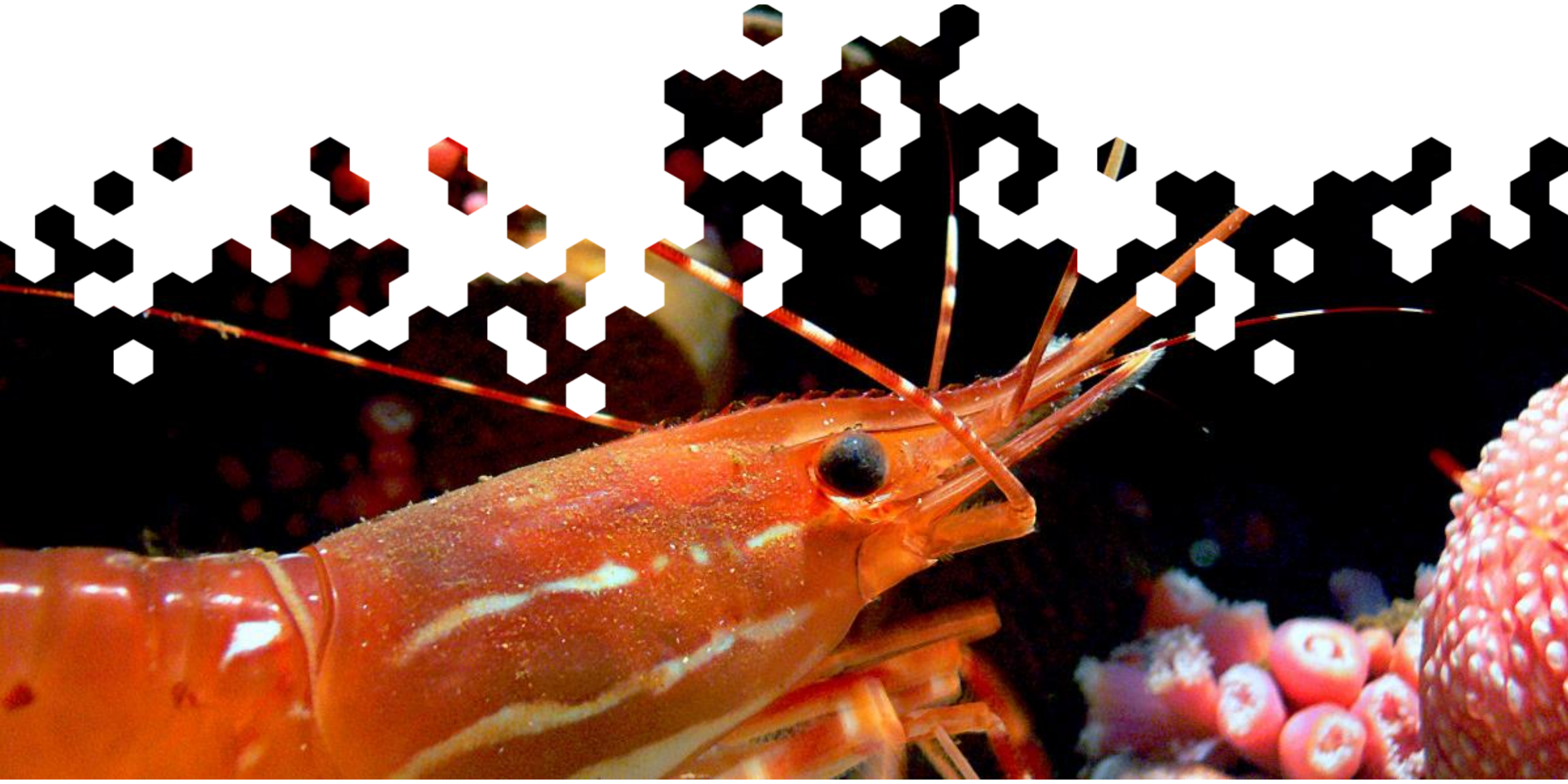
Aquaculture Health Research Survey

March 2026

Report of the global consultation on aquaculture research priorities: Crustaceans Section



World Organisation for Animal Health

www.woah.org
www.star-idaz.net

STAR IDAZ International Research Consortium on Animal Health

Required citations:

WOAH & STAR IDAZ IRC (2026). Report of the workshop to identify the highest-priority research areas for finfish diseases Available on-line at: https://doc.woah.org/ and https://www.star-idaz.net/reports/

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Organised by:

World Organisation for Animal Health

In collaboration with:

STAR IDAZ International Research Consortium on Animal Health

The activity has been possible thanks to sponsorship from:

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UKaid from the British people

GAMRIF Global AMR Innovation Fund

Australian Government Department of Agriculture, Fisheries and Forestry

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Executive Summary

This document summarises the findings of the Crustaceans section of the Global Aquaculture Health Research Survey, conducted jointly by WOAH and STAR IDAZ IRC. The survey, launched in January 2025, collected insights from 42 experts with experience in crustacean health. Their responses highlight the most urgent research priorities needed to strengthen crustacean aquaculture globally, covering diagnostics, prophylactics, therapeutics, and control strategies.

The crustacean aquaculture sector faces persistent challenges from high-impact viral and bacterial diseases, emerging pathogens, and gaps in diagnostic and prophylactic capability. Poor water quality, nutrition, and husbandry were repeatedly cited by respondents as drivers of disease outbreaks, highlighting the need for improved biosecurity, and integrated environmental and management-focused solutions, including practical tools for farmers. The findings provide a consolidated view of global research needs and can guide coordinated investment across research institutions, regulators, and industry stakeholders.

Priority Diseases

Experts identified a clear set of high-impact diseases requiring focused research attention. While viral pathogens dominated the Top-10, reflecting their major economic and biosecurity impacts on shrimp and prawn farming, the Top-3 also included bacterial and microsporidial diseases. The highest priority diseases include: infection with white spot syndrome virus (WSS); acute hepatopancreatic necrosis disease (AHPND); infection with *Enterocytozoon hepatopenaei* (EHP), Vibriosis; infection with yellow head virus (YHD); infection with Taura syndrome virus (TSV); infection with infectious myonecrosis virus (IMNV); infection with decapod iridescent virus 1 (DIV1); infection with infectious hypodermal and haematopoietic necrosis virus (IHHNV), and Nodavirus diseases (including infection with covert mortality nodavirus - CMNV). Crayfish plague was also flagged as an important fungal disease requiring focused research attention.

Diagnostics Research Priorities

In the area of diagnostics, short-term priorities focus on the development of rapid, sensitive and affordable field diagnostic tools such as pond-side PCR, lateral-flow tests, multiplex assays and non-lethal sampling techniques. Respondents stressed the need to strengthen advanced molecular methods including sequencing and molecular epidemiology, and the importance of standardising and validating diagnostic protocols while improving laboratory capacity in different countries. Expanded environmental surveillance using eDNA/eRNA and real-time environmental monitoring, as well as the adoption of AI-enabled tools for disease diagnosis and early warning, were also emphasised.

Over the medium to long-term, respondents highlighted similar priorities, including the need for multi-pathogen platforms, field-adapted rapid tests for key pathogens and diseases (e.g. EHP, AHPND, IMNV, Vibriosis), high-throughput genomic tools, ecosystem-based diagnostic approaches, global harmonisation of diagnostic systems, and increased integration of AI for predictive and automated diagnostics.

Prophylactics Research priorities

Regarding prophylactics, short-term priorities centered on strengthening biosecurity and promoting good aquaculture practices, including quarantine, water quality management, and the development of Specific Pathogen-Free (SPF), Specific Pathogen-Tolerant (SPT) and Specific Pathogen-Resistant (SPR) lines. Microbiota optimisation and probiotic strategies were seen as essential for stabilising pond ecosystems, while vaccine-related research, including immune priming approaches and novel delivery systems, was also prioritised. Respondents highlighted the value of nutritional and functional feeds containing phytochemicals and immunostimulants, as well as the need to develop alternatives to antimicrobials and support AMR mitigation.

Over the medium to long-term, innovation in vaccines and immunotherapies, including RNAi technologies and IgY-based approaches, was viewed as a key priority, along with digital and AI-driven biosecurity tools, selective breeding programmes for disease resistance, advanced immunostimulants, and microbiome engineering. Barriers to progress in this area include high development costs, fragmented regulation and limited understanding of crustacean immunology.

Therapeutics Research priorities

For therapeutics, respondents highlighted the need for improved monitoring and regulatory frameworks for antimicrobial use, residues and AMR. The validation of natural and plant-based therapeutics as safe and effective alternatives to antibiotics was seen as increasingly important, alongside the development of emerging technologies such as nanotherapeutics, RNAi and antibody-based treatments. Strengthening immunostimulant and passive immunity tools, as well as expanding research on bacteriophage therapy for *Vibrio* infections, were also identified as short-term needs.

Over the longer term, innovative antimicrobial platforms, including CRISPR-based tools, microbiome editing strategies and biobased antimicrobials, were prioritised. Respondents also emphasised the importance of improving regulatory mechanisms and farmer training for responsible antimicrobial use, validating phytotherapeutics and phage-based interventions, and integrating immunostimulants and stress reduction strategies into holistic farm management systems.

Control Strategies Research Priorities

In relation to control strategies, short-term priorities include strengthening and harmonising biosecurity systems at farm and national levels, improving zoning, quarantine and risk-based protocols, and enhancing epidemiology and modelling to better understand disease transmission and cross-species risks. There is a strong need to develop more robust surveillance and early warning systems using real-time digital tools, and to improve environmental management, disinfection practices and water treatment approaches. Respondents also highlighted the importance of integrating animal welfare principles into disease management frameworks.

Over the medium to long term, the adoption of AI-supported surveillance and predictive modelling tools is expected to play an increasingly important role. Additional priorities include improved national and regional biosecurity standards, the development of new nutritional, genetic and immunosupportive interventions, strengthened governance and socioeconomic frameworks, and a deeper understanding of host–pathogen–environment interactions

Final Note

For detailed results, including full response data and expert comments, readers are encouraged to refer to the full report and the complete set of survey responses, which provide additional context and evidence supporting the priorities summarised here.

Introduction

This report presents the dedicated analysis of the Crustaceans section of the *Global Aquaculture Health Research Survey*, jointly carried out by the **World Organisation for Animal Health (WOAH)** and the **STAR IDAZ International Research Consortium (IRC)**. This collaborative activity directly contributes to Activity 4.5 of **WOAH's Aquatic Animal Health Strategy**, which calls for improving the global understanding of research gaps, strengthening coordinated research, and supporting innovation for aquatic animal health.

To address these needs, WOAH and STAR IDAZ IRC launched an extensive international survey in January 2025, engaging experts across research, government authorities, international organisations, diagnostic laboratories, and industry. The objective was to identify the most urgent and emerging research priorities in aquaculture health across five major domains: diagnostics, epidemiology, prophylactics, therapeutics, and control strategies. More than 180 experts initiated the questionnaire, with 150 respondents completing the finfish section, 31 the molluscs section, 42 the crustaceans section, and 5 the amphibians section — a distribution that reflects global patterns of aquaculture production and research engagement.

Respondents were geographically diverse and professionally mixed as briefly highlighted in the infographic in the next page, and included researchers, regulators, veterinarians, farm health managers, and laboratory diagnosticians. Their combined insights provide a unique global perspective on current and future research needs. The broader methodological framework, details on respondent background, and cross-cutting findings from the global consultation are fully described in the previously published *Aquaculture Health Research Survey- Finfish Section*, available on both WOAH publication portal and STAR IDAZ IRC website.

Readers are encouraged to refer to the above document for a complete overview of the survey methodology, respondent demographics, data treatment, and transversal issues.

This present document narrows the focus to the analysis of crustacean-specific responses, reflecting the priorities raised by the 42 participants who answered at least part of the crustaceans section. Although the proportion of respondents engaging with this section was lower than for finfish — likely due to the specialised and geographically concentrated nature of crustacean aquaculture — the responses provide valuable and targeted insights. The data underscore the global importance of diseases affecting shrimp, prawns, and crabs, and highlight research gaps in diagnostics, molecular surveillance, environmental drivers of disease, biosecurity, vaccine-like approaches, immunostimulation, the need for alternatives to antimicrobials, and integrated modelling and early warning systems.

This crustacean-focused analysis follows the same structure and thematic grouping used in the global report, ensuring consistency and comparability of findings. The goal is to support funding bodies and national authorities and the overall research community in aligning their research agendas with the identified gaps, ultimately strengthening aquatic animal health systems and supporting sustainable, resilient crustacean production worldwide.

Global aquaculture survey

440 invitations distributed globally

187 countries engaged

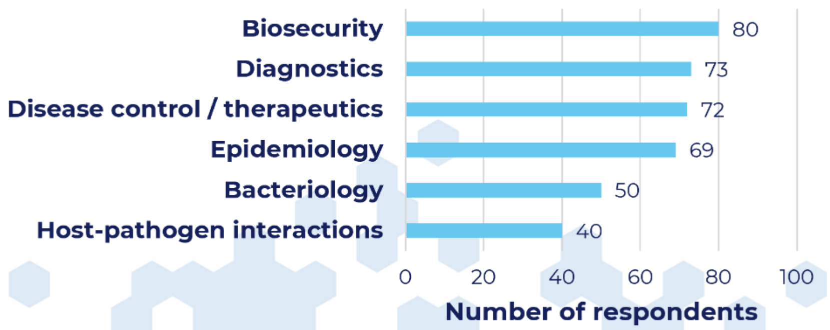
184 responses received from **89** countries

43% overall response rate

51 m 21 s average completion time

The survey had **global reach** with responses received from experts across the Americas, Europe, Africa & the Middle East, and Asia & Australasia

Respondents identified that they had **diverse expertise** across a range of topics relevant to aquaculture



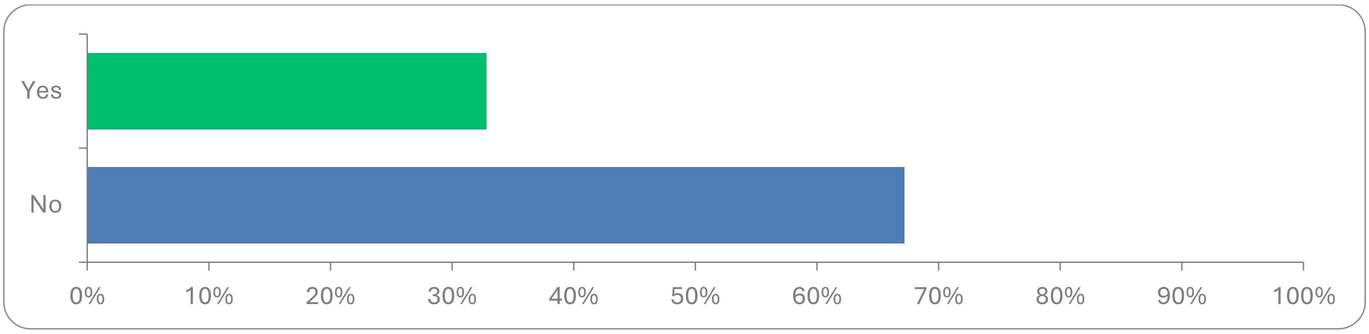
Other areas of expertise cited include:

- Virology
- Vaccine development
- Welfare
- Parasitology
- Immunology

Section: Crustaceans

Q 41: Would you like to fill the section on Crustaceans? Please respond to this section accordingly to your expertise. Feel free to skip questions not in your expertise.

In total, 42 experts elected to complete this section of the global consultation for advancing aquaculture research. Most respondents chose not to complete the Crustaceans section reflecting the proportion of crustacean specialists in the survey population. Further details on respondent profiles can be found in the *Expert background* section of the main report available on both the WOAH publication portal and STAR IDAZ IRC website.



Impactful diseases in aquatic health

Q42: Which are the most impactful diseases in your sector for which research actions would be needed? (Please list in order of importance up to 10 diseases only for the sector you have experience on: 1. Most impactful, 10 Less impactful).

Rank	Disease/Pathogen	Comment	Category
1	WSS	Infection with white spot syndrome virus	Viral
2	AHPND	Acute hepatopancreatic necrosis disease, also called early mortality syndrome (EMS) and caused by *Vibrio parahaemolyticus* (potential overlap with diseases called vibriosis)	Bacterial
3	EHP	Infection with *Enterocytozoon hepatopenaei*	Microsporidia
4	Vibriosis	Includes *V. parahaemolyticus* (may overlap with AHPND), *Vibrio* spp. causing translucent post-larvae disease (VTPD), *V. alginolyticus, V. harveyi* (luminous disease), *V. nigripulchritudo*, V. *penaeicida* and *Vibrio* in crabs	Bacterial
5.	YHD	Infection with yellow head virus (genotype I)	Viral

6.	TSV	Infection with Taura syndrome virus	Viral
7	IMNV	Infectious myonecrosis virus	Viral
8	DIV1	Infection with decapod iridescent virus 1	Viral
9.	IHHNV	Infectious with infectious hypodermal and hematopoietic necrosis	Viral
10.	NVD	Nodavirus disease, including *Macrobrachium rosenbergii* nodavirus (White tail disease), *Penaeus vannamei* nodavirus, and Infection with covert mortality nodavirus (CMNV).	Viral
11.*	Crayfish plague	Infection with *Aphanomyces astaci*	Fungal

** An 11th disease—Crayfish plague—was retained in the list because its score was nearly equal to the 10th-ranked disease and it was the only fungal pathogen repeatedly reported in the survey.*

Q43: Highlights and few quotes from comments received:

"TPD, iEHP and iCMNV represent emerging diseases that impact crustaceans and pose a high biosecurity risk."

(Anonymised quote from comments)

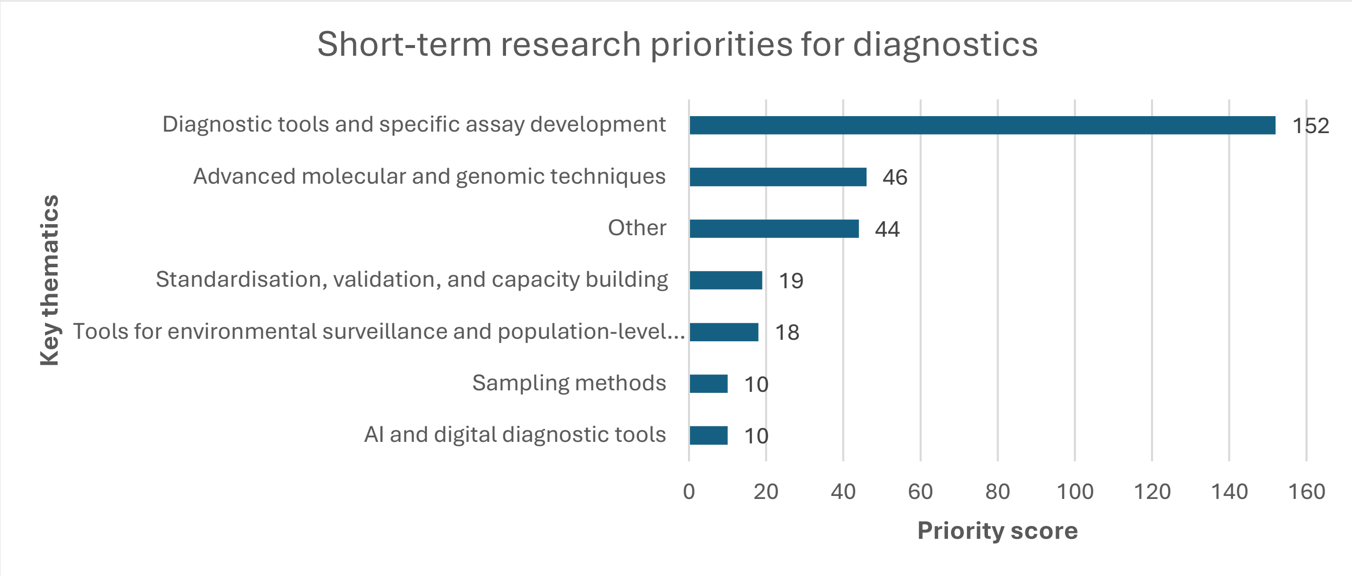
- **Dominant and emerging pathogens:**
  - Viral diseases dominated the priority list. Other diseases considered impactful are caused by bacteria, microsporidia and a water mould.
  - White spot syndrome virus (WSSV) remains a very important and serious viral pathogen, continuing to cause major economic losses despite improved management.
  - *Enterocytozoon hepatopenaei* (EHP) is a microsporidian parasite that was repeatedly cited as responsible for high losses and chronic production impacts.
  - Other pathogens and diseases such as decapod iridescent virus 1 (DIV1), *Vibrio* spp. causing translucent post-larvae disease (VTPD), infectious hypodermal and haematopoietic necrosis virus (IHHNV), infectious myonecrosis virus (IMNV) and infection with covert mortality nodavirus (iCMNV) were also recognised as emerging biosecurity risks, requiring further study on host range, geographic distribution, and transmission dynamics.
- **Environmental and husbandry factors:**
  Some experts noted that many disease outbreaks are linked to poor water quality, husbandry, and nutrition, rather than the pathogens alone. Improved environmental management, nutrition and biosecurity practices were highlighted as essential to reducing disease prevalence.
- **Species range and regional context:**
  Comments indicated that while tropical shrimp dominate research attention, non-tropical and non-shrimp species

(e.g., crayfish such as *Procambarus clarkii* (red swamp crayfish or Louisiana crawfish) and *Cherax quadricarinatus* (redclaw crayfish)) are also gaining importance because of their commercial value and expanding geographic distribution. Some noted emerging issues in Africa and other newly developing farming regions.

- **General considerations:**
  Respondents called for enhanced surveillance and preparedness for exotic and emerging pathogens.

Diagnostic research needs

Q44: What are the short-term (within 5 years) research priorities for diagnostics, including applications to emerging disease detection, and determination of infection at the individual animal and population levels?



Diagnostics: Summary of short-term research priorities from top 5 key trends
1. **Diagnostic tools and specific assay development (Score: 152)**
• Design of rapid, sensitive, and affordable pond-side diagnostic kits (e.g. pond-side PCR, strip, and lateral flow immuno-assay (LFIA)-based) for priority diseases such as white spot syndrome (WSS), acute hepatopancreatic necrosis disease (AHPND), infectious hypodermal and haematopoietic necrosis (IHHN), and disease caused by *EHP*. • Improvement of pathogen-specific assays for accurate identification of *Vibrio*, and fungi, notably *Aphanomyces astaci*, and emerging agents. • Establishment of multiplex and high-specificity assays to detect co-infections and low-prevalence pathogens. • Development of non-invasive and field-level diagnostic methods to support testing in hatcheries and production sites. • Improve cell culture, histology, and immunological assays (IgY-based). • Confirmatory diagnostics for fungi, notably *A. astaci.*

2. Advanced molecular and genomic techniques (Score: 46)

- Development of integrated omics-based diagnostic platforms to enhance early and accurate pathogen detection.
- Enhancement of PCR and real-time PCR applications for crustacean pathogens (e.g. Yellow Head Virus (YHV), DIV1, IHHNV).
- Adoption of long-read sequencing, genomic characterisation, and molecular epidemiology for co-infections and novel agents.
- Implementation of high-throughput detection technologies and data-sharing mechanisms to validate results across laboratories.
- Use of genome sequencing for pathogen typing, host–pathogen studies, and emerging disease surveillance.

3. Standardisation, validation, and capacity building (Score: 19)

- Establishment of accredited and standardised diagnostic protocols across laboratories and countries.
- Validation of assays and case definitions for consistency and reliability of results.
- Strengthening diagnostic laboratory capacity and inter-laboratory testing for harmonisation.
- Development of protocols for at-risk importation species and improved regulatory frameworks for diagnostics.

4. Tools for environmental surveillance and population-level monitoring (Score: 18)

- Expansion of environmental DNA (eDNA) and environmental nucleic acid (eNA)-based surveillance for early pathogen detection and disease forecasting.
- Integration of AI and environmental screening tools to monitor infection dynamics in aquaculture environments.
- Development of real-time surveillance networks and risk-based sampling frameworks for crustacean health management.
- Study of environment–host–pathogen relationships to improve disease detection at ecosystem scale.

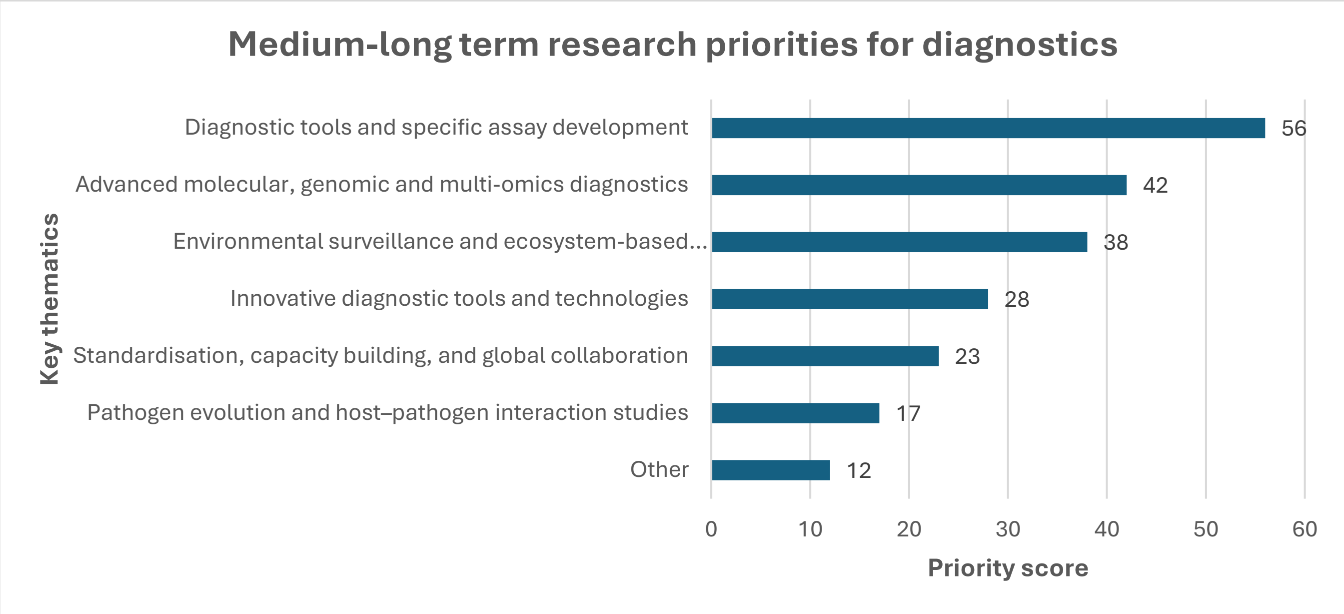
5. Sampling methods and non-lethal surveillance (Score: 10)

- Development of non-lethal diagnostic sampling methods to demonstrate disease freedom in broodstock and farmed populations—critical for high-value, repeat-spawning species.
- Exploration of optimised pooling and sampling strategies to improve diagnostic sensitivity and reduce cost.
- Application of non-lethal surveillance methods to verify freedom from infection in hatcheries and trade movements.

6. AI and digital diagnostic tools* (Score: 10)

- Use of AI-assisted applications to support presumptive diagnosis for farmers.
- Digitization of diagnostic data and integration of AI and machine learning to improve decision-making and disease prediction.
- Development of digital tools and analytics to enhance aquaculture health monitoring and early warning systems.

Q45: What are the medium-long term (5-15 years) research priorities for diagnostics, including applications to emerging disease detection, and determination of infection at the individual animal and population levels?



Diagnostics: Summary of long-term research priorities from top 5 key trends
1. Diagnostic tools and specific assay development (56)
• Development of low-cost, field-adapted diagnostic methods and rapid tests for key pathogens or diseases (*EHP, AHPND, IMNV, Vibriosis*). • Expansion of multi-pathogen diagnostic systems to detect multiple agents simultaneously. • Application of immunological techniques such as immunohistochemistry and immunohistopathology to improve diagnostic resolution. • Electron microscopy and bioassays for confirmation of pathogen identity and virulence in emerging diseases. • Refinement of in-field testing platforms for high-accuracy detection of disease under farm conditions. • Strengthening the diagnostic capacity for bacterial pathogens (e.g. *Vibrio parahaemolyticus* in AHPND or NHPB) and viruses affecting shrimp.
2. Advanced molecular, genomic, and multi-omics diagnostics (42)
• Expansion of molecular biology and PCR-based technologies, including droplet digital PCR (ddPCR), in situ hybridisation, and metagenomics for pathogen discovery. • Application of high-throughput detection and virome analysis tools to identify and monitor emerging pathogens. • Advancement of molecular epidemiology and genetic sequencing to track pathogen evolution, variation and origin, particularly for shrimps. • Integration of genomic and multi-omics approaches to characterise host–pathogen interactions. • Development of data-sharing frameworks and tools for comparative genomic analysis across laboratories.

3.	**Environmental surveillance and ecosystem-based diagnostics (38)**
•	Establishment of eDNA and eNA-based early detection systems for aquatic pathogens.
•	Implementation of environmental screening and AI-assisted surveillance linking pathogen data with environmental parameters.
•	Development of real-time, high-sensitivity environmental sensors for water quality, contaminants, and pathogen load.
•	Promotion of a holistic health approach that connects diagnostics, surveillance, and ecosystem health.
•	Study of horizontal gene transfer and host–pathogen–environment interactions driving disease emergence.
4.	**Innovative diagnostic tools and technologies* (28)**
•	Application of AI-supported diagnostic systems and precision analytics to assist farmers and laboratories.
•	Use of monoclonal antibodies and biosensor-based point-of-care tests for on-site detection.
•	Development of less-invasive diagnostic methods
•	Enhance early warning tools using epidemiological datasets.
•	Integration of big data and AI with diagnostic platforms for predictive accuracy and automation.
•	Advancement of portable point-of-care diagnostics for remote or resource-limited aquaculture settings.
5.	**Standardisation, capacity building, and global collaboration (23)**
•	Establishment of regional and global laboratory networks for disease surveillance and information sharing.
•	Development and harmonisation of diagnostic standards and training materials for crustacean diseases.
•	Expansion of training courses and inter-laboratory comparison programmes to ensure diagnostic consistency.
•	Creation of integrated reporting platforms to support global disease trend monitoring.
•	Capacity building in histopathology and molecular diagnostics to maintain a highly skilled workforce.

* **Note on AI-related diagnostic tools:**

Across both the short- and long-term research priorities, respondents mentioned AI-driven tools several times and were reported below different key thematic areas — including diagnostics, environmental surveillance, early warning systems, decision-support, and modelling. Because these references were dispersed throughout the dataset, a consolidated list is provided here to give readers a clearer overview of all AI-based diagnostic innovations identified in the consultation.

AI tools identified by respondents include:

1. AI-Assisted On-Farm Diagnosis and Decision Support

- Tools that support presumptive diagnosis for farmers using image, sensor, or pattern recognition.
- AI-based mobile or digital applications that interpret visual signs, mortality patterns, or behavioural changes.
- AI models that combine diagnostic inputs with environmental data to generate instant health alerts.

2. AI-Enhanced Diagnostic Interpretation and Automation

- Integration of AI and machine learning into diagnostic workflows (e.g. PCR, sequencing, multiplex assays) to improve interpretation accuracy.
- AI-driven algorithms to process large volumes of diagnostic data, identify anomalies, and signal possible outbreaks.
- Automation of diagnostic pipelines through big data + AI, improving precision and reducing human error.

3. AI-Powered Early Warning and Predictive Tools

- AI-driven early warning systems combining diagnostic, epidemiological, and environmental datasets.
- Development of predictive models using AI to forecast:
    - pathogen emergence,
    - infection hotspots,
    - disease spread,
    - outbreak probability at farm or regional level.
- Integration of AI tools with real-time environmental monitoring systems (temperature, salinity, water quality).

4. AI for Environmental Surveillance (AI + eDNA/eNA)

- AI-assisted platforms that analyse eDNA/eNA datasets to detect pathogens earlier.
- Tools that link environmental parameters with molecular signals to identify:
    - risk zones,
    - contamination events,
    - dynamics of Vibrio and other waterborne pathogens.

5. AI for High-Throughput and Genomic Diagnostics

- Application of AI to:
    - support genomic sequencing interpretation,
    - improve virome and metagenomic analysis,
    - accelerate identification of emerging pathogens.
- AI harmonisation tools to facilitate cross-laboratory genomic comparison, reducing false positives and enabling rapid alignment.

6. Precision AI Analytics for Laboratory and Field Diagnostics

- AI-supported systems for:
    - laboratory data management,
    - anomaly detection,
    - automated reporting.
- Precision analytics tools linking diagnostic, environmental, and production data to enhance multi-factorial disease interpretation.

7. Portable, Digital, and AI-Enabled Diagnostic Platforms

- Development of AI-enabled portable point-of-care devices for rapid testing in remote or resource-limited settings.
- Use of AI to support:
    - field PCR devices,
    - handheld biosensors,
    - smartphone-linked diagnostic kits.

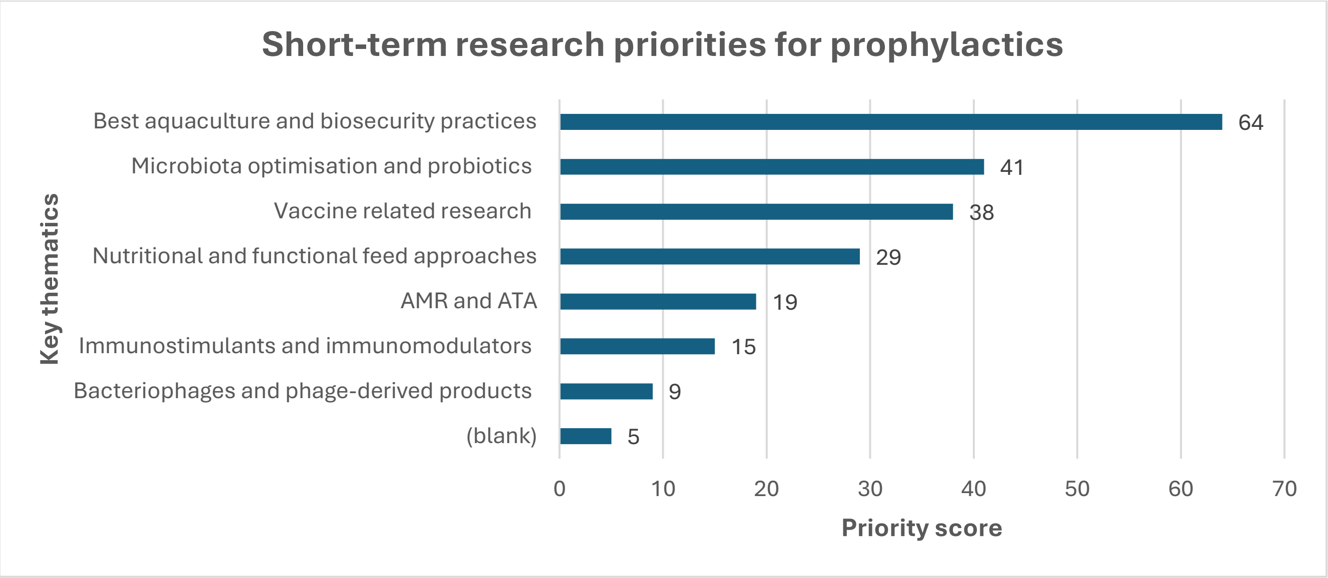
Q46: Highlights and few quotes from comments received

"Need for farmer friendly field level test kits for important diseases of shrimp, prawn and crab."
(Anonymised quote from comments)

- **Integrated diagnostic approaches** to move beyond single-pathogen tests toward multi-agent and multi-factorial diagnostic frameworks, better suited to complex disease syndromes in aquaculture. Regulatory and policy frameworks will need to evolve accordingly**.**
- **Data use and management:** Recognition that effective integration of complex "omics" and surveillance data will be central to future diagnostic and disease-management systems.
- **Reference materials and quality assurance:** Continued need for positive-control and reference standards to support inter-laboratory validation and global comparability of test results.
- **Climate and environmental change:** Greater attention required to understand how climate-driven shifts in pathogen–host distributions may influence diagnostic relevance and preparedness.
- **Accessible tools for farmers:** Development of farmer-friendly, field-level diagnostic kits for shrimp, prawn, and crab remains a high priority.
- **Support to biosecure production:** Improved diagnostics should be coupled with efforts to produce and certify disease-free stocking material.

Prophylactics

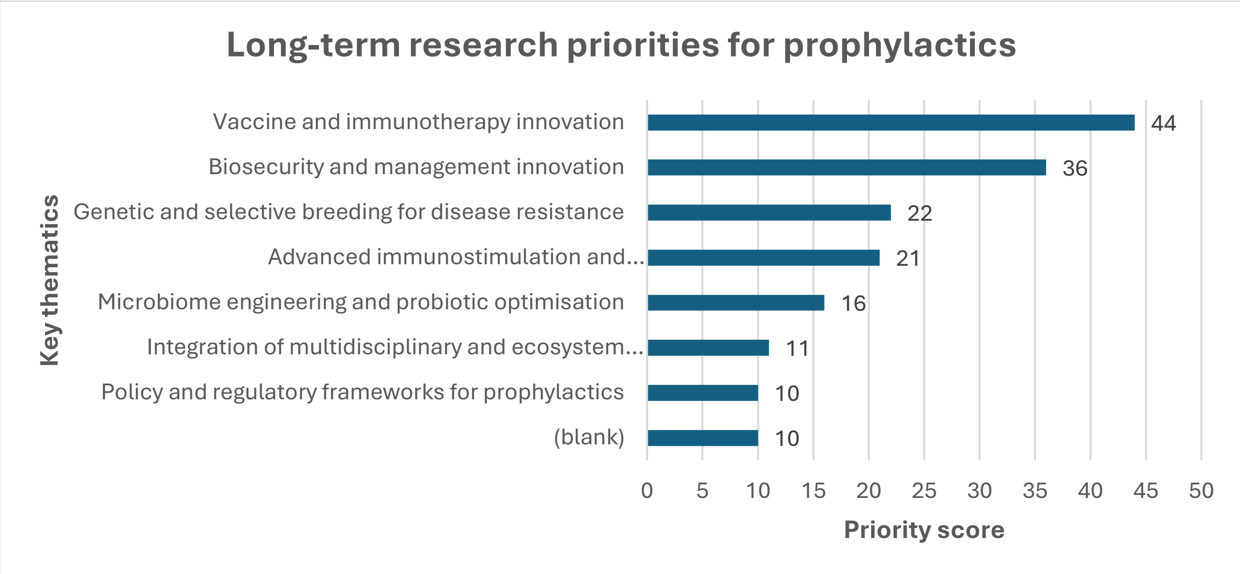
Q 47: What are the short-term (within 5 years) research priorities for development and optimal use of Prophylactics?



Prophylactics : Summary of identified short term research priorities from top 5 key trends
1. Best aquaculture and biosecurity practices (Score: 64)
• Strengthen farm-level biosecurity, including pond-bottom management, quarantine, and sanitary measures to prevent pathogen introduction. • Improve management of water quality and pond environments to control disease outbreaks and optimise microbial balance. • Promote best aquaculture practices (BAP) and good husbandry, such as discontinuing broodstock enucleation (eyestalk ablation) and maintaining biosecure breeding lines (specific pathogen free (SPF), specific pathogen tolerant (SPT) or specific pathogen resistant (SPR)). • Develop innovative biosecurity technologies and monitoring tools for early detection and containment of disease risks. • Conduct research on environmental dynamics and pathogen proliferation to identify ecological factors influencing disease occurrence. • Enhance disease control in production systems for viral, bacterial, and parasitic infections through integrated farm management. • Ensure responsible use of prophylactic products within overall biosecurity frameworks.
2. Microbiota optimisation and probiotics (Score: 41)
• Advance development of probiotics for water and gut health, including strains with medicinal or immunomodulatory claims. • Explore microbiome-based interventions to stabilise pond ecosystems and enhance resilience against pathogens. • Evaluate the long-term effects of probiotics in shrimp production and their role in disease prevention. • Encourage targeted, evidence-based use of prebiotics and probiotics for improved health outcomes. • Adapt concepts from terrestrial livestock alternatives to antimicrobials (ATA, e.g. gut modifiers, competitive exclusion) for aquaculture to reduce antimicrobial dependence.
3. Vaccine-related research (Score: 38)
• Deepen understanding of the crustacean immune system and its response to vaccination or immune priming stimuli. • Continue development of vaccines for WOAH-listed pathogens, including formulation, delivery routes, and efficacy testing. • Investigate environmental factors influencing vaccine performance and protective outcomes under farm conditions. • Explore novel immunotherapy platforms, such as dsRNA-expressing probiotics, recombinant viral proteins, and egg-yolk antibodies (IgY). • Assess the synergistic use of vaccines and immunostimulants (e.g. for IHHNV and WSSV) to improve disease control. • Address regulatory and trade considerations related to vaccine use and product registration in aquaculture.

4. Nutritional and functional feed approaches (Score: 29)
• Develop phytochemicals and feed additives with prophylactic and immunostimulant properties. • Incorporate nutraceuticals and herbal formulations to enhance shrimp immune response and growth performance. • Advance innovative feed formulations with nutraceuticals to improve resistance to infection.
5. AMR and ATA (Alternatives to Antimicrobials) (Score: 19)
• Promote development and responsible use of non-antibiotic prophylactic products, including immunostimulants, phytochemicals, and probiotics. • Support AMR research and adoption of ATA strategies • Integrate AMR mitigation measures into biosecurity and One Health programmes to safeguard sustainability and trade.

Q 48: What are the medium-long term (5-15 years) research priorities for development and optimal use of Prophylactics?



Prophylactics : Summary of identified long-term research priorities from top 5 key trends
1. Vaccine and immunotherapy innovation (44)
• Expand vaccine research for crustacean pathogens, including viral and bacterial agents relevant to shrimp, crabs, and prawns. • Advance dsRNA-based antiviral technologies and RNA interference (RNAi) platforms to inhibit viral replication (e.g. WSSV, IHHNV). • Explore use of egg-yolk antibodies (IgY) and recombinant antigens for passive immunisation and immune modulation. • Develop safe and efficient delivery systems adapted for aquatic use. • Investigate vaccine efficacy under field conditions, accounting for environmental influences and farm-level stressors.

2. Biosecurity and management innovation (36)
• Develop and apply artificial intelligence (AI) and digital tools to improve disease monitoring, early warning, and decision-making in aquaculture systems. • Strengthen farm-level biosecurity systems, including pond-bottom management. • Develop integrated biosafety management models for key biosafety indicators (biological or non-biological) for early detection and rapid response. • Promote good aquaculture practices (GAP), such as stopping broodstock enucleation and responsible use and disposal of veterinary medicines, reducing antimicrobial dependency and environmental impact • Control measures for viral and bacterial diseases, particularly in high-density crab and shrimp production sites.
3. Genetic and selective breeding for disease resistance (22)
• Advance selective breeding programmes to enhance disease resistance and resilience. • Study genetic modification and genetic resistance markers for priority pathogens to identify and propagate resistant lines. • Enhance climate-resilient breeding programmes, selecting families adapted to changing environmental conditions.
4. Advanced immunostimulation and immunomodulation (21)
• Develop diversified immunostimulation methods combining herbal, microbial, and synthetic bioactives to strengthen innate defences. • Identify and validate new immunostimulants to enhance shrimp resistance against viral infections. • Explore herbal and natural extracts as sustainable sources of immunostimulatory compounds.
5. Microbiome engineering and probiotic optimisation (16)
• Study management of microbial intestinal ecosystems to stabilise gut health and improve immune responses. • Advance microbiome engineering approaches in both host and environment to prevent pathogen proliferation. • Develop next-generation probiotics and prebiotics tailored to crustacean production systems.

Q 49: Do you anticipate any regulatory or technical or social/economic challenges in developing/using new ***Prophylactics?*** *If yes, please specify the issue.*

Highlights and few quotes from responses received:

"It is needed more flexible and risk-based regulation, including innovation."
(Anonymised quote from comments)

- Respondents identified major regulatory, technical, and economic barriers to the development and adoption of prophylactics for crustaceans.
- Regulatory frameworks were described as fragmented and restrictive, particularly for biotechnology-based products (e.g. recombinant antibodies, RNA vaccines).
- The high cost of prophylactic measures was seen as a key obstacle to farmer adoption and widespread use.
- Limited scientific understanding of crustacean immunology and insufficient local R&D capacity were viewed as key constraints on innovation.

- Vaccine remains technically challenging for crustaceans and current candidate vaccines have limited efficacy in shrimp, reducing confidence in their practical application.
- Respondents called for more flexible, risk-based regulations and faster approval processes for new prophylactic tools.
- The absence of clear frameworks to register alternatives to antimicrobials (ATA) was repeatedly mentioned as a challenge.
- Respondents highlighted that advancing prophylactic development would reduce antimicrobial use, improve biosecurity, and support trade and sustainability in the crustacean aquaculture sector.

"For economically farmed crustaceans, it is necessary to lower the cost of prophylactic measures to increase farmers' willingness to adopt them."

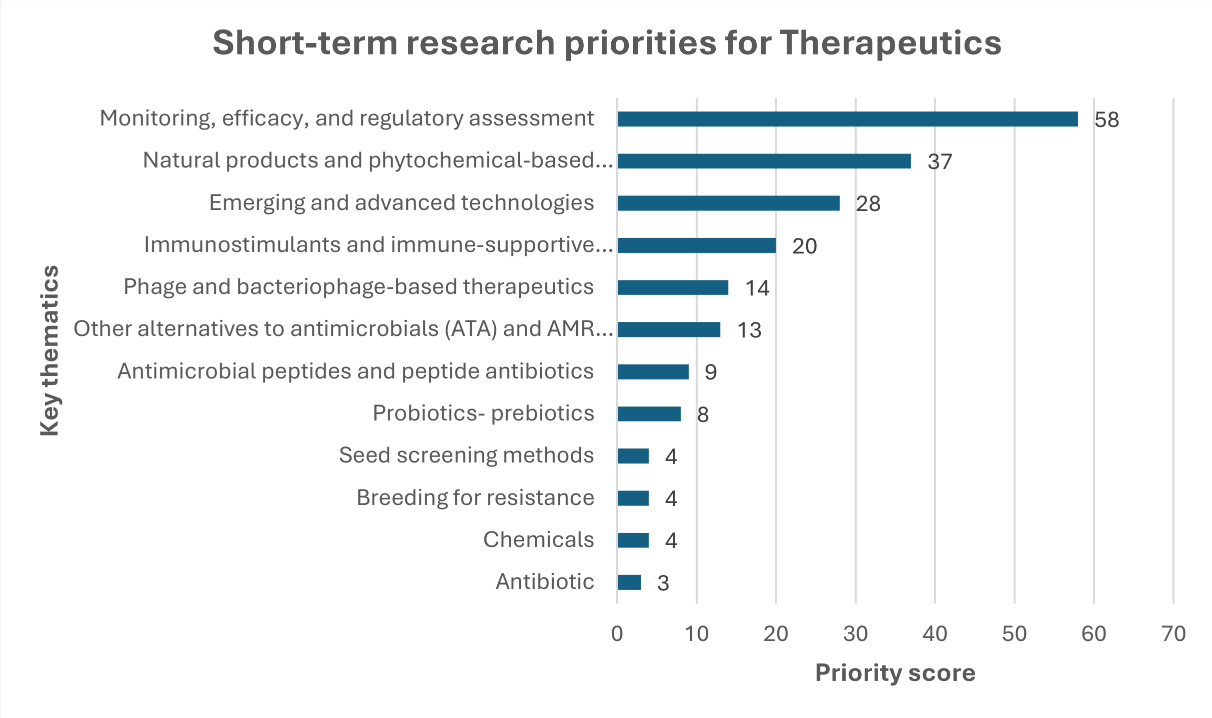
(Anonymised quote from comments)

Q 50: Highlights from comments received:

- Respondents emphasised animal welfare concerns, noting that practices such as broodstock enucleation are incompatible with welfare standards and that alternatives should be prioritised.
- Some participants reaffirmed the potential benefits of prophylactics for controlling viral and bacterial infections in farms and hatcheries, particularly to control concerning zoonotic diseases and aquaculture emerging virus
- WOAH should focus more on disease ecology — particularly the role of water pollution in disease emergence — to avoid hindering global progress in aquatic animal health management.
- Several responses underlined that aquaculture biosecurity remains the most effective and cost-efficient disease prevention strategy, outperforming prophylactic interventions in many contexts. They encouraged greater research, demonstration, and promotion of biosecurity technologies.
- A few respondents noted no immediate issues or that prophylactics fall outside their area of expertise.

Therapeutics

Q 51: What are the short-term (within 5 years) research priorities for therapeutics (e.g. antimicrobials or alternatives to antimicrobials)?



Therapeutics: Summary of short-term research priorities from top 5 key trends
1. Monitoring, efficacy, and regulatory assessment (58)
• Develop improved monitoring systems to track antimicrobial usage, efficacy, and residues in aquaculture, supported by national inventories of approved veterinary therapeutics. • Evaluate treatment efficacy and conduct field-based studies to assess outcomes in commercial crustacean systems. • Investigate the impacts of agricultural run-off, disinfectants, heavy metals, and other pollutants on the selection and spread of AMR in aquatic systems, identifying priority contaminants and exposure pathways. • Strengthen understanding of how biodiversity and pond ecosystem health influence disease risk and antimicrobial dependence. • Analyse regulatory frameworks to improve international regulations governing antimicrobial use and trade • Improve early-detection pond management strategies to minimise outbreaks. • Strengthen farmers capacity on responsible and prudent use of antimicrobials, including their safe and effective application.

2. Emerging and advanced technologies (28)

- Explore innovative therapeutic platforms, such as nanotherapeutics, RNAi, circular DNA, and antibody-based therapies.
- Research should target technologies that modulate microbial environments rather than relying solely on pathogen eradication, to create more stable pond ecosystems.
- Use of microalgae (“green water”) systems for disease control and AI-assisted drug discovery for antiviral and antifungal agents were noted as promising directions.
- Develop environmentally safe water treatment systems and novel formulations for sustainable therapeutic delivery were also highlighted.

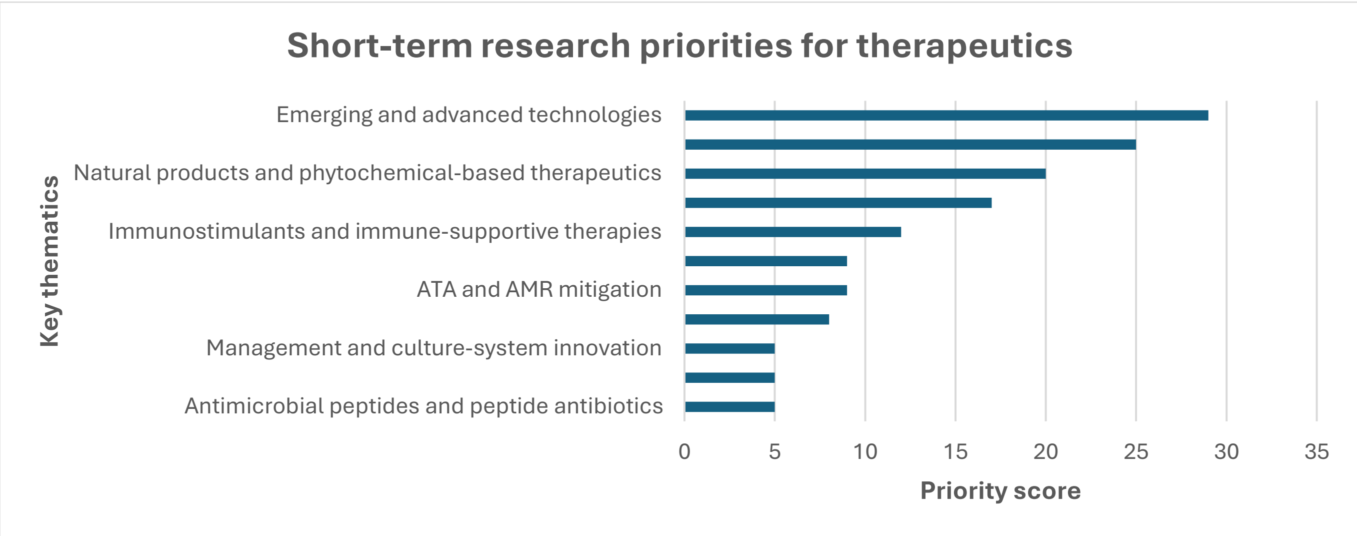
3. Immunostimulants and immune-supportive therapies (20)

- Develop feed-based natural immunostimulants and passive immunisation strategies (e.g. IgY) to enhance crustacean immune competence and reduce the need for antibiotics.
- Research on immunopotentiators and immune markers was highlighted to monitor and improve animal welfare and stress resilience.
- Respondents also underlined the link between animal welfare and immune health, supporting integrated approaches to disease prevention.

4. Phage and bacteriophage-based therapeutics (14)

- Develop phage therapy as an alternative to antibiotics for bacterial diseases such as *Vibrio* infections.
- Isolation, characterisation, and formulation of bacteriophages with proven efficacy under aquaculture conditions.
- Targeted phage application strategies to ensure pathogen specificity and avoid resistance development.

Q52: What are the medium-long term (5-15 years) research priorities for therapeutics (e.g. antimicrobials or alternatives to antimicrobials)?



Therapeutics: Summary of long-term research priorities from top 5 key trends
1. Emerging and advanced technologies (29)
• Develop innovative therapeutic platforms, including bio-based antimicrobials, RNAi, and CRISPR-Cas or microbiome-editing tools to enhance host resistance to pathogens. • Research on AI-assisted drug discovery and the use of artificial intelligence in designing novel antivirals and antifungals. • Explore of new composite therapeutic mechanisms combining bio-based antimicrobials with immunomodulators for broad-spectrum protection. • Continued development of shrimp-specific antimicrobials and new alternative products adapted to aquaculture environments. • Promotion of emerging biotechnologies, such as phage therapy, antibody-based therapeutics, and circular DNA platforms, to modernise disease control strategies.
2. Monitoring, efficacy, and regulatory assessment (22)
• Improve regulatory frameworks and harmonise guidelines for the approval and responsible use of therapeutics in aquaculture. • Strengthen farmer education and awareness programmes on the prudent use of antimicrobial substances remains a key priority. • Calls were made for clear national and regional regulations (including sanctions and legal modifications) to ensure compliance and environmental safety. • Investigate correct and safe application of antimicrobials in shrimp farming, alongside efforts to monitor residues and usage patterns.
3. Natural products and phytochemical-based therapeutics (20)
• Develop and validate of plant-derived antimicrobials, herbal formulations, and phytotherapeutic compounds for disease treatment. • Explore herbal extracts and ethnoveterinary medicine to identify safe, effective alternatives to synthetic antimicrobials. • Prioritise natural bioactive compounds that can be integrated into feed or water treatments to support sustainable aquaculture health management.
4. Phage and bacteriophage-based therapeutics (17)
• Investigate phage therapy as a key alternative to antibiotics for bacterial infections such as *Vibrio* spp. • Understand the environmental impact of phage use, optimising production and delivery methods, and ensuring scalability for industrial application. • Develop phage-based solutions tailored to hatchery environments and integrated disease management systems.
5. Immunostimulants and immune-supportive therapies (12)
• Develop immunostimulants and immune enhancers that strengthen crustacean health and reduce antibiotic dependence. • Investigate immunopotentiators and natural compounds to improve immune responses under stress conditions. • Emphasis on animal welfare as an integral component of therapeutic development, linking physiological health and immune performance.

Q 53: Do you anticipate any regulatory or technical or social/economic challenges in developing/using new therapeutics (e.g. antimicrobials or alternatives to antimicrobials)? If yes, please specify the issue.

"For alternatives to antimicrobials there are no or minimal regulations to register a product, and the approval of new therapeutics usually takes considerable time."
(Anonymised quote from comments)

Regulatory challenges

- Limited or inconsistent legislation regulating antimicrobial use and alternatives in aquaculture.
- Lack of regulatory frameworks for alternatives to antimicrobials (ATA) — few or no mechanisms exist to register or approve such products.
- Slow approval processes for new therapeutics due to complex government procedures and risk-assessment requirements.

Technical challenges

- Need for better understanding of bacteriophage applications and environmental impacts before widespread adoption.
- Limited research capacity for evaluating efficacy, safety, and dosage of both traditional antimicrobials and new alternatives.

Economic and social challenges

- The high cost of therapeutics was repeatedly cited as a barrier to adoption, especially for small-scale or low-margin crustacean producers.
- Economic feasibility is further constrained by limited therapeutics market demand and awareness, particularly in developing regions.

Other observations

- Continued unregulated or excessive antibiotic use in aquaculture poses a risk of accelerating antimicrobial resistance.
- Respondents linked AMR concerns to the need for stricter regulation, farmer training, and better monitoring of antibiotic application.
- A few respondents indicated no major challenges or that the topic was outside their area of expertise.
- One comment noted low interest in therapeutic development for crustaceans in Europe, suggesting regional differences in research focus.
- Another respondent highlighted the potential of bacteriophage therapy against *Vibrio* spp., viewing it as a promising innovation rather than a challenge.

"For economically farmed crustaceans, it is necessary to lower the cost of therapeutics to increase farmers' willingness to adopt them, especially where scientific and technical capacity is still limited."
(Anonymised quote from comments)

Q54: Highlights and few quotes from comments received:

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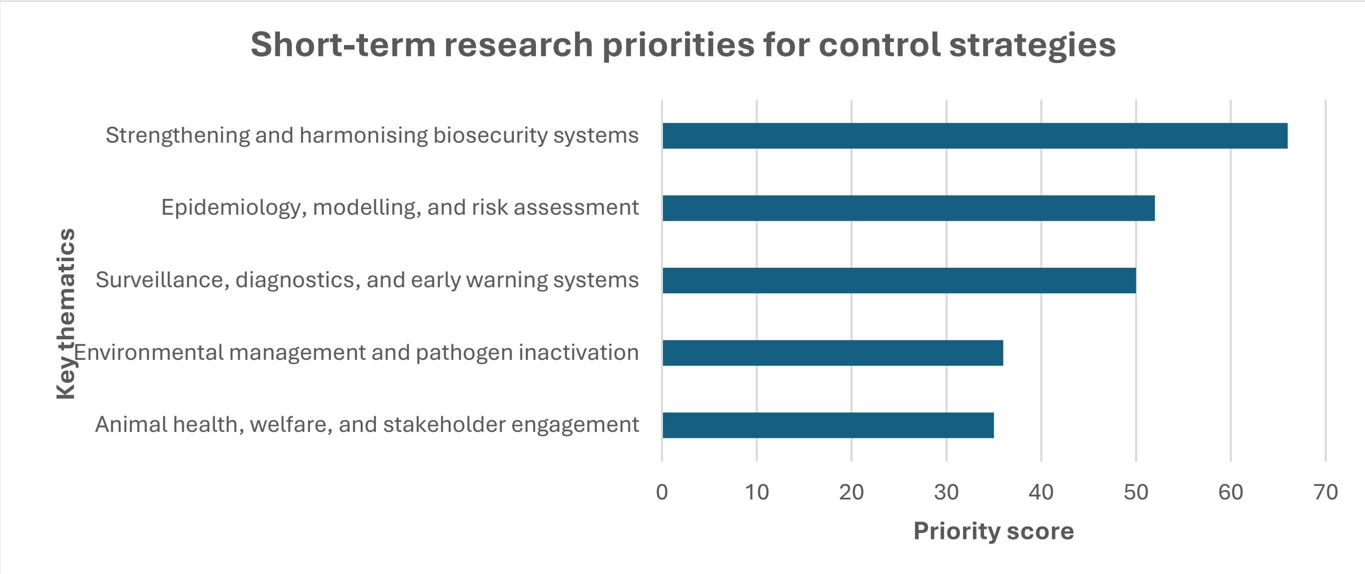
*"**Promoting new technologies such as phage therapy, antibody therapy, RNAi, and nanotherapeutics** can help the aquaculture sector move beyond traditional antimicrobials toward precision disease control." (Anonymised quote from comments)*

- Some respondents indicated limited relevance of therapeutics for their national aquaculture sectors or personal areas of expertise.
- One respondent highlighted the ongoing need to control bacterial infections in shrimp, prawn, and crab hatcheries.
- Another that aquaculture biosecurity measures are generally more effective and cost-efficient than therapeutics, calling for further research and promotion of biosecurity technologies.
- A forward-looking response pointed to the potential of emerging technologies such as phage therapy, antibody therapy, RNAi, and nanotherapeutics to advance precision disease control beyond conventional antimicrobial use.

"The implementation of aquaculture biosecurity is more effective and cost-saving than the use of therapeutics. It is strongly recommended that research for demonstration and promotion of aquaculture biosecurity technologies should be strengthened." (Anonymised quote from comments)

Control strategies

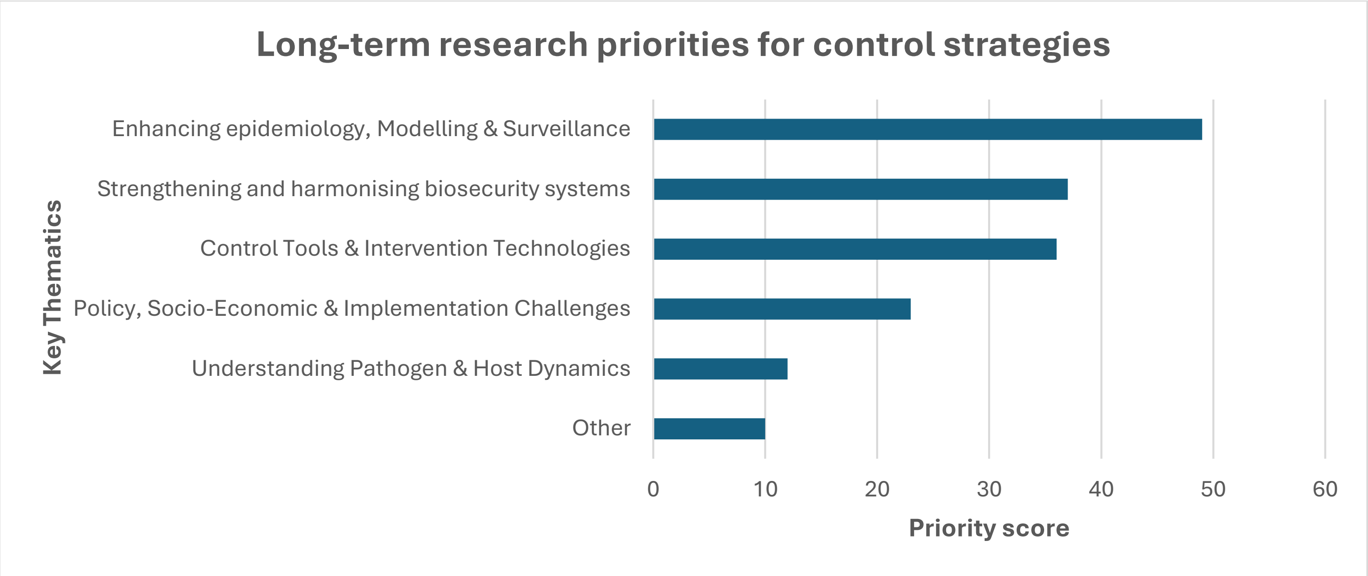
Q55: What are the short-term (within 5 years) research priorities for optimizing or implementing control strategies?



Control strategies: Summary of short-term research priorities from top 5 key trends
1. Strengthening and harmonising biosecurity systems (Score: 66)
• Develop and validate biosecurity strategies, SOPs, and disease control programmes, including those tailored to artisanal shrimp farms. • Harmonise and implement farm-level and national biosecurity systems across crustacean production sectors. • Investigate effective quarantine measure, zoning and compartmentalisation to establish disease-free areas and enable trade certification, particularly for IHHNV and WSSV. • Integrate innovation in pond management, quarantine procedures, and risk-based biosecurity practices. • Strengthen capacity building to improve response preparedness and ensure biosecurity measures are adapted to different species and production systems.
2. Epidemiology, modelling, and risk assessment (Score: 52)
• Expansion of epidemiological data and modelling capacity to better understand disease risks and transmission dynamics. • Enhance understanding of risk of introduction, spread and mitigation measures of existing and new pathogens. • Strengthen research on the cross-species transmission and hazard assessment of emerging aquatic viruses, focusing on their potential biosecurity and ecological security risks. • Research on susceptibility, pathogen reservoirs (wild and alternate hosts) and wildlife spillover risks affecting aquaculture species, including origination studies on newly emerging viruses (e.g. CMNV) and their reservoir hosts (e.g. Antarctic Krill), to prevent spread into aquaculture and human populations. • Develop molecular epidemiology studies to trace pathogen strains and evolutionary patterns. • Enhance regional and transboundary risk analyses, including the assessment of susceptible host species and cross-border disease threats. • Evaluate the effectiveness of antibiotics and management practices in disease control. • Strengthen national epidemiological capacity and surveillance personnel training.
3. Surveillance, diagnostics, and early warning systems (Score: 50)
• Develop of rapid and sensitive diagnostic tools and early warning systems for disease detection. • Integrate of real-time monitoring and digital reporting systems for improved outbreak response and data sharing. • Research on surveillance strategies targeting covert infections, new and emerging diseases, and AMR. • Establish platforms for reporting outbreaks and tracking pathogens, with a focus on interoperability between laboratories and agencies. • Best use of disease-free broodstock and proper screening before stocking to reduce pathogen introduction risks.

4.	**Environmental management and pathogen inactivation (Score: 36)**
•	Strengthen pathogen inactivation and disinfection methods, including: development of effective inactivation techniques for surfaces, effluent, and recirculating systems across all WOAH-listed diseases; and a systematic review of existing disinfection research to support disease classification, validate surrogate pathogen use, and guide disinfection during outbreak response.
•	Develop of low-cost, energy-efficient water treatment and pollution prevention technologies for sustainable aquaculture.
•	Studies to quantify environmental carrying capacity and inform farm siting to reduce disease pressure.
•	Integrate of innovative water management practices and ecosystem-based approaches to minimise environmental reservoirs of pathogens.
•	Increase understanding of environment–host–pathogen interactions for improved control strategies.
5.	**Animal health, welfare, and stakeholder engagement (Score: 35)**
•	Inclusion of animal welfare principles within disease control and farm management frameworks.
•	Research on welfare indicators for crustaceans and their link to health and productivity.
•	Establish neurophysiological assessment techniques for decapod crustaceans, supporting evidence-based welfare standards and humane management.
•	Develop veterinary products authorised for aquatic species to improve treatment options.
•	Capacity building and stakeholder engagement to support implementation of control strategies.
•	Explore of probiotics, bioactive compounds, and immune-enhancing innovations as part of integrated health management approaches.

Q56: What are the medium-long term (5-15 years) research priorities for optimizing or implementing control strategies?



Control strategies: Summary of long-term research priorities from top 5 key trends
1. Enhancing Epidemiology, Modelling & Surveillance (49)
• Develop and apply AI and machine-learning tools for disease prediction and early detection. • Strengthen AI-supported surveillance systems for crustacean health. • Improve risk analysis for imported aquatic products. • Standardise and enhance data collection, sharing, and interoperability across countries. • Develop early warning technologies using epidemiological and environmental datasets. • Advance epidemiological research on crustacean diseases and transmission. • Create international platforms to integrate and report diagnostic outcomes. • Strengthen diagnostic and reference laboratories in participating countries. • Increase use of AI for disease modelling and forecasting.
2. Strengthening & Harmonising Biosecurity Systems (37)
• Implement and reinforce aquaculture farm biosecurity protocols. • Improve biosecurity control measures across the production cycle. • Conduct cost–benefit analyses to optimise biosecurity strategies. • Strengthen border-control biosecurity for pathogen introduction prevention, including risks associated with special habitats such as polar regions and deep-sea environments. • Develop and validate SOPs for risk-based biosecurity management. • Improve disinfection and water-treatment practices in farms and hatcheries. • Advance eradication strategies and zoning for key diseases (e.g., IHHNV, WSSV). • Promote national and regional harmonisation of biosecurity standards.
3. Control Tools & Intervention Technologies (36)
• Develop and validate immunostimulants and immune-supportive treatments. • Ensure that control measures are species-appropriate and effective. • Improve nutritional and feed-based disease-reducing diets. • Develop new veterinary medicinal products authorised specifically for crustaceans. • Advance genetic and breeding strategies to improve resilience and health. • Improve non-lethal diagnostic and sampling techniques. • Develop pathogen-agnostic diagnostic tools for co-occurring or emerging pathogens. • Evaluate probiotics and water treatments as preventive interventions. • Explore molecular feed innovations that enhance immunity and nutrient utilisation.
4. Policy, Socio-Economic & Implementation Challenges (23)
• Improve culture models and production systems to support health management. • Strengthen governance frameworks for crustacean health and disease control. • Develop legislation and welfare standards tailored to crustaceans. • Enhance policy evaluation to ensure effective implementation of control strategies. • Improve disease-management protocols for farms and hatcheries. • Promote integrated management strategies to reduce disease transmission.
5. Understanding Pathogen & Host Dynamics (12)
• Improve understanding of host susceptibility traits in crustaceans. • Enhance knowledge of wildlife reservoirs, viral biosecurity risks in aquaculture, and spillover/spillback dynamics, including zoonotic disease risks. • Investigate pathogen profiles and invasion patterns, including Trojan-horse dynamics.

Q57: Highlights and few quotes from comments received:

"Guide the farmers properly to follow SOP related to disease management"
(Anonymised quote from comments)

- Biosecurity was highlighted as a promising and effective disease control strategy, with emphasis on preventing the entry and spread of notifiable diseases.
- Respondents underlined the importance of farmer guidance and training, particularly in following standard operating procedures (SOPs) for disease management.
- Genetic improvement for health and resistance was recognised as valuable but described as a long-term process requiring sustained investment.
- Some noted the need to better understand pathogen biology and population dynamics, including fungal pathogens and their impacts on aquaculture and natural fisheries.
- For the crayfish plague, caused by the fungus *Aphanomyces astaci*, prevention focuses on avoiding introduction ("preventing entry") into unaffected regions or facilities (a contingency or preparedness measure rather than active disease management at the moment)
- Calls were made for greater attention to animal welfare within control strategies.

"Aquaculture biosecurity represents a very promising disease control strategy."
(Anonymised quote from comments)

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