OPTIMISING THE INVESTIGATION OF UNEXPLAINED OYSTER MORTALITY

WORKSHOP REPORT

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Optimising the Investigation of Unexplained Oyster Mortality - Workshop

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Abbreviations

ASI	Australian Seafood Industries
DAFF	Department of Agriculture, Fisheries & Forestry
HAB	Harmful Algal Bloom
IMAS	Institute for Marine and Antarctic Studies
NACA	Network of Aquaculture Centres in Asia-Pacific
NGO	Non-Government Organisation
NRE	Department of Natural Resources and Environment Tasmania
NSW DPIRD	NSW Department of Primary Industry & Regional Development
POMS	Pacific Oyster Mortality Syndrome
QX	Queensland unknown
SFG	Scope For Growth
SRO	Sydney Rock oyster
WOAH	World Organisation for Animal Health

Glossary

Aetiology	The cause, or set of causes, for a disease or health condition.
Bacteriology	The study of bacteria.
Epidemiology	The incidence, distribution, and possible control of a disease.
Epigenetic	Heritable change in the characteristics of a cell or organism that result from altered gene expression.
Gross pathology	The examination of diseased tissues that are visible to the naked eye.
Histopathology	The microscopic study of changes in tissues caused by disease.
Infectome	The infectious component of the microbiome that contributes to the development and progression of disease.
Microbiome	The community of micro-organisms found in a particular environment.
Parasitology	The study of parasitic organisms.
PCR – Polymerase Chain Reaction	A PCR test detects the presence of specific genetic material, such as that of a pathogen. It is therefore highly targeted and can be pathogen specific.
Proximate analysis	A method for calculating the composition of a product by measuring the concentrations of six key constituents: moisture, protein, fat, fibre, ash, and nitrogen-free extract.
Putative agent	Something which is assumed or commonly accepted to be the agent, rather than on direct evidence.
Scope For Growth	The net energy available for growth, reproduction, and immune function after accounting for basic metabolic demands.
Serology	The study of blood serum, with a particular focus on its role in modulating immune responses to pathogenic exposure.
Transmission Electron Microscopy (TEM)	A high-resolution imaging technique, that transmits a beam of electrons through a thin sample to create a detailed image of its internal structure.
Virology	The study of viruses and viral diseases.

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Executive Summary

Unexplained oyster mortality continues to undermine the productivity, resilience, and investment confidence of Australia's oyster industry. Recent events in regions such as the Hawkesbury River, Port Stephens (NSW), and Pipeclay Lagoon (Tasmania) have resulted in severe losses without clear links to notifiable diseases, environmental stressors, or husbandry practices. These events are likely multifactorial and exacerbated by fragmented investigations, limited diagnostic capacity, and the absence of a coordinated response framework.

In August 2025, Oysters Australia, supported by the Fisheries Research Development Corporation (FRDC), hosted a national workshop to address this challenge. The workshop brought together producers, researchers, veterinarians, government representatives and other stakeholders to identify systemic gaps, and explore strategic options for strengthening mortality investigations of unknown aetiology.

Key Challenges Identified

- **Absence of a Clear Investigative Framework**: There is no agreed framework to guide timely, multidisciplinary investigations. This leaves growers navigating crises without structured support, or access to expert-led diagnostic pathways.

- **Coordination & Communication Barriers**: Low awareness of aquatic veterinarians and unclear definition of roles and responsibilities contribute to fragmented and delayed investigations.

- **Limited Diagnostic Capacity**: Specialist expertise is increasingly constrained, with critical gaps emerging in disciplines such as shellfish pathology. Novel technologies need real-world validation and further integration into investigative frameworks.

- **Environmental & Anthropogenic Complexity**: Oyster mortality often arises from cumulative, often synergistic, stressors, rather than a single cause. Anthropogenic influences further complicate disease dynamics in open farming systems.

- **Inconsistent Husbandry & Data Gaps**: Inconsistent farm records and limited environmental monitoring make it difficult to distinguish between management-related and external stressors. The absence of shared data systems delays early detection and coordinated response.

- **Resource Constraints**: Funding shortages, strained laboratory capacity, and limited training restrict investigative scope.

Strategic Options

Workshop participants highlighted a suite of actionable strategies to strengthen industry preparedness and response capacity, including:

1. **Establish a National Investigative Framework**: Establish a formal, step-by-step fraemwork. Include emergency response protocols and clear role delineation. This could include a three-stage diagnostic approach:
    - **Data Collection & Case Definition**: Robust farm records, environmental surveillance, and timely sample collection.
    - **Traditional Diagnostics**: Apply established diagnostic tools for known pathogens.
    - **Advanced Technologies**: Use metatranscriptomics and other 'omics' approaches to detect unknown agents and understand host-pathogen dynamics.
2. **Promote Investigation Coordinators**: Increase awareness of aquatic veterinarians and their critical role in leading and coordinating mortality investigations.
3. **Enhance Data Collection and Sharing**: Promote digital farm management platforms to standardise husbandry data collection and create opportunities for collaborative surveillance and traceability.
4. **Strengthen Funding Mechanisms**: Identify and create dedicated pools of funding to support rapid and sustained investigations.
5. **Advance Diagnostic Tools**: Incorporate novel technologies, such as metatranscriptomics, to complement traditional methods and potentially uncover novel drivers of mortality.
6. **Build Diagnostic Capacity**: In partnership with other aquaculture sectors, support the training, accreditation, and professional development of aquatic animal health professionals, particularly shellfish pathologists.

Unexplained oyster mortality events pose a significant threat to Australia's oyster industry, but a proactive, coordinated approach can help mitigate some of these risks. By addressing gaps in resources, technology, and collaboration, the industry can enhance its resilience and adapt to future challenges.

The Issue

The health of farmed oyster stock is fundamental to the commercial viability of Australia's oyster industry. Despite farmers' best efforts to maintain healthy, high-quality oysters, even the most experienced growers are vulnerable to losses in the dynamic and often unpredictable marine environment. Part of this challenge is that oysters are encapsulated within their shell, making it difficult to detect problems until mortality occurs. Unlike other aquatic or terrestrial animals, this hidden physiology complicates timely investigation. In New South Wales, it's not uncommon for growers to cite a 30% mortality rate across the production cycle, a broadly accepted norm that underscores the persistent risks facing oyster health.

Unexplained oyster mortality events have affected many different growing regions across Australia. While recent attention has focused on estuaries such as Pipeclay Lagoon in Tasmania and the Hawkesbury River and Port Stephens in New South Wales, the issue is far more widespread. Tasmania has experienced long-standing unexplained mortalities in St Helens and Bruny Island, and the far south coast of NSW reported elevated mortalities across the 2024/25 summer. In South Australia, the severity and persistence of these events led to the naming of a distinct syndrome, South Australian Mortality Syndrome (SAMS), with reported losses often exceeding 40%.

Targeted testing for a narrow range of 'notifiable' pathogens has failed to identify a likely cause, and limited follow-up investigations in Pipeclay Lagoon and the Hawkesbury Rivers are yet to offer a clear explanation. Broad and in-depth investigation into all possible infectious and non-infectious causes remains largely unexplored.

Box 1. Notifiable diseases affecting oysters

Each jurisdiction maintains its own list of notifiable diseases, generally aligned with Australia's *National List of Reportable Diseases of Aquatic Animals*. Diseases listed that affect oysters include:

- Infection with *Bonamia exitosa*
- Infection with *Marteilia sydneyi* (Qx disease)
- Infection with *Ostreid herpesvirus-1* (POMS)
- Infection with *Bonamia ostreae* (exotic disease)
- Infection with *Marteilia refringens* (exotic disease)
- Infection with *Marteilioides chungmuensis* (exotic disease)
- Infection with *Mikrocytos mackini* (exotic disease)
- Infection with *Perkinsus marinus* (exotic disease)

Unexplained mortality events occur without a clear cause; they have an unknown aetiology. **They have not been found to be associated with any notifiable oyster pathogen, obvious environmental stressor, or restricted to a particular management practice.** This highlights the complexity and uncertainty surrounding such events, emphasising the need for further investigation and collaborative inquiry.

For the most part, the causes of these mortalities remain poorly described, leaving growers without effective strategies to prevent or mitigate ongoing impacts. The high variability in survival and performance undermines investment and the ongoing viability of those businesses that are affected.

Two case-studies elaborating on the unexplained oyster mortality events in the Hawkesbury River (NSW) and Pipeclay Lagoon (Tas), are provided below in Box 2 and Box 3 respectively.

Box 2 – Unexplained Pacific oyster mortality event in the Hawkesbury River (NSW).

Accommodating information from Ben Ralston's presentation (see Appendix 1 – Presentation 1).

In December 2024, oyster farmers in the Hawkesbury River began observing signs of mortality in triploid Pacific oyster stock in Porto Bay, in the lower reaches of the estuary. Samples were submitted to a state government laboratory, who subsequently ruled out POMS and other 'notifiable' pathogens as the causative agent.

At the request of affected farmers, an outbreak investigation was initiated on 17th December and undertaken pro bono by specialist aquatic veterinary diagnosticians from the University of Sydney. The investigation was coordinated and broadly aligned with the framework outlined in Figure 4 of this report, with University of Sydney researchers also deployed in a pro bono capacity. Vibrio infection was ruled out within 24 hours, and a comprehensive funded investigation was recommended.

Farmers requested support to set up a testing plan, however no government funding was available to support further investigation. By the end of December, mortality had spread throughout the river with some growers suffering catastrophic losses, up to 85% mortality across all gear types. Without a structured framework farmers were left to navigate the crisis alone, relying on significant in-kind assistance from researchers at the University of Sydney to undertake sample collection and preliminary investigation with minimal resources.

Uncertainty around the cause of oyster mortality has made it difficult for growers to make informed business decisions. If losses continue, the long-term commercial viability of affected leases is at serious risk. Farmers are calling for a dedicated pool of funding to enable timely, expert-led investigation during future mortality events, including the capacity to assess whether lease areas are suitable for shellfish cultivation.

Farmers also emphasise the need to ease interstate biosecurity restrictions to support window farming, particularly in estuaries like Port Stephens and the Hawkesbury River, where a growing window exists between April and December. To make this approach viable, growers require access to larger-sized input stock. Progressing this strategy would require further engagement with government agencies and may require targeted funding to address knowledge gaps that support regulatory or policy reform.

Box 3 – Unexplained Pacific oyster mortality in Pipeclay Lagoon (TAS).

Accommodating information from John Ramsden's presentation (see Appendix 1 – Presentation 2).

Pipeclay Lagoon, once a highly productive oyster-growing region, has experienced a dramatic decline in production since 2016. By 2022, all farmers were struggling to maintain commercially viable operations, with Tasmanian Oyster Company (TOC) alone losing 40 million Pacific oysters between 2021-22. Laboratory testing using traditional histopathology and microbiological assessment ruled out notifiable pathogens such as *Ostreid herpesvirus-1* (POMS), *Perkinsus marinus*, *Mikrocytos mackini* and no definitive cause was identified.

Following these losses, TOC removed all remaining stock from the estuary and redeployed eight full-time staff to other sites. Notably, relocated stock recovered and went on to produce a viable product. With a three-year growth cycle required for market-ready Pacific oysters in Tasmania, the disruption to production and cashflow has been significant. Several other operators highly dependent on Pipeclay have entered receivership, and a once-thriving local industry that supported 30 full-time roles has been reduced to a fraction of its previous capacity.

A range of hypotheses have been proposed, ranging from altered hydrodynamics in the lagoon and seagrass proliferation, to food limitation and feral oyster competition. In response, growers began informal field trials, while ASI (Australian Seafood Industries) and IMAS (Institute for Marine and Antarctic Studies) launched more structured research efforts.

TOC adopted a solution-focused approach, trialing diploid and triploid Pacific oysters in hatchery raceways adjacent to the lagoon with promising results. Subsequent trials demonstrated that seed trays outperformed baskets threefold, and larger input stock improved survival and growth. While time will tell, with cautious optimism TOC are gradually scaling up production in Pipeclay Lagoon and reinstating staff in the region.

The company emphasises the critical need for robust farm data management systems, and urges all growers to maintain detailed grading records, photographs, and field notes to support mortality investigations and guide future decision-making.

IMAS Research in Pipeclay Lagoon.

Accommodating information from Andrew Trotter's presentation (see Appendix 1 – Presentation 8).

The Institute for Marine and Antarctic Studies (IMAS) was ultimately commissioned by the Department of Natural Resources and Environment Tasmania (NRE) to investigate these mortalities, although limited funding has constrained the scope of this work. Growers expressed frustration at delays in IMAS's involvement, unaware that such investigations fall outside the institute's core remit. IMAS supports the government under agreement and was subject to contracting and political processes before work could begin.

IMAS assembled an interdisciplinary team comprising a physiologist, aquatic veterinarian, marine ecologist, molecular microbiologist, and nutritionist to carry out a broad suite of diagnostic and environmental assessments. However, efforts were hampered by limited access to reliable mortality data, with growers often providing conflicting accounts. Coordinating a unified approach was also difficult, with challenges in bringing farmers together.

With only one summer of sampling completed, results are preliminary. Early findings suggest that parts of Pipeclay Lagoon are subject to extreme fluctuations in dissolved oxygen and pH. Ongoing research is exploring potential links to seagrass proliferation and restricted flushing within the lagoon. Additional engagement with phycologists is needed to assess the possible ecological impact of a red algae species observed within the seagrass meadows.

Of the producers participating in the workshop on the 20th August 2025, 58% reported ongoing unexplained mortalities on their farms, 34% had experienced similar events in the past five years that had since resolved, with only 8% able to identify the cause of stock losses.

Pinpointing the cause(s) of disease in aquatic animals is inherently challenging due to the complex and dynamic interactions of the host, its environment, potential pathogens, and anthropogenic factors. In aquatic animals many environmentally ubiquitous or host commensal organisms can, under certain /conditions, cause opportunistic or secondary infections. As such, complete avoidance of potentially harmful pathogens is often not achievable.

Filter feeders like oysters are especially vulnerable, continuously processing vast volumes of water, and with it, a constant exposure to potential pathogens. Yet, exposure to a pathogen does not guarantee disease, and there are usually other factors involved.

Anthropogenic influences further complicate the picture. Nutrient and sediment run-off, agricultural and urban pollutants, translocation of aquatic species, and degradation of catchment health all contribute to a shifting disease landscape. Rarely is there a single cause.

Overlooking any contributing factors can obscure the true drivers of disease and undermine mitigation efforts, increasing the likelihood of repeat mortality events in the future.

The epidemiological triad is a well-established concept that explains how infectious diseases arise: a **pathogen** interacts with a **susceptible host** within a **supportive environment**, leading to infection and disease. Recognising the profound and growing impact of human activity on animal health, in 2013, Shields expanded the triad to include anthropogenic influences, acknowledging that factors such as pollution and climate change now play a critical role in shaping disease dynamics.

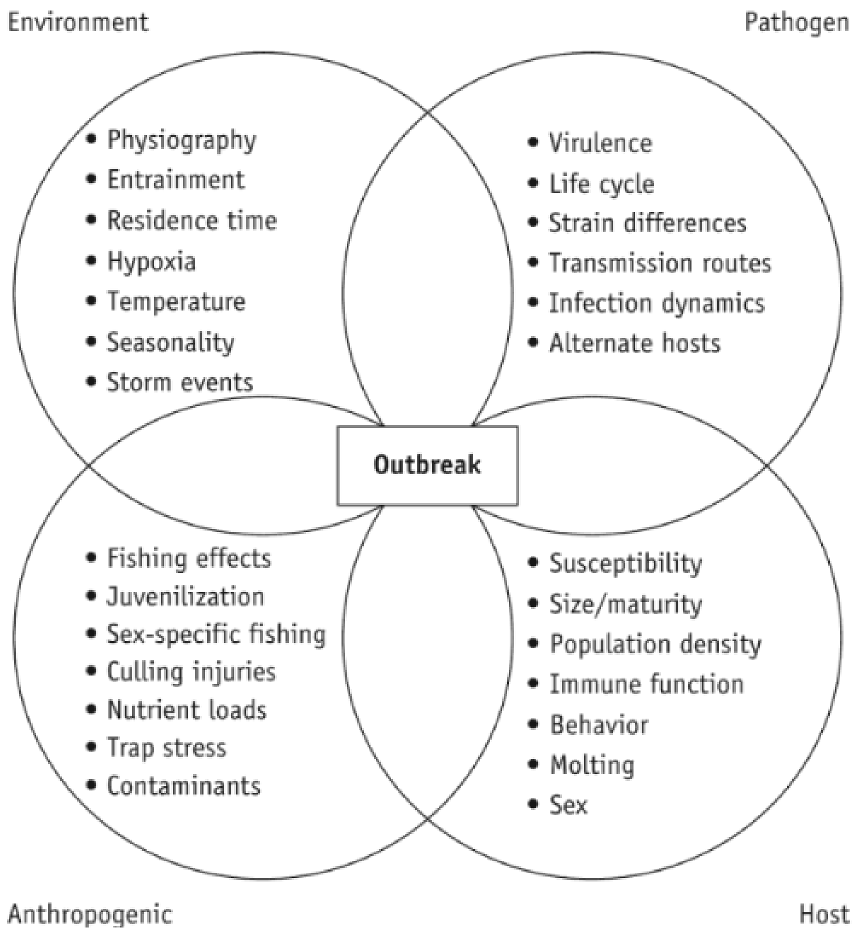


Figure 1. The adapted epidemiological triad to include potential anthropogenic impacts. Note that not all these factors apply to oysters. (Shields 2013)

In a similar manner, King et al. (2019) highlights that oyster health is governed by a complex interplay between environmental conditions and the host microbiome, with mortality events typically arising from cumulative, synergistic stressors rather than a single causative agent. Figure 2 depicts the diverse, layered factors that can interact to undermine oyster health.

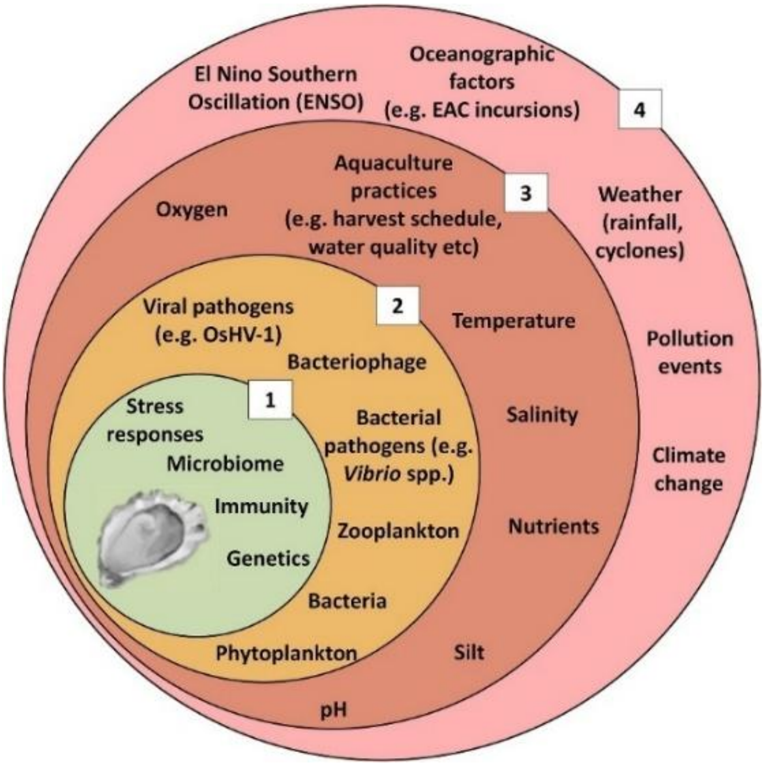


Figure 2. Some of the influences that can synergistically impact on oyster health (King et. al. 2019).

Purpose of the Workshop

On the 20th August 2025, Oysters Australia convened a workshop on the topic of oyster mortality of unknown aetiology. The workshop set out to review and develop a more robust framework to investigate and respond to unexplained mortality events by refining the investigative framework, clarifying the role of government, aquatic animal veterinarians, and researchers, and identifying practical tools and resources to support growers.

By fostering collaboration between industry, researchers, private consultants, universities and government, the workshop sought to shape a targeted, cost-effective program of work that enables the industry to more effectively detect, investigate, and respond to unexplained mortality events.

Investigating Oyster Mortality

The Role of The Australian Government

Accommodating information from Jeffrey Go's presentation (see Appendix 1 – Presentation 4).

The Australian Government (Department of Agriculture, Fisheries & Forestry (DAFF)) has a role to play in addressing issues of national concern e.g. coordinating a response to an exotic disease incursion.

Through the Australian Centre for Disease Preparedness, the CSIRO also operates the *National Reference Laboratory* which diagnoses exotic and internationally notifiable diseases.

The Role of State & Territory Governments

Accommodating information from Jeffrey Go's presentation (see Appendix 1 – Presentation 4).

Jurisdictional governments are responsible for implementing aquatic biosecurity within their respective legislative frameworks. Their core responsibilities in oyster mortality investigations include:

- **Excluding 'notifiable' diseases**
  e.g. ruling out Qx disease in Sydney rock oyster mortality events.
- **Conducting initial investigations into potential emerging biosecurity threats**
  e.g. the 2010 investigation of the index case of POMS in George's River (NSW).

Jurisdictional governments investigate suspected notifiable diseases, even where these are known to occur, to support containment, in efforts to mitigate spread to suspected unaffected regions. This also ensures compliance with international reporting obligations, including those required by the World Organisation for Animal Health (WOAH) and the Network of Aquaculture Centres in Asia-Pacific (NACA), helping maintain transparency and uphold Australia's biosecurity commitments.

Accurate diagnosis hinges on collecting suitable samples at the time of the mortality event, as delayed sampling may miss the disease processes that contributed to the decline in oyster health. This is especially challenging in oysters, where the animal is enclosed within its shell, making early detection of issues difficult. Regular stock surveillance, thorough record-keeping, and prompt reporting of losses are essential. Since oysters in poor health can host a wide range of opportunistic organisms, proactive sampling may be particularly valuable in supporting accurate diagnosis.

Some of the key diagnostic tools that government use include:

- **Histopathology** - Microscopic examination of tissue
- **Molecular testing e.g. PCR (Polymerase Chain Reaction) tests** - PCR detects the presence of specific genetic material, and hence PCR tests are highly targeted and pathogen specific.

Crucially, there are areas of investigation which fall outside the scope of jurisdictional governments. These include:

- **Detailed, ongoing mortality investigations, where no clear cause is identified** through initial assessments.
- Mortalities linked to **widespread ubiquitous pathogens that are not controllable** e.g. *Vibrio*.
- Mortalities associated with **environmental causes**.

This underscores the limited capacity of state governments to conduct thorough investigations into mortality events of unknown aetiology. As oysters are extensively cultivated in open systems leased from the state, the role of jurisdictional governments is a point of contention, raising concerns about potential impacts not only on commercial species, but also on recreational fisheries and broader public assets.

Across the industry, there is a common misconception about the extent of government responsibility in such investigations, with many advocating for a broader mandate. There is also limited awareness and engagement of aquatic veterinarians, whose specialised expertise could significantly strengthen efforts to support and investigate aquatic animal health.

Box 4. Australia's Veterinary Laboratory Network

Accommodating information from Richard Whittington's presentation (see Appendix 1 – Presentation 7).

Australia's veterinary laboratory network has undergone a marked contraction over the past few decades. As Rahaley (2013) observes, state and territory government services have become increasingly centralised, with a growing emphasis on surveillance for exotic and emerging animal diseases and a corresponding retreat from endemic animal health research. In 1990, there were 23 jurisdictional veterinary laboratories operating nationwide; today, that number has dwindled to five.

The Role of Aquatic Veterinarians

Accommodating information from James Fensham's presentation (see Appendix 1 – Presentation 9).

Aquatic veterinarians can play a pivotal role in understanding and managing disease in aquatic systems. Their role extends well beyond identifying pathogens - they act as integrators of different scientific disciplines; piecing together clinical diagnostics, environmental insights, and epidemiological data to build a more complete picture of disease dynamics. In aquatic environments, where pathogens are often naturally present, vets are trained to look past simplistic cause-and-effect assumptions. Disease rarely arises from a single agent; instead, it emerges from the interplay of environmental stressors, human activities, and host characteristics. Without a broad, adaptive investigative approach, important contributing factors can be overlooked.

Veterinarians rarely work alone. They often lead multidisciplinary teams, coordinating efforts of specialists such as virologists, bacteriologists, parasitologists etc. to ensure a comprehensive response. Much like a conductor guiding an orchestra, they coordinate diverse expertise to achieve the desired outcome. Aquatic veterinarian can play this pivotal role, ensuring that the grower's interests remain central to decision-making.

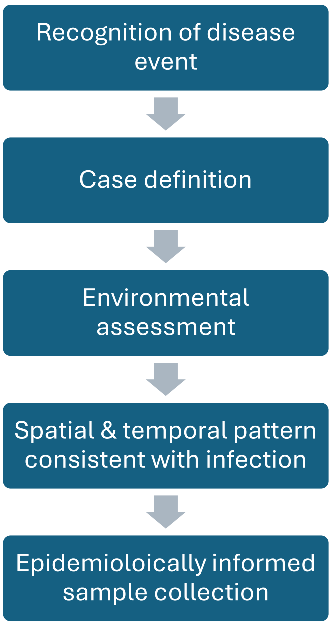
An aquatic veterinarian's approach is also pragmatic, grounded in a stepped investigation process that begins with farm visits and history-taking, and evolves into hypothesis testing and targeted interventions. Importantly, aquatic vets understand that managing disease doesn't always require pinpointing the exact pathogen. Rapid trials and practical solutions can be implemented early, especially when supported by robust farm data. This in turn allows hypotheses to be tested in commercially relevant situations that work towards evidence-based and practical solutions. Epidemiology underpins their work, helping to explore complex or poorly understood outbreaks.

The Investigation Framework

A mortality investigation process typically unfolds in three stages. These are summarised in Costa et. al. (2024), and comprise of:

- Stage 1: Case definition and data collection.
- Stage 2: Diagnostic investigation using traditional tools & procedures.
- Stage 3: Diagnostic investigation using novel tools & procedures.

Stage 1: Case definition and data collection.



The starting point for any disease investigation is the recognition that mortality is occurring beyond expected levels. While this may seem obvious, many producers do not consistently record growth & mortality rates, or key operational details such as growing heights, grading schedules, and other oyster husbandry practices. These practices can expose stock to varying degrees of environmental stress, making it difficult to distinguish between management-related and non-management-related impacts.

To start ruling out environmental causes, investigators require not only robust environmental datasets but also accurate, site-specific records of farm operations. In some cases, analysing these two data streams in parallel may reveal practical interventions to reduce risk, well before the underlying cause of the outbreak is fully understood.

Figure 3. Stage 1 of mortality investigation. Adapted from Costa et. al. 2024.

Farm Management Data - Modern oyster farming is beginning to embrace digital farm management platforms, such as miShell, Oceanfarmr, MusselAPP and OysterCloud, to collect detailed husbandry data in real time. These tools allow growers to log operational metrics like growth rates, mortality, gear types, line heights, grade cycles, biomass and much more. This information can significantly help improve outcomes in mortality investigations.

Box 5. Monitoring and improving oyster survival using a farm management tool.

Accommodating information from Ken Rowe's presentation (see Appendix 1 – Presentation 12).

Blue Farm Intelligence has been conducting a multi-year project to optimise grading schedules based on product size, with the goal of reducing oyster mortality to below 10%. By adjusting grading practices alone, the project has delivered encouraging results. Building on this success, the scope is now expanded to explore additional survival factors, including line height, cultivation method, and other operational variables, to further strengthen farm performance.

When standardised and shared across a region, this farm data becomes a valuable asset. Beyond benchmarking and optimising individual farm performance, it can support industry-wide surveillance. For example, if multiple farms record spikes in mortality or grading irregularities, it can trigger early alerts and guide targeted investigations. This kind of networked surveillance is therefore especially valuable in estuarine systems where mortality events often extend across multiple leases operated by different businesses. Historically, mortality events have often gone underreported, with growers second-guessing their own practices, unaware of broader patterns. It's typically through informal conversations with neighbouring farmers that the true scale of these events becomes evident.

By integrating husbandry records with environmental datasets (e.g. in-water sensors, satellite imagery, predictive modelling), farmers, veterinarians and researchers can begin to identify patterns associated with disease outbreaks or sub-optimal oyster performance.

Realising the potential of 'power in numbers' requires growers to be central to the process; a process built on trust and collaboration. Farmers must be confident that their intellectual property (IP) is protected and that data sharing serves a clear, beneficial purpose.

Environmental data – Across Australia, a diverse network of organisations, including government agencies, councils, universities, industry bodies, farmers and environmental NGO's, actively collect physico-chemical and biological data to monitor our coastal waterways. However, access to this information remains fragmented. While some datasets are publicly available, others are siloed or informally shared, making it difficult to build a comprehensive picture of baseline conditions or detect anomalies. For farmers, veterinarians and researchers alike, navigating this landscape often depends on personal networks rather than transparent data infrastructure.

It should be acknowledged that while in-water sensor networks are increasingly used to monitor parameters like temperature, salinity, and pH in real time, the detection of contaminants, such as pesticides, herbicides, and pharmaceuticals, remains rare. These toxicants are more challenging to monitor, which has limited their inclusion in standard water quality frameworks. However, advances in technology are making detection more affordable, accurate, and reliable, improving accessibility, particularly when mortality events appear epidemiologically linked to water-based drivers.

In NSW, the Shellfish Transformation Project set a new benchmark for co-designed environmental monitoring and research tailored to the shellfish industry. In 2018, real-time sensors were deployed across 13 oyster-producing estuaries, capturing salinity, temperature, and water level data every 15 minutes. These strategically placed sensors, the locations of which were negotiated with industry, provided a high-resolution environmental dataset that underpinned a suite of targeted investigations. One such initiative involved the regular collection and analysis of environmental DNA (eDNA), enabling researchers to detect and map potentially pathogenic bacteria and trace their sources (livestock / bird / human), using microbial source tracking. This integration of microbial and environmental data allowed for more accurate modelling of harvest area conditions, leading some estuaries to shift from rainfall-triggers to salinity-based management plans.

Another key component of the project was the deployment of genetically identical oysters from the SRO selective breeding program. By standardising the genetic baseline, researchers could investigate environmental influences on growth and mortality. After two years, stark differences emerged with oysters at the 'best' performing site 30mm larger than those at the 'poorest' performing site, despite identical genetics. These findings underscore the importance of site-specific environmental conditions and reinforce the need for robust, accessible data to support adaptive farm management.

Box 6. The impact of harmful algae on oysters.

Accommodating information from Shauna Murray's presentation (see Appendix 1 – Presentation 13).

Harmful algae are microscopic organisms that, under certain conditions, can pose serious risks to both human health and oyster viability. When these species proliferate, forming what are known as Harmful Algal Blooms (HAB's), they can produce potent toxins that accumulate in oyster tissues. This renders oysters temporarily unsafe for human consumption and can trigger widespread harvest area closures. In South Australia, for example, a recent bloom led to the quarantine of millions of market-ready oysters, leaving farmers grappling with severe cash-flow disruptions and operational uncertainty.

While food safety is often the headline concern, the physiological impacts of HAB's on oysters can also be significant, and far more nuanced. Effects can be species-specific, with some algae causing immunosuppression, metabolic stress, and disruptions to oysters' natural defence mechanisms. These sub-lethal stressors may not result in immediate mortality but can undermine long-term stock performance, growth rates, and resilience. Research from Florida has shown that exposure to certain algal toxins can even lead to DNA damage and epigenetic changes in Eastern oysters, with potential implications for reproduction and intergenerational health (Gonzalez-Romero et. al 2017).

Despite growing awareness, there remains limited research on the combined effects of harmful algae and pathogens acting in tandem. As climate variability and nutrient loading continue to drive bloom frequency and intensity, further work is needed to understand these interactions to help safeguard oyster health.

Sample collection – The Outbreak! handbook by Bradley & McLaughlin (2023) provides useful guidance on water and specimen sampling protocols, which may assist growers. However, collecting representative samples during unexplained mortality events is inherently challenging. Reporting, sampling, and analysis procedures vary across states and territories, making consistency difficult. To ensure appropriate and high-quality samples, this process is best undertaken with the support of an aquatic veterinarian. Timing is critical: accurate diagnosis depends on capturing samples at the onset of mortality, as delays can obscure the disease processes involved. Furthermore, without proper training or access to pre-prepared kits and materials, the risk of sample contamination increases significantly

Stage 2: Diagnostic investigation using traditional tools & procedures.

A suite of diagnostic tools and procedures underpin aquatic animal health investigations. These methods have been rigorously validated over many years and remain essential for identifying, characterising, and understanding disease outbreaks across aquaculture and wild fisheries. They are routinely employed by multidisciplinary experts, including bacteriologists, virologists, parasitologists, immunologists, and serologists, each bringing a unique lens to the diagnostic process. A selection of these diagnostic tools are described below.

- **Gross Pathology** - Visual inspection of external and internal features to detect lesions, deformities, discoloration, or organ abnormalities.
- **Histopathology** - Microscopic examination of stained tissue sections to identify cellular changes, tissue degeneration, inflammation, or pathogen presence. This technique can provide useful insights into disease progression, host response and the overall health status of the animal. However, it is limited in that not all diseases cause physical changes in tissues and tissue responses are often non-specific, so it broadly a qualitative tool.
- **Bacterial Culture** - Isolation and identification of bacteria using selective media and biochemical profiling. Despite being the cornerstone for confirming bacterial infections, culturing aquatic bacteria is challenging, and carries a high risk of false positives.
- **Enzyme-Linked Immunosorbent Assay (ELISA)** – A sensitive immunological test used to detect specific antigens or antibodies in tissue or serum samples.

Modern molecular diagnostics complement these methods by offering high sensitivity and specificity. These include:

- **Polymerase Chain Reaction (PCR)** - Amplifies target DNA sequences to detect the presence of specific pathogens. This is widely used for rapid and sensitive identification.
- **Quantitative PCR (qPCR)** - Provides both detection and relative quantification of pathogen abundance, offering insights into infection severity.
- **Multiplex PCR** - Enables simultaneous detection of multiple target pathogens in a single reaction.

These modern diagnostic tools can however generate false positives and false negatives and generally need to be used with other diagnostic tools to aid interpretation.

Complex disease investigations rarely yield answers in a single pass. Progress often requires repetition, retesting hypotheses, revisiting differential diagnoses, and pivoting across disciplines. Rather than digging deeper into one avenue, investigators frequently need to reset, widen the field of view, and explore overlooked factors or alternative explanations.

Throughout this process, conventional diagnostic tools remain essential, yet they are fundamentally constrained by their reliance on known pathogens. Techniques like PCR and ELISA are targeted, or ‘biased’, by design - they look for what we expect to find. Even multiplex PCR, while more expansive, still depends on existing genetic sequences and fails to detect novel or unexpected agents.

When the underlying cause (aetiology) of a disease outbreak remains unresolved despite thorough investigation using established diagnostic methods, it may be necessary to implement the use of emerging, novel tools.

Stage 3: Diagnostic investigation using novel tools & procedures.

Accommodating information from Francisca Samsing Pedrals presentation (see Appendix 1 – Presentation 6).

The 'omics' toolkit, comprising metagenomics, metatranscriptomics, and metaproteomics, enables broad-spectrum pathogen discovery without relying on prior assumptions. Although researchers are still learning about how to interpret complex outputs, these technologies are gradually moving beyond the research and development phase and starting to inform real-world surveillance efforts. Further investment is required to evaluate their functionality within an investigative framework, and case-studies required to demonstrate how the results can be translated to real-world actions that improve outcomes.

Metagenomics focuses on analysing all the DNA present in a sample. This allows researchers to identify which organisms are there and what genetic capabilities they possess. In aquaculture, metagenomics can be used to detect the presence of pathogens, monitor biodiversity, and track genes related to antimicrobial resistance.

Metatranscriptomics takes things a step further by examining all the RNA present in a sample, which reveals which genes are actively being expressed at a given moment. This offers a dynamic snapshot of microbial activity and how communities respond to environmental stressors like temperature fluctuations, pollutants, or disease pressure.

As summarised in Costa et. al (2025), metatranscriptomics offers several key advantages:

- it can reveal the genomes of several novel or existing potential pathogens in a single test,
- it does not require the known sequence of a pathogen,
- it can detect pathogens at the variant level, and
- it can identify pathogens in parallel with the expression of host genes allowing for the detection of pre-clinical infections.

Metaproteomics then drills down into the proteins being produced by these microbial communities. Since proteins are the functional workhorses of cells, this approach provides direct evidence of what microbes are actually doing, whether it's producing toxins, cycling nutrients, or interacting with host organisms.

Together, these tools offer layered and holistic information of microbial ecosystems, from genetic potential (DNA) to activity (RNA), to function (proteins).

Box 7. Combing the old and the new - a case for metatranscriptomics.

Accommodating information from Francisca Samsing Pedrals presentation (see Appendix 1 – Presentation 6).

As discussed previously, inshore marine systems are teeming with microbial life, making it hard to distinguish harmful pathogens from background noise. As metatranscriptomics is highly sensitive, a key challenge is to avoid 'false positives' i.e. detecting pathogens in the sample that aren't impacting on the host. As indicated by Costa et. al (2025) this limitation can be addressed by combining metatranscriptomics with traditional diagnostic approaches for confirmation.

A project leveraging metatranscriptomics to investigate unexplained oyster mortality events offers great potential for the aquaculture industry. Traditional diagnostic tools, such as histopathology, PCR, and bacterial culture, are invaluable but inherently limited by their reliance on known pathogens and targeted screening. Metatranscriptomics is immediately applicable in cases where these traditional diagnostic approaches fail to identify the causative agent, providing an unbiased, high-resolution snapshot of microbial activity and host response. These advanced tools may therefore provide researchers with new clues about the underlying cause of mortality.

Box 8. Investigating the role of *Vibrio* in oyster mortalities in NSW.

Accommodating information from Justin Seymour's presentation (see Appendix 1 – Presentation 5).

For many years UTS has been investigating the relationship between oyster health, microbial communities, and environmental conditions. Using advanced molecular techniques, including qPCR, customised DNA sequencing, metagenomics, gene expression analysis, and Nanostring technology, researchers have sought to understand the drivers of oyster mortality.

One of the consistent findings is a strong association between elevated levels of *Vibrio harveyi* and oyster deaths, particularly during marine heatwaves (King et. al 2019c). Experimental work by Green et al. (2019), which used antibiotics to suppress bacterial activity, demonstrated that thermal stress alone did not cause significant mortality. This potential points to a critical interaction between temperature and microbial agents in driving disease outcomes.

Although Vibrio species are ubiquitous in marine ecosystems (Hedges 2022), rising water temperatures have been linked to increased prevalence. This warming trend exerts a dual pressure: it creates favourable conditions for microbial proliferation while simultaneously weakening host resilience through physiological stress and immune suppression (Yttebord et al. 2023). The result is a heightened vulnerability in oysters during periods of thermal stress.

To further investigate these dynamics, UTS developed a customized DNA sequencing approach (King et al. 2019c), which was applied to archived samples from a 2013 mass mortality event in Port Stephens (King et al. 2019b). *Vibrio harveyi* was found to be significantly over-represented in the analysis. Water sampling from the area has also shown a cyclical pattern of *V. harveyi* levels that tracks closely with temperature fluctuations. Field studies across multiple sites confirmed strong correlations between oyster mortality and *V. harveyi* concentrations in both water & oyster tissues.

Additional experimental work explored the influence of microclimatic conditions on disease susceptibility. In tile color trials, oysters placed on black tiles (which absorb more heat), exhibited higher mortality and increased *V. harveyi* colonisation on their gills compared to those situated on white tiles (Scanes et al. 2025). These results suggest that even subtle shifts in local temperature can alter microbial load and host vulnerability.

While elimination of *Vibrio* from open systems is clearly impossible, insights from field studies can potentially be used to train forecasting models that alert farmers to high-risk periods and locations. These early warnings would enable farmers to take proactive steps to mitigate exposure.

Coordinating the Investigation

Accommodating information from James Fensham's presentation (see Appendix 1 – Presentation 9).

Disease investigation relies on strong central coordination. A designated coordinator serves as the linchpin, providing a clear, reliable point of contact, essential for managing communications, engaging specialists, and aligning investigative efforts in a timely and targeted way.

This role is not merely administrative. Working on behalf of their client (usually the farmer), their incentive is to get a result, providing an efficient and effective service that provides growers with a pathway forward. By actively orchestrating the involvement of diverse specialists, the coordinator ensures each contributor is engaged at the right moment, with the right information, and for the right purpose.

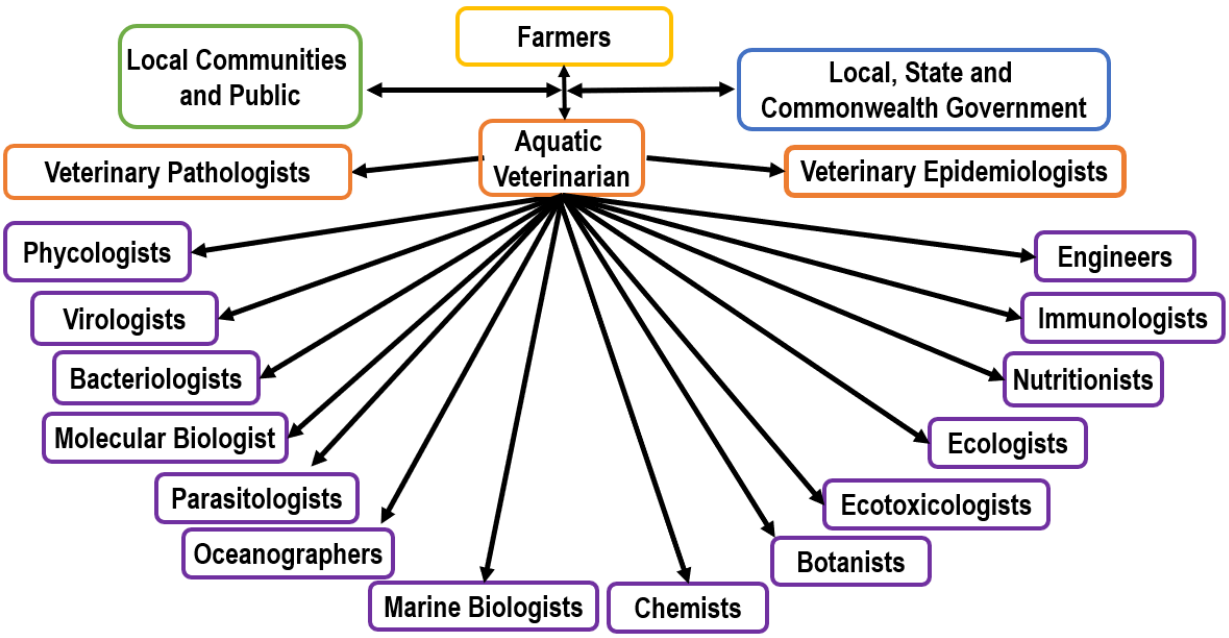


Figure 4. The central role of a coordinator, in this case an aquatic veterinarian, with an example of some of the specialists that may be engaged during an investigation (Future Fisheries Veterinary Service, 2025).

Crucially, the coordinator must be collaborative by nature and comfortable operating beyond their own disciplinary boundaries. Their strength lies in knowing when to seek external expertise, how to foster trust across sectors, and how to integrate disparate data streams into a coherent diagnostic narrative.

Box 9. Distinguishing ‘Mortality Investigation’ from ‘Research’

Accommodating information from James Fensham’s presentation (see Appendix 1 – Presentation 9).

Oyster mortality investigations and research serve fundamentally different purposes and conflating them risks misaligning expectations and ineffective responses.

Mortality investigations are broad, adaptive and collaborative efforts focused on identifying and addressing all plausible causes of disease or loss. They are inherently practical, multidisciplinary, and as investigators work directly for growers, they have a clear mandate: to help mitigate impacts and restore operations for their client through practical solutions.

In contrast, research is designed to explore specific questions in depth beyond what is achievable in a disease investigation, but in doing so is typically more narrowly focused. While research may emerge from investigations to deepen understanding, it shouldn’t substitute for the rapid, grower-oriented nature of a mortality response.

Recognising and respecting this separation is needed to build resilient, responsive systems that serve both immediate industry needs and longer-term understanding.

The Challenges of Unravelling Oyster Mortality

At the workshop held on 20th August 2025, participants conducted a **root-cause analysis** using a Fishbone (Ishikawa) diagram. Each “bone” represented a key thematic category, under which participants identified contributing factors, highlighting why mortality events remain unresolved. This structured method helps to summarise barriers to diagnosis. Information provided by participants was submitted via an online platform, and AI used to group the responses. The information provided is summarised below, with additional commentary provided on the following pages.

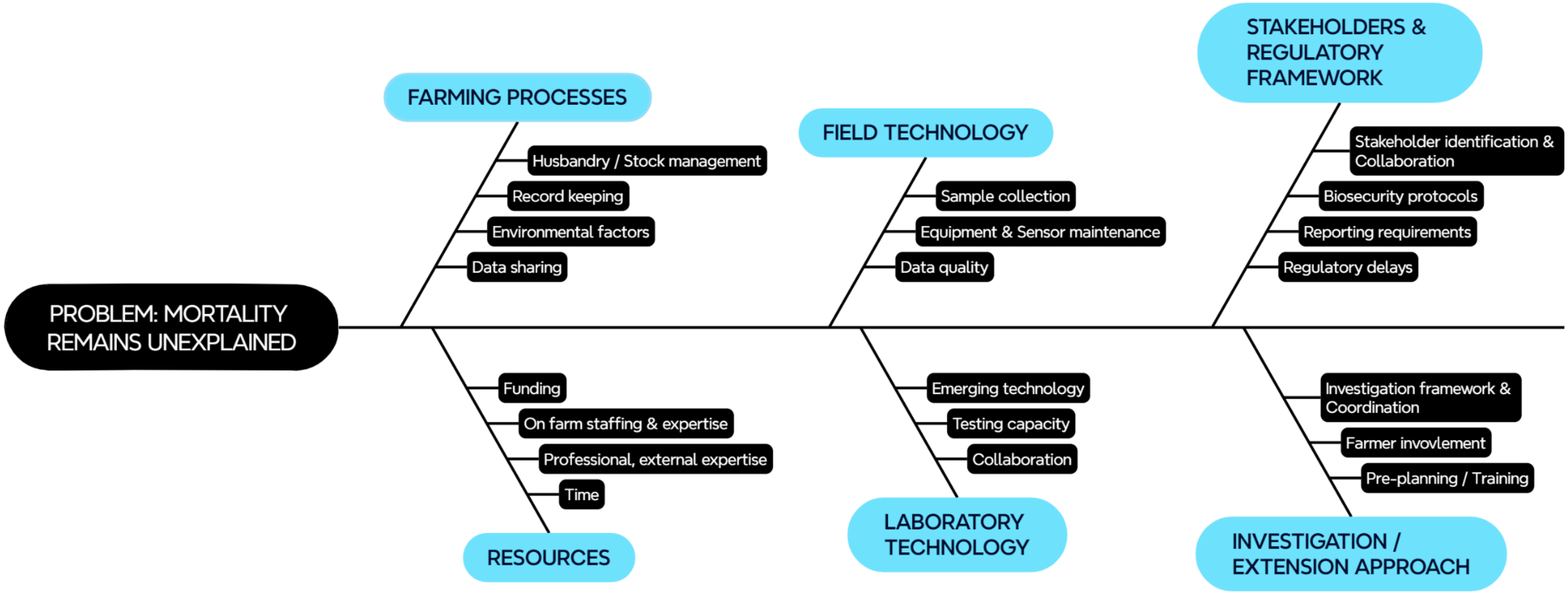


Figure 5. The Fishbone diagram offers a structured framework for categorising the underlying factors that contribute to the identified issue.

More information about the potential use of a Fishbone tool is provided in Appendix 5.

Farming Processes

Husbandry / Stock management | **Environmental factors** | **Record keeping** | **Data sharing**

Husbandry practices can constrain the investigation of oyster mortality events by introducing variability and obscuring causal links. There is little consistency in farming methods, and variations in grading cycles, growing heights, drying regimes, stocking densities etc. can potentially mask early signs of disease or stress. Conversely, variability in practice can help with an investigation provided it is consistent, and investigators are provided with clear information on what was performed. Documented husbandry practices, ideally in the form of Standard Operating Procedures (SOP's), are incredibly useful for investigators.

There may also be a lack of recognition within industry of potentially stressful management practices.

Environmental factors add ambiguity, often through complex interactions that remain poorly understood or inadequately monitored. Site-specific conditions like salinity, temperature and dissolved oxygen can fluctuate unpredictably, interact with husbandry practices, and provide for unexpected outcomes. Analysis of data and investigation of these interactions is needed to provide useful information for diagnosis. Without reliable current and long-term environmental data, it's difficult to pinpoint when and how these factors contribute to stock losses.

Record keeping is inconsistent and often inadequate. Not all farmers record production data, let alone farm management information. Without reliable data on key oyster metrics (e.g. growth & survival), husbandry practice, environmental conditions, and stock movements, it's difficult to distinguish between management-induced stress and other contributing factors. This lack of documentation is a critical constraint. Without detailed records, particularly for vulnerable stock or high-risk periods, diagnosis becomes extremely challenging, investigations more costly, and as a result this significantly reduces the likelihood of delivering meaningful outcomes.

Compounding the challenge, batches of oysters are often co-mingled during grading, obscuring their origins and performance histories. Maintaining batch separation throughout cultivation would enable meaningful comparisons across genetic lines. e.g. evaluating family-line performance from the SRO breeding program under commercial settings or contrasting wild-caught spat from different locations. This unlocks valuable opportunities for industry-wide learning and builds the evidence base for future breeding and husbandry decisions.

Data sharing is also limited. The reluctance to report mortality or disclose farming practices currently limits the opportunity for collective learning. When farmers are reluctant to disclose operational details, information remains siloed, and opportunities to identify common stressors or effective interventions are lost.

Field Technology

Sample collection | **Equipment & Sensor maintenance** | **Data quality**

Sample collection. Oysters are notoriously difficult to assess in real time. Sedentary and encased in shell, they often appear healthy until the moment they die. Once an oyster is in declining health, opportunistic bacteria can colonise quickly, making diagnosis difficult.

Routine sampling by farmers can potentially provide useful baselines and material for retrospective examination, however collecting representative samples during unexplained mortality events is not straightforward. Designing an effective sampling program requires specialist input, and timing is critical. Without appropriate training or access to ready-to-use kits, there's a risk of collecting poor-quality or contaminated samples that yield little diagnostic value.

While this risk may be acceptable for routine surveillance, investigating unexplained mortality requires high-integrity samples suitable for advanced diagnostics or research, where sub-optimal collection can potentially undermine investigations and waste limited resources.

Equipment & sensors maintenance. Diagnostic efforts may be undermined by deficiencies in environmental monitoring infrastructure. Such equipment can come with a large price tag and also requires ongoing maintenance, calibration and quality assurance to remain effective. Sensor placement and data continuity is also important, yet many programs rely on short-term public funding, limiting long-term data access and reliability. Even where regional monitoring programs exist, data is often siloed and not shared openly. A lack of investment in data analysis further limits the identification of actionable insights.

Despite the growing availability of ag-tech tools to monitor water quality, stock performance, and husbandry impacts, on-farm adoption in the oyster industry remains low. Most farmers have yet to integrate these technologies into daily operations, limiting their ability to rapidly detect, understand and respond to environmental or biological shifts.

Data quality. Accurate, high-quality data underpins effective investigations. This presents a clear extension opportunity to strengthen diagnostic outcomes by supporting farmers in better sample handling, equipment use, and data recording. Training programs that focus on both procedures and purpose can elevate the value of record-keeping, empowering farm staff to generate reliable data that strengthens timely, evidence-based responses.

Stakeholders & Regulatory Framework

Stakeholder identification & Collaboration | **Biosecurity protocols** | **Reporting requirements** | **Regulatory delays**

Stakeholder identification & collaboration. A lack of coordinated leadership and communication has left stakeholders disjointed, with no clear investigative framework or delineation of roles and responsibilities. Government agencies have limited capacity to respond to unexplained mortality events, yet farmers continue to rely heavily on them, often unaware of these limitations or alternative support avenues, such as aquatic veterinarians. Stakeholder mapping is needed to identify a network of knowledgeable practitioners and to clarify pathways for collaboration and effective investigation. The absence of national information-sharing further hampers cross-jurisdictional learning and trust.

Environmental regulators currently seem peripheral to mortality investigations, despite their critical role in identifying environmental contaminants and key role in remediation / resolution. Their integration into investigative processes would strengthen the process and ensure environmental factors are not overlooked.

Biosecurity protocols Evidence suggests that window farming (targeted cultivation outside peak mortality windows) is viable in some waterways. Success depends on sourcing larger input stock capable of reaching market size within the shortened growing window. Current translocation protocols on interstate oyster shipment limit the viability of this option. Updating these protocols to permit carefully managed access to larger stock, without compromising biosecurity, would deliver real advantages for growers. Progressing this strategy would require further engagement with government agencies and may require targeted funding to address knowledge gaps that support regulatory or policy reform.

Risk management planning in the oyster industry remains underdeveloped, with existing tools inadequately extended and under-utilised. There is a clear opportunity to establish a practical response framework, clarifying who to contact, how to sample, and how to escalate unexplained mortality events. Rapid reporting is essential for timely investigation, yet current systems lack clarity and responsiveness, especially after state government investigations are inconclusive.

Mandatory **reporting requirements** are not always clear and are sometimes ignored, undermining early detection and coordinated response efforts. Greater emphasis on education is needed to ensure mortalities are flagged early and investigated promptly.

Finally, **regulatory change** often lags behind evolving industry needs, limiting opportunities for innovation and adaptive management. This presents a valuable opportunity to deepen understanding of regulatory decision-making, build trust between stakeholders and identify pathways for more responsive processes.

Resources

Funding | **On-farm staffing & expertise** | **External / Professional expertise** | **Time**

Funding remains a foundational constraint in oyster mortality investigations. Growers frequently expect jurisdictional governments to intervene during mortality events, yet these agencies are constrained in their ability to respond (see page 8). In emergency scenarios, the FRDC can sometimes activate short-term 'public good' funding through programs like the Aquatic Animal Health Biosecurity Coordination Program. These rapid responses are designed to address a specific, critical RD&E question. There is no dedicated funding mechanism for broader or sustained diagnostic efforts. The absence of established structures to collect and administer such funding leaves both government and industry unable to respond systematically. High investigation costs, especially when mortality events are geographically limited, raise difficult questions about responsibility and cost-sharing, often stalling coordinated action and delaying timely intervention.

> Box 10. Emergency Aquatic Disease Response Agreements (EADRA)
>
> The Emergency Animal Disease Response Agreement (EADRA) is a cost-sharing framework co-signed by industry, the Commonwealth, and jurisdictional governments. It enables coordinated responses to pest and disease outbreaks, with financial contributions from affected industries typically collected retrospectively through a levy system. While EADRA's function effectively for terrestrial livestock, its structure is not well-suited to aquatic industries, especially those that operate in open systems.
>
> A key limitation is its narrow scope - an aquatic EADRA would only apply to exotic disease incursions, excluding endemic threats such as QX disease and POMS. This exclusion remains a central concern for Oysters Australia, highlighting the need for more tailored mechanisms that address the unique vulnerabilities of the industry.

On-farm staffing & expertise are also limited. Many growers and farm staff lack formal training in aquatic animal health, biosecurity, and environmental monitoring. Without clear Standard Operating Procedures (SOP's), staff may not know how to collect high-quality samples, interpret early warning signs, or follow a basic sampling program. Reliable environmental and husbandry data are often critical to understanding mortality events, yet poor data quality has the potential to undermine investigations. Staff need to be trained not only in the operational process of capturing this information but also an appreciation of why they are doing this. Larger operations, or those spread across multiple sites, may struggle to check stock regularly or report issues in a timely manner. This compromises the quality of information submitted for epidemiological interrogation and reduces the likelihood of identifying the root cause.

External / Professional expertise is increasingly constrained for some disciplines. While histopathology professionals exist, few possess the specialised knowledge required to interpret oyster tissue accurately. The retirement of key shellfish pathologists has eroded national diagnostic capacity, and structured training, accreditation, and professional development are urgently needed to rebuild expertise across aquatic animal health disciplines. Without a coordinated pipeline of skilled diagnosticians, investigations risk being delayed, misinterpreted, or deprioritised.

Potential solutions may include the development of resources such as an annotated slide reference library and the digitisation of slide images for remote interpretation. This challenge spans all Australian aquaculture species, not just shellfish, underscoring the need for coordinated efforts across sectors to build capacity.

Time is another significant constraint. Without a clear investigative framework, delays in initiating investigations can result in missed sampling opportunities. Slow funding approvals and diagnostic turnaround times can also leave farmers managing uncertainty without timely support. Retrospective investigations often depend on archived samples and complex datasets, requiring substantial analytical effort and coordination. The lack of real-time data capture and response mechanisms further limits the ability to act on early signs of stress or disease.

Laboratory Technology

Emerging technology | **Testing capacity** | **Collaboration**

Emerging technology. While specific diagnostic tests exist for notifiable diseases, they are inherently 'biased' and unsuitable for detecting novel or emerging pathogens. Unbiased approaches, such as metatranscriptomics, and other 'omics' technologies, potentially offer promise in identifying novel disease agents. These methods however come with high costs, particularly around validation and implementation / analysis. Traditional diagnostic methods remain valuable and cost-effective in disease investigations, and emerging tools should complement, not replace, established approaches, especially when resources are limited.

Testing capacity. Core diagnostic technologies are generally available, but access is constrained by funding and human resources. Expertise in some disciplines is waning, and while skilled operators exist, their services often come at a high cost. The issue is less about technological availability and more about the systemic underfunding of specialist diagnostic work, with Australian universities increasingly operating under highly commercial models. Moreover, the effectiveness of laboratory equipment hinges on the technician's skill. Interpretation of complex results demands specialist knowledge, which is threatened by limited professional development pathways and the erosion of niche expertise. Addressing these gaps requires investment in training, retention, and career development (see previous 'Resources' section).

Collaboration. While aquatic veterinarians operate within established professional networks and maintain visibility of diagnostic and response capabilities, many farmers and other stakeholders lack this knowledge. Weak networks and limited visibility of service providers can hinder rapid investigative responses, especially when time-sensitive coordination is required.

To address this, farmers can develop and routinely practice a response plan that maps out stakeholder roles, capacities, and contact details. Pre-established relationships and transparent knowledge of available expertise will help accelerate response times and potentially improve outcomes.

Investigation / Extension Approach

Investigation framework & coordination

Farmer involvement

Pre-planning / Training

Investigation framework & coordination. The oyster sector currently lacks a formal, integrated investigative framework to guide mortality responses. Without a clear, step-by-step process that brings together husbandry practices, environmental data, and diagnostic expertise, investigations remain fragmented and reactive. While this workshop has begun to outline what such a framework might look like, this needs to be formally developed and then simplified and communicated to stakeholders in a format that is accessible and actionable.

A major barrier is the lack of clarity around coordination. Many stakeholders are unsure who to contact during mortality events, what support is available, or how investigations are funded and delivered. Engagement with aquatic veterinarians remains low, despite the presence of private entities capable of assisting.

Farmer involvement is potentially another constraint. Participation varies widely, and internal politics can obscure valuable insights. Yet growers possess deep, site-specific knowledge and are often best placed to identify practical solutions. Investigations must actively integrate multiple farmers to avoid narrow perspectives and ensure diverse insights. Building trust and fostering transparent communication across farms is essential for collaborative problem solving and knowledge sharing.

Pre-planning & training is also underdeveloped. While some emergency response materials exist, their format and dissemination have been sub-optimal, resulting in low adoption. Farmers typically report mortality events to government agencies but often lack guidance on next steps, especially when causes remain unexplained. There is limited awareness of additional investigative support, and roles and responsibilities are poorly defined. To strengthen preparedness, pre-planning should include targeted staff training, clear coordination protocols, and systematic collection of environmental and husbandry data to enable a rapid, informed response.

Options for Consideration

During the workshop presentations and discussions, participants identified a range of potential projects / proposals. These concepts are summarised below in no particular order, with a brief context provided for each.

Appendix 7 outlines additional options that, while not central to the workshop's primary objective of strengthening the investigative framework for mortality events of unknown aetiology, may nonetheless support broader response and research efforts.

1. **Support, develop and extend an 'Investigative Framework for Oyster Mortality'.**

   Brief rationale: The oyster industry currently lacks a formal, integrated framework to guide mortality investigations. Without a clear, step-to-step process that brings together husbandry practices, environmental data and diagnostic expertise, investigations remain fragmented and reactive. Embedding emergency protocols within this framework is essential, providing farmers with a clear pathway during these highly traumatic events, as well an indication of the timeframes and resources that might be involved.

   To be effective, the framework must map all relevant stakeholders and clearly define their roles and responsibilities. This includes identifying potential investigation coordinators and ensuring their contact details are readily available. Involving social scientists may help understand the social dynamics of industry - how growers, regulators, vets, labs and researchers interact, aligning diverse perspectives and identifying tools and opportunities to bridge these gaps and foster trust.

   Crucially, the framework needs to be accessible and actionable for farmers. Information should be simplified and communicated to industry in a way that resonates and promotes adoption. Extension strategies might include ongoing education, scenario-based training, and tailored outreach.

   The 2023 Outbreak! handbook provides a foundation; outlining investigative protocols for aquatic animal disease events. This workshop has also begun to outline what such a framework might look like, however this needs to be formally developed and tested with stakeholders.

2. **Explore or develop funding buckets that enable investigations to further understand oyster mortality events.**

   Brief rationale: Jurisdictional government involvement in disease investigation is generally limited to ruling out notifiable diseases and conducting preliminary assessments of potentially emerging biosecurity threats. Investigations beyond this limited scope require external, non-government expertise, which often comes at a significant cost. Given that unexplained oyster mortality events frequently impact multiple growers, response efforts could be resourced at an estuary or regional scale.

   In 2024, Deloitte Access Economics explored the viability of different financial mechanisms to support the NSW oyster industry during disease outbreaks. The project report examined options such as voluntary and mandatory industry trust accounts. The recommendations from the report have not yet progressed to implementation and require further industry consideration. Although developed for NSW, the recommendations are worth industry consideration in other jurisdictions.

3. **Advocate for an expansion of the role of State & Territory Governments in the investigation of unexplained oyster mortality.**

   Brief rationale: As oysters are extensively cultivated in open systems leased from State or Territory Government, there's ongoing debate about the role these jurisdictions should play in investigating unexplained mortality events. The stakes extend beyond commercial aquaculture, if mortality also affects recreational fisheries or other shared public resources, the consequences could be far-reaching.

4. **Support industry-wide efforts to collect and manage farm data, working toward a shared framework that enables consistency and comparability.**

   Brief rationale: Robust husbandry data is critical for investigating mortality events and informing future on-farm decision making. A variety of farm management tools are available, including miShell, Oceanfarmr, and OysterCloud, enabling growers to record operational data at the push of a button in real time. The value of this information is amplified when the data collected is standardised across a waterway or region. A harmonised, shared dataset would allow for meaningful network analysis during mortality events, potentially revealing patterns or management strategies that reduce risk.

5. **Establish 'peacetime' monitoring programs – longitudinal sampling, collation and analysis of available data.**

   Brief rationale: **'**Peacetime' monitoring and longitudinal sampling are essential to build knowledge and enhance capacity for disease outbreak investigations. Strengthening farmers ability to collect, store and document high-quality samples for laboratory analysis is a critical part of this preparedness. By collecting and preserving samples over time, growers and researchers can establish baseline health data, detect early warning signs, and revisit historical material to track changes in oyster health. This ongoing archive enables faster, more targeted responses during outbreaks, supports risk-based surveillance, and helps distinguish between endemic issues and emerging threats.

   'Peacetime' monitoring must also encompass environmental datasets to provide a more holistic understanding on baseline conditions. Identifying key environmental parameters relevant to oyster health, and mapping existing data sources, will help identify gaps in knowledge. Strategic expansion of accurate data collection should be pursued to enhance early warning systems and enable adaptive management.

6. **Multi-disciplinary project combining the old and the new – the omics toolbox – metatranscriptomics.**

   Brief rationale: Metatranscriptomics offers a powerful, next-generation diagnostic tool for investigating oyster mortality of unknown aetiology. When integrated with established diagnostic methods and comprehensive environmental and farm management datasets, this approach has the potential to uncover previously hidden drivers and interactions. This could potentially advance our understanding of complex mortality events and inform a more targeted response.

7. **Collaborate with other aquaculture sectors to explore opportunities to build aquatic animal health diagnostic capacity and expertise.**

   Brief rationale: The retirement of key shellfish pathologists has significantly weakened national diagnostic capacity, exposing a critical gap in aquatic animal health expertise. Rebuilding this capability requires urgent investment in structured training, accreditation pathways, and ongoing professional development, not just within shellfish, but across all Australian aquaculture sectors.

   Beyond workforce development, complementary solutions could include the creation of an annotated slide reference library and digitisation of histopathological material to enable remote interpretation.

8. **Strengthen professional networks and visibility of providers.**

   Brief rationale: Building on the recommendation to map stakeholders involved in aquatic mortality investigations, there is a clear need to enhance professional networks and raise the visibility of diagnostic expertise across the sector.

   While researchers in different institutions can work collaboratively towards an common goal, an understanding of the diagnostic capabilities and expertise that resides in Australia does not appear to be well known. These resources are under-recognised or poorly understood. More regular engagement, and opportunities to build relationships should be actively encouraged. A more connected and informed industry and support network will be better equipped to respond collaboratively and effectively to emerging health challenges.

Prioritisation

Although the concepts provided in the previous section are listed in no particular order, workshop participants ranked the overarching themes in order of priority, with the following result.

Priority 1) Resources
Priority 2) Investigation / Extension approach
Priority 3) Field technology
Priority 4) Stakeholder / Regulatory Framework
Priority 5) Farming processes
Priority 6) Laboratory technology

Oysters Australia will continue to explore these ideas, and others, using them to guide and shape future initiatives supported by the organisation.

Extension

This report will be distributed by Oysters Australia to workshop participants and state industry associations. It will also be archived on both the Oysters Australia and FRDC website and help inform the development of the upcoming Oysters Australia Strategic Plan 2026-2031.

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Appendix 1. Workshop Agenda

Date: 20th August 2025
Location: University of Technology Sydney
Time: 8:30 – 4:30pm

Where permission has been provided, presentations have been hyperlinked to titles.

8:15 – 8:30am	Registration

Introduction

8:30 – 8:45am	Introductory remarks	Charles Caraguel Workshop Facilitator

Defining unexplained mortalities

8:45 – 9:15am	Case studies of past oyster mortality events remaining unexplained 1) Hawkesbury (MP4) 2) Pipeclay Lagoon (MP4 / PDF)	Ben Ralston (Hawkesbury, NSW) John Ramsden (Pipeclay, TAS)
9:15 – 9:30am	3) Principles of animal disease and participant profile	Charles Caraguel The University of Sydney

Current investigation capacity and approach

9:30 – 9:40am	4) Role of jurisdictional aquatic biosecurity agencies in investigations of unexplained mortalities (MP4 / PDF)	Jeffrey Go NSW Department of Primary Industries & Regional Development
9:40 – 10:00am	5) Molecular microbiological approaches for examining the causes of oyster mortality events in changing coastal ecosystems (MP4 / PDF)	Justin Seymour University of Technology Sydney
10:00 – 10:20am	Morning tea	
10:20 – 10:40am	6) A multidisciplinary and integrated approach for investigating outbreaks of unknown aetiology (PDF)	Francisca Samsing The University of Sydney
10:40 – 11:00am	7) Marine and estuarine disease investigations – important lessons from history	Richard Whittington The University of Sydney
11:00 – 11:20am	8) A researchers view of the mystery of Pipe Clay Lagoon (PDF)	Andrew Trotter Institute for Marine and Antarctic Studies
11:20 – 11:40am	9) 'Power in numbers' – Unravelling disease outbreaks in aquatic animals through a coordinated response (PDF)	James Fensham Future Fisheries Veterinary Services
11:40 – 12:00pm	Panel session questions	

Potential opportunities

1:00 – 1:20pm	10) Using breeding programs for known and unknown diseases: Lessons from the Sydney rock oyster breeding program (MP4 / PDF)	Laura Parker NSW Department of Primary Industries & Regional Development
1:20 – 1:40pm	11) Improving oyster survival – the simple genetic improvement approach (MP4)	Ian Duthie (presented on behalf of Rob Banks) Australian Seafood Industries
1:40 – 2:00pm	12) Tools for collecting and sharing oyster husbandry data (MP4)	Ken Rowe Blue Farm Intelligence
2:00 – 2:20pm	13) Estuary environmental datasets and algae potentially relevant to oyster mortalities (MP4 / PDF)	Shauna Murray University of Technology Sydney
2:20 – 2:30pm	Panel session questions	

Workshop

3:30 – 4:30pm	World Cafe • Farming processes • Field technology • Stakeholders & Regulatory framework • Resources • Laboratory technology • Investigation / Extension approach
4:30 – 4:45pm	Current state / challenges / opportunities for improvement / what does good look like
4:45 – 5:00pm	Concluding remarks with action plan
5:00pm	Workshop close

Appendix 2. Presenter Contact Details

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Ian Duthie	Australian Seafood Industries	P: 0409 411 322 E: ian@oysterstasmania.org
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Ken Rowe	Blue Farm Intelligence	P: 0427 233 886 E: ken.rowe@bigpond.com
Shauna Murray	University of Technology Sydney	P: 0416 084 121 E: shauna.murray@uts.edu.au

Appendix 3. List of Workshop Participants

Name	Organisation
Charles Caraguel	The University of Sydney
Ben Ralston	Hawkesbury River Oyster Company
John Stubbs	Hawkesbury River Oyster Company
Rob Moxham	Hawkesbury River Oyster Company
Devin Watson	Australia's Oyster Coast
Warwick Anderson	Australia's Oyster Coast
Matt Toan	Yumbah Aquaculture
Robert Redmayne	Seven Seas Oysters
Angus Rivett	Five Star Oyster Company
Celeste Boonearts	Hawkesbury River oyster farmer
John Ramsden	Tasmanian Oyster Company
Jeffrey Go	NSW Department of Primary Industries & Regional Development
Laura Parker	NSW Department of Primary Industries & Regional Development
Cheryl Jenkins	NSW Department of Primary Industries & Regional Development
Ian Lyall	NSW Department of Primary Industries & Regional Development
Emma Wilkie	NSW Department of Primary Industries & Regional Development
Wayne O'Connor	NSW Department of Primary Industries & Regional Development
Melissa Walker	NSW Department of Primary Industries & Regional Development
Michael Dove	NSW Department of Primary Industries & Regional Development
Stephan O'Connor	NSW Department of Primary Industries & Regional Development
Justin Seymour	University of Technology Sydney
Nachshon Siboni	University of Technology Sydney
Elliot Scanes	University of Technology Sydney
Shauna Murray	University of Technology Sydney
Francisca Samsing	University of Sydney
Richard Whittington	University of Sydney
Pauline Ross	University of Sydney
Andrew Trotter	Institute for Marine and Antarctic Studies
Ivona Mladineo	Institute for Marine and Antarctic Studies
James Fensham	Future Fisheries Veterinary Services
Henry Hewish	Australian Seafood Industries
Ian Duthie	Australian Seafood Industries
Ken Rowe	Blue Farm Intelligence
Gary Zippel	South Australian Oyster Growers Association
Tracey Zippel	South Australian Oyster Growers Association
Lynlee Lowe	South Australian Oyster Growers Association
Duncan Spender	Oysters Tasmania
Bob Milne	Oysters Tasmania
Andy Myers	NSW Farmers Association
Marty Deveney	South Australia Oyster Research Council
Crispian Ashby	Fisheries Research and Development Corporation
Aiden Mellor	Department of Primary Industries Queensland
Matt Bansemar	Department of Primary Industries and Regions South Australia
Xiaoxu Li	Department of Primary Industries and Regions South Australia
Jennifer Voss	Department of Natural Resources and Environment Tasmania
Jasmine Knowles	Aquaculture Veterinary Services
Johnathan Bilton	Albany Shellfish Hatchery
Megan Huggett	University of Newcastle
Anne Stünzner	Oysters Australia
Julien Manterola	SeaPerfect (NSW) Pty Ltd.

Appendix 4. Demographics of Workshop Participants

Around 65 delegates attended the workshop, with data gathered via an online survey app (Menti.com). However, not all participants completed these online questions.

- In which State/Territory is your primary activity based in?

New South Wales	16
Tasmania	7
South Australia	6
Queensland	4
Australian Capital Territory	1
Western Australia	1
Northern Territory	0
Victoria	0

- In which sector do you primarily work?

Government agency	14
Primary producer	10
Industry service provider	6
Academic	5
Other	3

- Producers Only – Do you monitor and record your stock mortality?

Yes – Only by subtracting harvested stock	6
Yes – Regularly to detect early any anomaly	6
No – Poor cost:benefit ratio	0
No – Other reasons	0

- Producers Only – Select the approximate, whole cycle, oyster mortality (%)

Average cumulative mortality on farm	52%
Maximum cumulative mortality for my farm to be sustainable (i.e. not acceptable beyond this level)	50%

Appendix 5. The Fishbone (Ishikawa) Tool

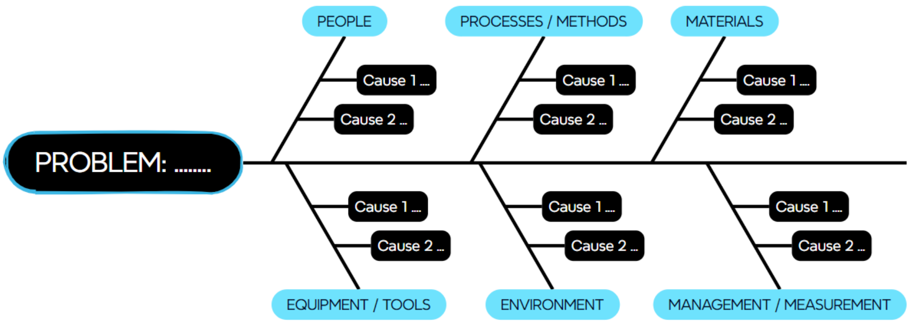
A Fishbone or Ishikawa diagram is used for root cause analysis, a tool to identify and organise potential causes of a problem or effect by categorizing them, ultimately helping teams discover the underlying reasons for issues in systems, processes, or products. It visually maps these causes, branching from a central effect, into categories like People, Process, Materials, and Environment, allowing for a structured and systematic approach to problem-solving.

What it is used for:

- Problem-solving: It helps teams to brainstorm and identify all possible causes of a specific problem or challenge.
- Root Cause Analysis: The diagram helps to uncover the fundamental reasons behind a recurring issue, rather than just addressing the symptoms.
- Systemic thinking: It encourages a holistic view by prompting analysis from various perspectives and how different factors interrelate.
- Process improvement: By visually representing causes and effects, it aids in understanding complex systems and finding ways to improve them.

How it works:

1) Define the problem: The problem or effect is placed at the "head" of the fishbone.
2) Identify categories: Major causal categories are established as the main "bones" extending from the head. Common categories include:
    - People
    - Process/Methods
    - Materials
    - Equipment/Tools
    - Environment
    - Management/Measurement
3) Brainstorm causes: For each category, potential causes are brainstormed and added as sub-branches.
4) Drill down: The team continues to ask "Why?" for each identified cause to uncover deeper, more fundamental issues, creating layers of detail.
5) Analyse and prioritise: The diagram is then used to analyse the identified causes and prioritise the most significant ones to address.



A fishbone is a useful systematic tool that could be employed by growers to assess the circumstances of a mortality event prior to engaging professionals - it might just be that stock has left drying for too long in hot weather, it was worked at inappropriate times etc.

Appendix 6. Resources & Tools

Documents

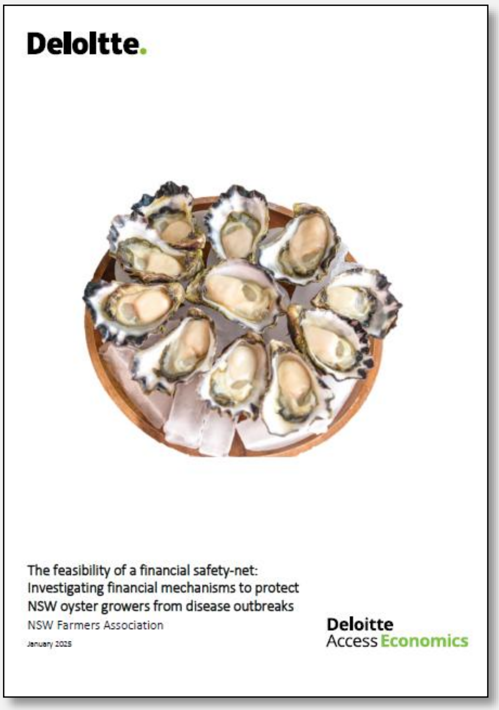
Outbreak! Investigation guidelines for aquatic animal disease events.

This guide provides a structured, epidemiological approach to investigate disease outbreaks in aquatic animals. It outlines 10 steps - from confirming an outbreak and defining cases, to collecting and analysing data, verifying diagnoses, and communicating findings. The methodology integrates both traditional diagnostic techniques and modern molecular tools.

The document also offers practical guidance on sample collection, submission protocols and diagnostic test interpretation. It underscores the complexity of aquatic environments, where disease emergence may be influenced by environmental stressors, management practices, and pathogen dynamics.

Ultimately, the guide aims to equip aquatic animal health professionals, farmers, and investigators with the tools to respond swiftly & effectively to disease events, minimise impact, & inform future prevention strategies.

https://www.frdc.com.au/sites/default/files/products/2021-061-DLD.pdf

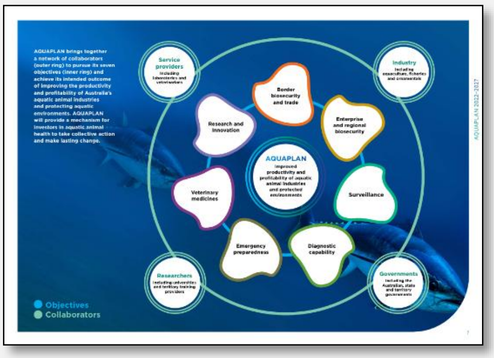


Investigating financial mechanisms to protect NSW oyster growers from disease outbreaks.

This work explores financial mechanisms to support oyster growers in NSW from disease outbreaks. Drawing on case studies from other aquaculture and agriculture sectors, the report identifies viable financial support options for consideration, notably a tiered support mechanism co-funded by government and industry, an industry-led common fund, and a bespoke insurance product. Each is evaluated for practicality, sustainability, fairness, and adaptability, with detailed design considerations and implementation pathways.

It also outlines next steps for each option, including stakeholder engagement, legislative considerations, and data requirements.

https://www.frdc.com.au/sites/default/files/products/2023-070-DLD.pdf

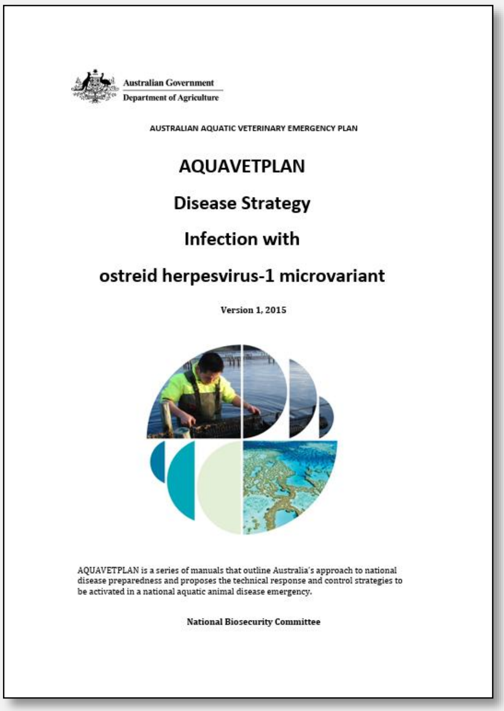


AquaPlan 2022-2027.

AquaPlan 2022-2027 is Australia's 4th national strategic plan for aquatic animal health. It represents shared industry, state and territory and Australian government priorities for investing in the aquatic animal health system to promote healthy aquatic animals, prevent disease and ensure Australia has a strong system in place to respond should disease occur. The plan outlines 7 key objectives, which are each pursued through a series of defined activities.

1. Surveillance,
2. Diagnostic Capability,
3. Emergency Preparedness,
4. Veterinary Medicines,
5. Research & Innovation,
6. Border Biosecurity & Trade, and
7. Enterprise & Regional Biosecurity.

https://www.agriculture.gov.au/sites/default/files/documents/aquaplan-2022-2027.pdf


Australian Government
Department of Agriculture

AUSTRALIAN AQUATIC VETERINARY EMERGENCY PLAN

AQUAVETPLAN

Disease Strategy

Infection with

ostreid herpesvirus-1 microvariant

Version 1, 2015

AQUAVETPLAN is a series of manuals that outline Australia's approach to national disease preparedness and proposes the technical response and control strategies to be activated in a national aquatic animal disease emergency.

National Biosecurity Committee

AquaVetPlan

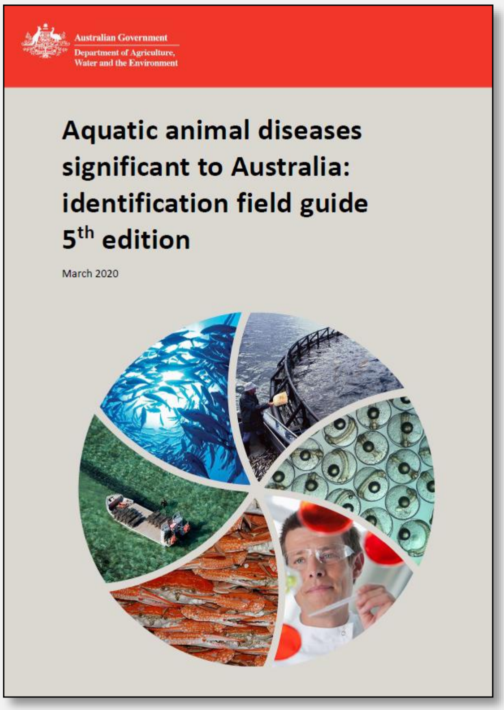
AquaVetPlan is the Australian Aquatic Veterinary Emergency Plan. It is a series of manuals that outline Australia's approach to national disease preparedness and proposes the technical response and control strategies to be activated in a national aquatic animal disease emergency. There is currently only one disease strategy developed that is relevant to oysters, being '*Infection with Ostreid herpesvirus-1 microvariant*' (the causative agent of POMS).

Other AquaVet Plan manuals available online for potential oyster industry use include:

- Control Centre Management Manual, describes the role of personnel in the early stages of activation of an exotic disease emergency.
- Operational Procedure Manual – Destruction, provides guiding principles on the decision to destroy stock and the application of appropriate techniques.
- Operational Procedure Manual – Disposal, provides guidance on the selection of disposal sites and methods for transportation.

Disease Strategy for Ostreid herpesvirus-1 microvariant
https://www.agriculture.gov.au/sites/default/files/sitecollectiondocuments/animal-plant-health/aquatic/aquavetplan/aquavetplan-dsm-ostreid-herpes.pdf

Aquatic Animal Diseases Significant to Australia: Identification Field Guide 5th Edition



The field guide, available online and as a mobile app, aims to help people recognise diseases of significance to aquaculture and fisheries in Australia. It covers 53 aquatic animal diseases of significance to Australia that affect species of finfish, crustaceans, molluscs and amphibians.

In relation to oysters, it includes information on *Bonamia exitosa, Bonamia ostreae, Bomania species, Marteilia refringens, Martelia sydneyi, Marteiloides chungmuensis, Mikrocytos mackini, Perkinsus marinus, Perkinsus olseni*.

https://www.agriculture.gov.au/sites/default/files/documents/field-guide-5th-edition.pdf

Oyster Breeding Programs

It should be noted that oyster breeding programs are not investigative tools and they do-not and can-not replace more immediate responses to understand and respond to mortalities. They do however, potentially offer a longer-term mitigation strategy noting that breeding for unknown mortality may not be possible if the trait is not heritable.

Sydney Rock Oysters

Accommodating information from Laura Parker's presentation (see Appendix 1 – Presentation 10).

The Sydney rock oyster breeding program offers a genetics-based approach to enhance resilience against mortality events, regardless of whether their underlying causes are known.

By using pair-mated family lines and conducting field challenge trials at historically impacted sites, the program identifies oysters with heritable resilience to certain stressors. These trials not only reveal families that have greater tolerance to known threats, like QX disease, but can also uncover latent robustness that may help withstand emerging or unidentified stressors.

A growing focus is the calculation of energy budgets under climate change scenarios, specifically ocean acidification and warming, to determine a particular family's Scope for Growth (SFG). SFG represents the net energy available for growth, reproduction, and immune function after accounting for basic metabolic demands. Families that maintain high SFG under climate stress are hypothesised to be metabolically robust and potentially more likely to tolerate additional stressors such as poor water quality, low food availability or exposure to pathogens.

A recent study conducted by Parker et. al. (2024) demonstrated that while several families exhibited tolerance to climate stress (ocean acidification & warming), only a subset retained a high SFG, making them prime candidates for selective breeding. Selective breeding that prioritises both climate tolerance and elevated SFG may therefore produce generalist oyster lines with enhanced general resilience.

Pacific Oysters

Accommodating information from Ian Duthie's presentation (see Appendix 1 – Presentation 11).

Australian Seafood Industries (ASI) manages the selective breeding program for the Pacific oyster industry. It aims to improve oyster resilience and performance across diverse farming conditions. The program is built on three core principles of genetic improvement: 1) the ability to measure survival as a trait under certain field conditions, 2) the existence of heritable variation in survival among oyster families, and 3) the capacity to selectively breed from individuals that consistently perform well in certain field conditions. Together, these principles enable ASI to identify and propagate oysters that are more robust, even when the underlying causes of mortality remain unclear.

The cornerstone of this strategy is the use of field challenge experiments. In these trials, oysters from known families are deployed across multiple sites and environmental contexts. Survival rates are carefully monitored, and families that demonstrate superior performance are selected for future breeding. This approach can prove effective even in the absence of pathogen identification, with survival itself serving as a proxy for general robustness against a range of stressors.

Box 11. Breeding resistance for South Australian Mortality Syndrome (SAMS)

ASI have been working on an FRDC-funded project (2020-064) aimed at enhancing resistance to South Australian Mortality Syndrome (SAMS) within their oyster family lines. As part of the initiative, 40 families were deployed, with survival rates ranging from 15% in susceptible lines to over 90% in the more resilient ones. Heritability for this 'resilience' has been confirmed, enabling selective breeding to deliver meaningful gains for commercial oyster growers.

Genomic technology now offers the potential to transform oyster breeding. Supported with funding from the FRDC and Oysters Australia, both the Pacific oyster and Sydney Rock oyster breeding programs are currently exploring the integration of genomic tools to enhance their selection processes. By leveraging genetic insights, it is anticipated that adopting genomic tools will enable faster, more accurate, and more targeted trait improvements, particularly for traits expressed later in life.

Appendix 7. Supporting Activities & Research.

While the primary purpose of the workshop was to review and strengthen the investigative framework to unexplained oyster mortalities, presentations and discussions raised a number of other supportive actions. These have been captured below.

1. **Review interstate translocation protocols and policies, particularly those governing oyster size limits for import.**

   Brief rationale: Oyster mortality events tend to coincide with specific seasonal and environmental conditions. In the short term, the most effective strategy for growers to reduce stock loss is to avoid farming during these high-risk periods. Evidence suggests that window farming - targeted cultivation outside peak mortality periods - is viable in estuaries such as the Hawkesbury and Port Stephens. Success however depends on sourcing larger input stock capable of reaching market size within the shortened growing window. Improved access to interstate supplies of larger oysters would significantly expand window-farming opportunities.

2. **Conduct sustained molecular monitoring for *Vibrio* (and other putative pathogens) within oyster harvesting regions.**

   Brief rationale: Limited field sampling in NSW has revealed a correlation between oyster mortality and *Vibrio harveyi* levels in both water and oyster tissue. More thorough and sustained monitoring is needed with samples collected over time. Analysis using molecular techniques would offer deeper insights into the changes in the microbiome, and how this may be influenced by environmental conditions.

3. **Perform detailed manipulative experiments to better understand *Vibrio* and oyster dynamics under future warming scenarios.**

   Brief rationale: Recent Pacific oyster mortality events in Port Stephens have coincided with elevated water temperatures and the presence of *Vibrio* species, suggesting a likely environmental trigger. Given that these bacteria are long-established in the environment, their emerging impact signals a shift, likely linked to changing conditions. While correlative evidence points to warming as a driver, causality remains uncertain. Targeted manipulative experiments are needed to directly test how pathogenic *Vibrio* strains interact with oysters under future climate scenarios. Understanding this dynamic is critical to predicting and mitigating future disease outbreaks.

4. **Develop new capacity to forecast mortality events using machine learning approaches.**

   Brief rationale: A lot of data has been collected in recent years, providing a strong foundation for applying machine learning to identify patterns in oyster mortality risk. By leveraging these datasets, there is the opportunity to develop a predictive tool that can forecast high-risk periods with greater accuracy. If paired with effective mitigation strategies, such a tool could become a useful resource for oyster farmers, helping to anticipate threats, reduce stock losses, and improve resilience under changing environmental conditions.

5. **Utilisation of the tools and approaches used in breeding programs to identify families that show greater resilience to known / unknown stressors.**

   Brief rationale: Breeding programs utilise a range of proven tools and methodologies to identify family lines with enhanced resilience to both known and unknown stressors. The Sydney Rock oyster and Pacific oyster programs have demonstrated that disease survival and Scope for Growth (SFG) can be assessed through field challenge trials and energy budgeting, even when the underlying causes of mortality remain unclear.

   These approaches can be used to uncover metabolically robust families capable of maintaining performance under climate stressors such as ocean acidification and warming, while also tolerating secondary pressures like poor water quality, food scarcity, or novel pathogens.

   Farmers can play a key role here by leading or supporting field trials, collecting robust performance data from different families under commercial conditions. An important consideration, however, will be how to over-come co-mingling during grading, and maintain the integrity of family lines through commercial production cycles.

6. **Encourage farmers to set-aside a section of their farm for research and development.**

   Brief rationale: Farmers should be encouraged to allocate part of their operational resources (space, time and stock) for ongoing research and development as part of their business planning. By formalising R&D within routine farm activities, investigations become proactive rather than reactive, fostering a culture of continuous learning and innovation.

   This dedicated R&D space could be used to trial variations in growing height, cultivation techniques, stocking densities, drying cycles, or the genetic performance of different family lines. Having structured variability enables meaningful data comparisons, which are invaluable during mortality investigations and broader performance assessments.