appropriate as a stand-alone quality assurance measure at that time (Ajani, Sarowar, et al., 2021).

qPCR and molecular barcoding (amplicon sequencing) using high-throughput sequencing have been increasingly applied to quantify HAB species for ecological analyses and monitoring (McLennan et al., 2021). Aside from the Australian study reporting the development of qPCR assays to detect *Dinophysis* (Ajani et al., 2022), assays have also been described for the on-site detection of several other harmful algal species including *Prorocentrum minimum* (McLennan et al., 2021) and *Pseudo-nitzschia* (Ajani, Verma, et al., 2021). Field methods to identify harmful algal species in seawater or their toxins in shellfish are in various stages of development worldwide. In New Zealand, the Ministry for Primary Industries (MPI) has published a Guide for the validation and approval of new marine biotoxin test methods (MPI, 2017). Validation and application of rapid, automated and sensitive on-site detection methods for harmful algal species and biotoxins, holds the promise of enhancing the future management and mitigation of public health threats associated with these hazards.

One of the most important methods of preventing exposure to marine biotoxins is to ensure that there is a robust system of seafood biotoxin monitoring that clearly communicates timely risk information to harvesters and consumers. In the evaluation of the NSW Shellfish Program conducted in 2018, it was concluded that the Program manages the risk of biotoxin contamination in a meticulous and stringent manner (NSW Food Authority, 2018c). A number of advances have been made since the time of the evaluation, including the completion of the Food Agility CRC *Transforming Australian Shellfish Production* project (Ajani et al., 2024), which included the development of some of the qPCR assays noted above. Work is ongoing to develop a multiplex qPCR assay to target a range of potentially harmful species.

While exceedances of the regulatory limits for algal toxins in NSW have been relatively rare, a historical low frequency of algal events does not mean that blooms and/or toxic events will not occur in the future (NSW Food Authority, 2017a). The NSW *Marine Biotoxin Management Plan* contains a list of phytoplankton species present or likely to be present in Australian waters categorised according to their toxin-producing status (for example, proven to produce toxins, toxicity untested or unclear) (NSW Food Authority, 2015a). Phytoplankton species and toxicity can change over time and blooms are unpredictable. Worldwide, the frequency, intensity and geographical distribution of harmful algal blooms appear to be changing as a result of human impacts such as climate change, eutrophication, increase in global aquaculture ventures and the introduction of new species to new areas (Ajani et al., 2022). Indeed, an unusual occurrence was reported in NSW during late 2024, of high levels of the potential PST-producing species *Alexandrium minutum* in the Shoalhaven River (WaterNSW, 2024b).

Advances in screening methods may also lead to the discovery of emergent marine biotoxins which are not yet regulated nor monitored regularly (García-Cazorla & Vasconcelos, 2022). High-throughput sequencing, using metabarcoding techniques, enabled the detection of new species of toxin-producing dinoflagellates in New Zealand, that were previously overlooked by microscopy (Rhodes & and Smith, 2019). While shotgun metagenomic sequencing was evaluated to be a promising risk assessment tool to screen for genes encoding new toxins and their producing organisms in samples taken from cyanobacteria blooms along the archipelago of Cabo Verde (García-Cazorla & Vasconcelos, 2022). Despite technological advances in the ability to screen for emerging toxins, toxicity data together with adequate detection methods for monitoring procedures will also be crucial to protecting human health.

Conclusion

Histamine poisoning has remained the leading cause of seafood outbreaks in NSW (2005 – 2020). The majority of histamine poisoning events in NSW (2016 to 2020) were due to the consumption of tuna and mackerel, which are traditionally considered to present the highest risk of histamine poisoning. Aside from further promotion of seafood food safety resource materials already developed by the NSW Food Authority, education initiatives targeting high-risk practices like longlining and gillnetting could be warranted.

Ciguatera poisoning was responsible for the second highest number of seafood related outbreaks in NSW (2016 to 2020). The majority of ciguatera outbreaks were due to consumption of Spanish mackerel, which is a high-risk species for ciguatoxin. Climate change will impact the migration and establishment of new species in NSW coastal waters. Efforts to raise awareness amongst the public, particularly in previously unaffected locations, could aid in the future management and mitigation of public health threats associated with ciguatera poisoning.

Climate change has introduced uncertainty to many seafood safety monitoring programmes globally. To support *Vibrio* risk management in NSW, data on the presence and prevalence of *V. parahaemolyticus* in oyster harvest areas has been modelled with high-resolution data from sensors and weather records. This has resulted in enhanced risk management advice for the oyster industry. Further work utilising WGS technologies will provide insight into the genetic variability and risk posed by *V. parahaemolyticus* strains currently present in NSW waters.

Listeriosis outbreaks associated with seafood in Australia are relatively rare and the overall risk to the general population remains low. Smoked fish is a high-risk RTE product for invasive listeriosis in vulnerable groups, as demonstrated by the high mortality rate and advanced age of human cases in the 2019 outbreak. Guidance material for NSW licensees producing RTE seafood products could be updated as previously discussed, to reflect the updated information and guidance now available and currently under development domestically and internationally. Further, as the Australian population is aging, it will be important to continue raising awareness of listeriosis and its risks to the increasing proportion of vulnerable people in households consuming these high-risk RTE foods.

Seafood safety will be enhanced as technological resources become available to enable the rapid, automated and sensitive on-site detection of seafood safety hazards. Various studies on the development and assessment of rapid methods for the detection of norovirus, pathogenic *Vibrio*, ciguatoxin and other marine biotoxins in seafood have been reported. Field methods to identify harmful algal species in seawater are also in various stages of development. Validated rapid methods could significantly aid the management and mitigation of public health threats if successfully implemented for end-product testing of seafood or during environmental monitoring, as part of either a routine surveillance program or as required on a risk assessment basis.

Finally, temperature is the single most important factor affecting the rate of caught or harvested fish and shellfish deterioration and multiplication of microorganisms. Fresh fish, fillets, shellfish and their products should be chilled rapidly and held at a temperature below 5°C. For fish species prone to histamine production, time and temperature control is also the most effective method for ensuring food safety. Those preparing raw or undercooked seafood for consumption must be aware of the risk of parasites to food safety, which can be improved by using high-value marine fish and freezing fish using a validated method to inactivate parasites.

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