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IGB MANUAL

Health and welfare monitoring in Whiteleg shrimp *(Litopenaeus vannamei)* aquaculture

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Summary

This *IGB Manual* provides an overview of the current global status of Whiteleg shrimp (*Litopenaeus vannamei)* farming. It focuses on shrimp welfare in aquaculture, with emphasis of morphological modifications under stress conditions. Morphological lesions are presented through figures, along with recommended observation procedures. Experimental results and farm observations are described to support the index interpretation. This *IGB Manual* especially addresses practitioners, companies and associations from the aquaculture sector to foster animal welfare aspects in shrimp farming. It can also serve as a reference resource in experimental settings or routine farm observations, particularly at small-scale, where standardised operational protocols are often less developed. Shrimp experts are invited to provide feedback and suggestions, and to submit filled morphological index forms for expansion of the dataset.

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Shrimp aquaculture

Brief History

Shrimp farming originated from incidental harvests in India, Bangladesh, and Vietnam's Mekong Delta, where wild shrimp fry naturally entered tidal rice fields. These fields were later modified for dry-season shrimp production through raised dikes and weirs. Modern shrimp aquaculture emerged in Japan in the 1930s, where protocols for spawning, larval rearing and grow-out for *Penaeus japonicus* were developed. Commercial-scale production of shrimp postlarvae as a prerequisite for further expansion began in the 1940s and 1950s, but expansion soon shifted to regions with more favourable climates, land availability, and suitable species. By the late 1960s and 1970s, Taiwan and Ecuador had become major producers of penaeid shrimp. From the 1980s onward, inadequate management led to widespread disease outbreaks, causing severe production losses. In response, the U.S. Department of Agriculture's Marine Shrimp Farming Program introduced biosecurity-based management and genetically selected *Litopenaeus vannamei* in the late 1980s and early 1990s. These innovations triggered a second global expansion of shrimp aquaculture. Disease-resistant and low-salinity strains were later adopted in China, where freshwater shrimp culture and cross-sector technological integration drove rapid growth in the early 2000s. At the same time, the rapid global growth of shrimp aquaculture in open systems also caused negative environmental impacts such as pollution with nutrients and chemicals and the loss of mangrove ecosystems.

Current situation

Over the past two decades, crustacean aquaculture increased dramatically from 1.7 to 12.7 million tonnes annual production, accounting for 68% of global crustacean output. Penaeid shrimp dominate the sector, with *L. vannamei* as the leading species at 6.8 million tonnes[1]. China leads global production (51%), primarily using pond-based systems. Shrimp are among the most valued seafood products in Europe. Between 600-900 thousand tonnes are imported per year, at prices between 5 and 10 €/kg (marine shrimps)[2,3]. Most consumers prefer peeled products.

Consumer awareness of ethical issues has increased, while imported shrimp have been associated with labor abuses, food safety concerns, and illicit practices. Additionally, there is more awareness of environmental issues often related with shrimp farming, such as water and ecosystem pollution. Consumers and, consequently, at least a number of market players and retailers pay more attention to environmental sustainability, carbon/water footprints, as well as life-cycle assessment. Concurrently, technological advances have enabled shrimp farming in indoor aquaculture systems, offering enhanced biosecurity, sustainability, and geographic flexibility through artificial seawater.

Initially focused on *L. vannamei,* European shrimp farming is now experiencing a second investment wave, driven by proven business models and sustained demand. Several facilities are under construction or expansion towards capacities of several thousand tonnes per year. Europe has also begun developing its own shrimp hatchery capacity, reducing reliance on U.S. larvae imports. Currently, approximately 25 indoor RAS shrimp farms operate across Europe, producing an estimated 418 tonnes annually[1]. Shrimp are typically marketed at 12–25 g individual size, sold fresh or frozen, peeled or unpeeled, through retailers, restaurants, and online platforms. Prices vary widely, from around 25 €/kg in Spain to 100 €/kg in Switzerland and Germany.

Aquaculture systems

Ponds are the most widely used shrimp aquaculture systems, with widespread adoption in Asia. They are usually located in the intertidal zone or in proximity to a source of water. They range from extensive to hyper-intensive, depending on stocking density, feed inputs, technology, and management (water exchange, fertilisers, medication).

Ponds for tropical species are impractical in colder nations and shrimp farming in such nations usually occurs in recirculating aquaculture systems (RAS). These are closed-loop systems that maintain water quality through mechanical and biological filtration, with daily water exchange typically below 5%. Mechanical filtration uses drum filters for solids removal and protein skimmers for foam fractionation. A biofilter converts ammonium, the main metabolic waste, into less toxic nitrite and nitrate via microbial nitrification. Water is disinfected using UV filters or ozone, while aerators or liquid oxygen ensure adequate oxygenation. Typically, continuous measurement of the system parameters using modern measurement technology and alarms is used for the control of a RAS.

Similarly, biofloc systems are also closed systems but rely on simpler, more cost-effective technology. In these systems, bacteria, algae, and other microorganisms form aggregates ("flocs") that assimilate excess nutrients such as ammonia, nitrite, and organic matter, reducing the need for water exchange. These microbial flocs also serve as a supplementary food source, lowering feed costs and improving animal health. Continuous aeration maintains oxygen levels and prevents the Biofloc from settling and accumulating.

Hybrid systems are increasingly adopted to reduce costs, combining simplified RAS or biofloc approaches with selected RAS components (bio-RAS). Beyond these indoor systems, emerging technologies such as integrated multitrophic aquaculture (IMTA) are under investigation for commercial application. In IMTA, organic waste from shrimp is utilized by plants, algae, or lower trophic species, which act as biofilters, improving water quality before water is recirculated to the shrimp tanks.

Figure 1. Example of shrimp pond (left, Photo: Björn Suckow) and a recirculating aquaculture system (right, Photo: Alfred-Wegener-Institute).

The Whiteleg shrimp *Litopenaeus vannamei*

Life cycle

Litopenaeus vannamei belongs to the order Decapoda within the crustaceans, characterized by ten extremities. Native to the eastern Pacific – from Mexico to northern Peru – this species inhabits warm waters (>25 °C), typically over muddy bottoms, with adults occurring at depths of up to 72 m. Females generally grow faster than males, reaching about 15 cm in length and 20 g in weight at maturity.

The life cycle of the Whiteleg shrimp comprises six stages: nauplius, zoea, mysis, postlarva, juvenile, and adult (Figure 2). After mating, females release hundreds of thousands of eggs, which hatch into yolk-dependent nauplii. Following yolk absorption and several moltings, larvae develop into zoea that feed on phytoplankton. Subsequent molts lead to the mysis stage, characterized by the formation of swimming extremities; mysis feed on zooplankton and migrate toward estuaries and mangroves. Postlarvae resemble miniature adults and grow through juvenile and subadult stages before returning to open waters. Adults are omnivorous detritivores, consuming organic matter, small invertebrates, and algae. After each molting, lost extremities or injuries are regenerated.

External and internal morphology

The adult body is divided into three regions: head (cephalon), thorax, and abdomen (Figure 1.7). The cephalon (five segments) and thorax (eight segments) are fused into the cephalothorax, while the abdomen comprises six segments. The first five abdominal segments bear pleopods used for swimming; the last segment carries uropods and a telson, enabling rapid escape responses. The body is encased in a rigid exoskeleton.

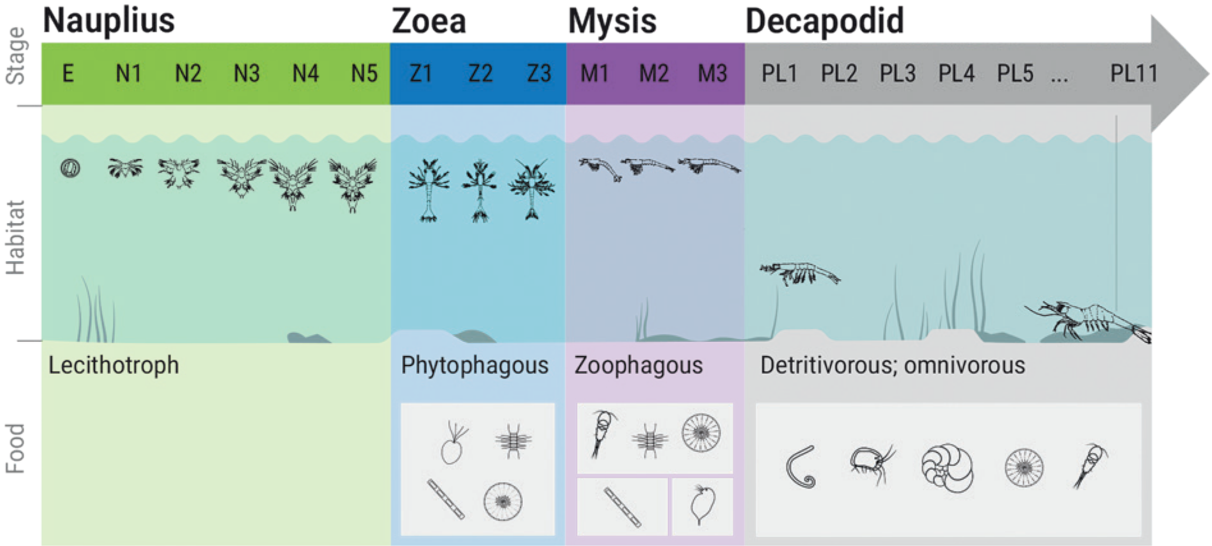

Figure 2. Life cycle of Whiteleg shrimp (*Litopenaeus vannamei*) showing larval stages, habitats and food sources. N – Nauplius stages, Z – Zoea stages, M – Mysis stages, PL – postlarval stages. Redrawn from Rojo Arreola et al., 2020[4].

Paired gills, enclosed in a branchial chamber, are main respiratory organs. The digestive system consists of a foregut (mouth, oesophagus, stomach), a midgut containing the hepatopancreas, the main organ for enzyme production and nutrient absorption, and a hindgut ending at the anus. *L. vannamei* has a semi-open circulatory system in which hemolymph, pumped by the heart, circulates through vessels and body cavities to deliver oxygen and nutrients. The male reproductive system consists of paired testes and sperm ducts; females possess paired ovaries with oocytes released through oviducts for external fertilization. The nervous system is centred in a dorsal brain within the cephalothorax, coordinating sensory and motor functions.

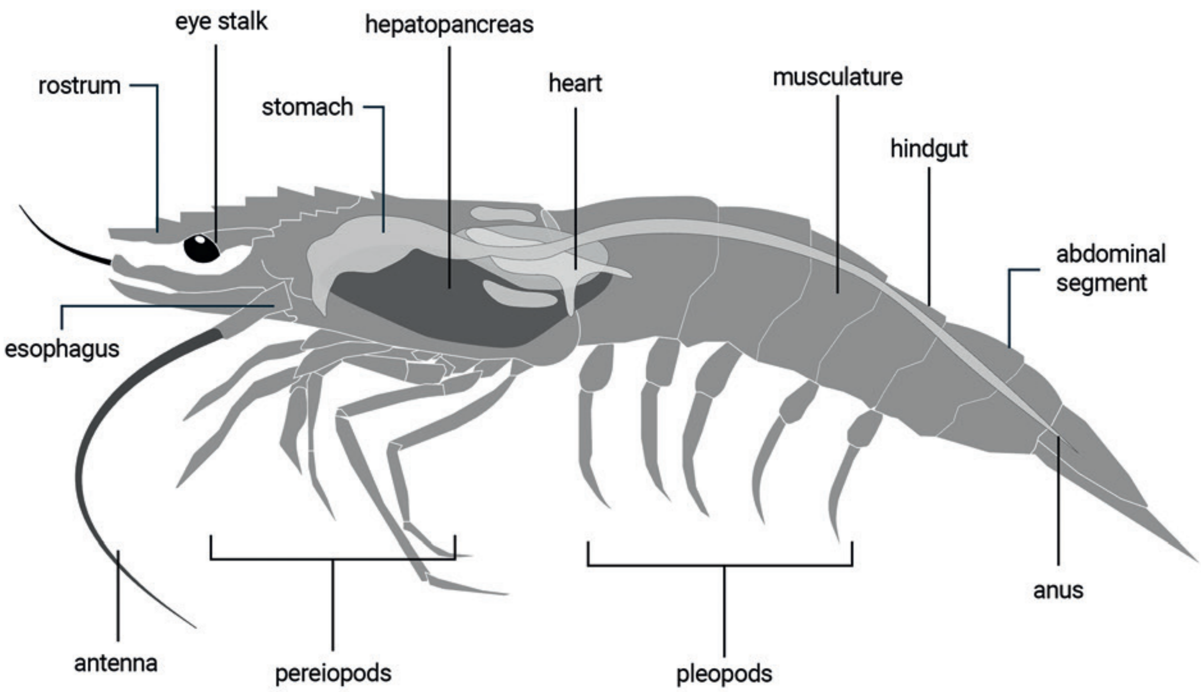

Figure 3. Anatomy of Whiteleg shrimp (*Litopenaeus vannamei*) (Larissa Lachmann).

Shrimp welfare

Concern for animal welfare is growing worldwide, alongside with awareness for environmental and sustainability issues. Consumers are also paying closer attention to how farmed animals are treated, pushing retailers and producers to improve standards.

Animal welfare is often framed around the "Five Freedoms": freedom from hunger and thirst; discomfort; pain, injury and disease; fear and distress; and the freedom to express normal behaviour. While originally developed for vertebrates, these principles are increasingly discussed for invertebrates in aquaculture.

For shrimp and other decapod crustaceans (such as crabs and lobsters), key welfare issues include hatchery practices, transport, stocking, keeping and slaughter. Eyestalk ablation, used to stimulate reproduction in broodstock shrimp is most controversial, but the stunning and killing methods are equally criticised. As global production expands, tailoring farming conditions to each species and life stage while reducing environmental impacts is seen as essential for sustainable aquaculture.

Legislation and indicators of welfare

Whether decapods can feel pain is the subject of ongoing scientific debate. Some studies report behaviours consistent with pain perception; others argue that stronger evidence is needed before firm conclusions are drawn[5]. This discussion has important legal implications.

Several countries have already extended legal protection to decapods. Switzerland and Norway were among the first in Europe to recognize welfare protections for these animals. In the UK, the Animal Welfare (Sentience) Act 2022 formally recognizes decapod crustaceans as sentient. At EU level, the European Food Safety Authority has highlighted the need for humane practices, though comprehensive binding legislation is still developing.

Retailers, in response to consumer concerns, are also driving change, committing to phase out practices such as eyestalk ablation and to adopt humane slaughter methods. Overall, there is a clear trend toward greater recognition of shrimp welfare, even as scientific debate on certain aspects continues.

Stress – definition and response

In aquaculture, stress occurs when environmental or management factors disrupt an animal's internal balance (homeostasis). Common stressors include:

- Environmental (abiotic): temperature, salinity, pH, low oxygen, high ammonia or nitrate.
- Biological (biotic): pathogens and parasites.
- Management-related: high stocking density, handling, transport and poor water quality.

Stress can be acute (short-term and intense) or chronic (long-lasting). While shrimp can adapt to mild stress, prolonged or severe stress leads to reduced growth, weakened immunity and higher mortality. Stress responses occur at three levels:

Primary response (hormonal)
Shrimp release hormones such as the crustacean hyperglycaemic hormone (CHH), which mobilizes energy reserves (glucose from trehalose) to cope with challenges.

Secondary response (physiological and immune changes)
This includes:

- Shifts in metabolism (glucose, lipids, digestive enzymes)
- Changes in immune cells and antimicrobial defences
- Increased oxidative stress and activation of antioxidant enzymes
- Altered ion balance and respiration

The former two responses aim to restore balance but can impair health if prolonged.

Tertiary response (whole-animal effects)
When stress persists, visible and economic impacts appear:

- Reduced growth and survival
- Lower disease resistance
- Reproductive problems
- Physical damage (e.g., melanised shells, damaged appendages, gill discoloration, muscle necrosis)
- Abnormal behaviours such as erratic swimming, clustering or inactivity

Tools to improve welfare in practice

To improve welfare in practice, farmers need clear and practical tools. Operational Welfare Indicators (OWIs) are measurable parameters used to monitor animal health and well-being in aquaculture. These indicators can be:

- Indirect, such as water quality, nutrition and system management.
- Direct, based on the animals themselves, including growth, survival, physical condition, behaviour or physiological markers.

Assessments often follow a stepwise approach: first checking environmental conditions, then examining animals more closely if problems are suspected. The goal is to develop reliable, easy-to-use indicators that work in real farming conditions and allow welfare to be monitored throughout the production cycle.

An easy to handle morphological index to assess welfare and well-being in shrimp

Recent progress has been made toward establishing welfare standards in shrimp aquaculture. Scientific frameworks for operational welfare indicators (OWIs) and specific welfare indicators for *L. vannamei* have been proposed by Albalat et al. (2022)[6] and Pedrazzani et al. (2023)[7], respectively, alongside the development of industry standards by the Aquaculture Stewardship Council (ASC) (https://asc-aqua.org/producers/asc-standards/species-standards/shrimp/).

As part of this comprehensive approach to assessing shrimp welfare in aquaculture, existing concepts of optimal morphology and its potential modification have been critically reviewed here. In addition, observations have been conducted both in laboratory-scale experiments and across three indoor shrimp farms in Germany.

Procedure for handling and observation

The first consideration when assessing shrimp morphology concerns the sampling procedure. If the collection of tissue, fluid, or organs is required, the animals must be anaesthetised. However, most external morphological characteristics can be evaluated without anaesthesia, allowing for minimally disruptive, animal-friendly assessments. At the farm scale, less invasive methods should be applied in accordance with the principle of non-invasive assessment. Detailed requirements for determining individual morphological characteristics are provided in Table 1.

Specific guidelines for shrimp handling and manipulation are largely absent from the literature. Nevertheless, it is generally recommended that handling be performed only when necessary and not repeated excessively. Frameworks developed for fish suggest the use of non-destructive equipment, such as soft nets and wet gloves, to minimise friction and potential injury.

For shrimp observations, a bucket containing approximately 20 cm of system water can be prepared, and individuals can be gently captured using a soft net. Most assessments can be conducted within the bucket (Tab. 1). If needed, shrimp may then be carefully held by the carapace to examine appendages, assess uropod condition, and verify earlier observations (Figure 3). Out-of-water handling should be limited to approximately 20 seconds, after which the shrimp should be gently returned to the tank.

It is essential to evaluate handling-related stress on a case-by-case basis, as responses may vary depending on environmental conditions, genetic background, moulting stage, and growth phase. If signs of stress

Table 1. Handling required for the morphological assessment of the respective parameter including 1) direct observations in water without manipulation, 2) careful manipulation of the respective body part upon capture, 3) sampling upon humane sacrifice, recommended during regular harvesting.

Parameter	Directly observable	Manipulation required	Necessary sampling
Antennae	X		
Eyes	X		
Rostrum and Telson	X		
Exoskeleton	X		
Musculature	X[1]		
Hepatopancreas			X
Stomach/ Intestine fullness	X[1]		
Gills			X
Legs		X	
Uropods		X	

[1] This parameters' quality assessment interpretation is tricky when slaughtering for sampling is performed

Figure 4. Shrimp recommendation for observation and handling (Photo: Paolo Gamberoni).

are observed, including severe reactions that may lead to mortality, the use of anaesthesia is recommended to minimise animal suffering during observation.

The ASC recommends at least weekly morphological evaluations, although no specific guidance is provided regarding sample size for shrimp species[8]. In general, the sample should be sufficiently large to represent the overall population. For comparison, recommendations for trout suggest that assessing around 30 individuals may be adequate for a single-tank or raceway, small- to medium-scale farm, while up to 100 individuals should be observed when multiple tanks are in operation[9].

For practical reasons related to shrimp size, the proposed assessment method is most suitable for individuals weighing 3 or more grams, corresponding to the grow-out phase of *L. vannamei.* In smaller shrimp, visual inspection by the naked eye becomes more challenging; in such cases, optical aids or photographic methods may be used to assure accurate evaluation.

Description of morphological abnormalities

The shrimp body can be divided into five main sections: the sensory system (antennae and eyes), the muscoloskeletal system (rostrum/telson, exoskeleton, musculature), the digestive system (stomach/intestine fullness, hepatopancreas), the respiratory system (gills) and appendages (legs and uropods).

Antennae are frequently found to be broken or shortened in intensive commercial farming conditions (Figure 5), in some cases almost entirely absent. The underlying causes remain unclear, although the most plausible explanations include mechanical damage (e.g. from contact with tank structures or conspecifics) and agonistic interactions between individuals.

Alterations in the eyes, such as whitening or cataract-like appearances, are typically observed as white spots or discolouration (Figure 6). The causes of these conditions are also not well understood. Possible explanations include mechanical abrasion from contact with tank surfaces or equipment, as well as nutritional deficiencies, as suggested by shrimp farmers. However, robust scientific evidence is currently lacking. Further in-

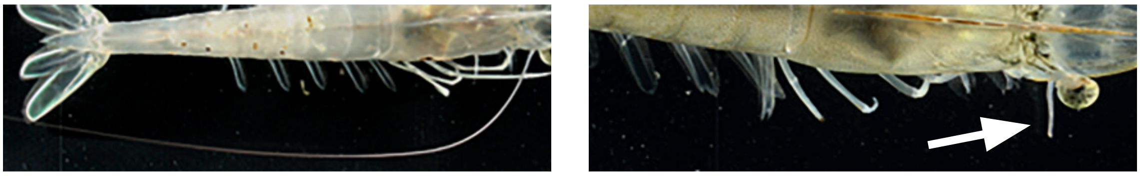

Figure 5. Whiteleg shrimp with normal intact antenna (on the left, Photo: Paolo Gamberoni) and a severely shortened antenna (right, Photo: Paolo Gamberoni).

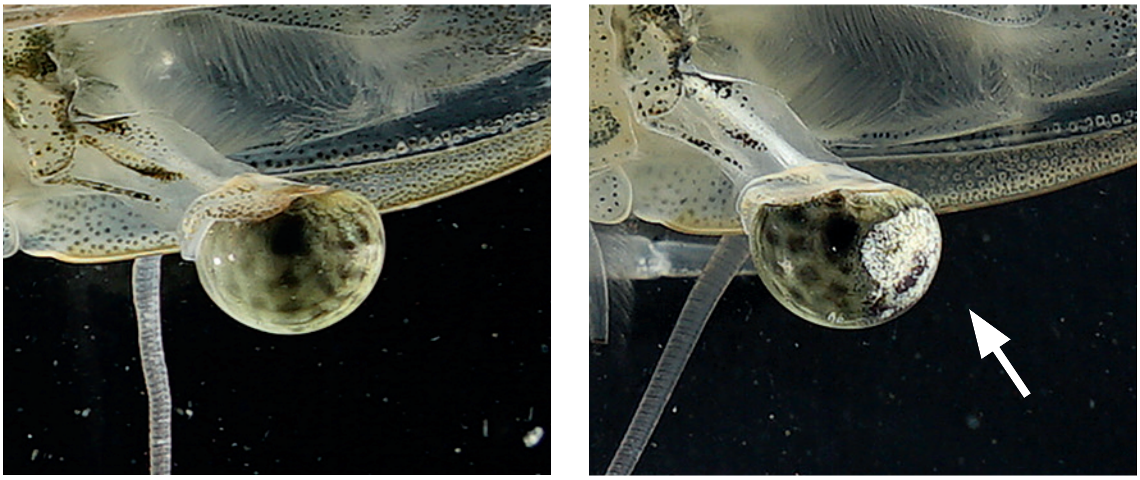

Figure 6. Eye in optimal condition (on the left, Photo: Mirko Bögner) and an extended eye whitening/cataract (right, Photo: Paolo Gamberoni).

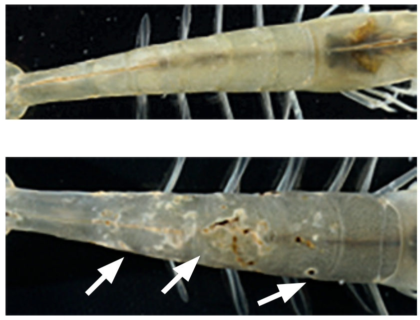

Figure 8. Optimal condition of the exoskeleton (top, Photo: Mirko Bögner) and exoskeleton presenting severe encrustations and melanosis (below, Photo: Mirko Bögner).

Figure 7. Rostrum and telson sharp and intact (left, Photo: Mirko Bögner). Severe broken rostrum and missing telson edge (right, Photo: Mirko Bögner).

Figure 9. Translucent, optimal muscle condition (left, Photo: Mirko Bögner). Small melanosis in the muscle (middle, Photo: Paolo Gamberoni) and cramping with opaque muscle or necrosis (right, Photo: Janek Neuse).

vestigation – through controlled experiments or by incorporating these observations into nutritional trials – would help clarify the underlying mechanisms.

The rostrum and telson, which function as terminal defensive structures, are occasionally observed to be bent, crooked, or shortened (Figure 7). These modifications are primarily attributed to antagonistic behaviour or trauma from contact with tank structures or enrichment devices.

Similarly, melanosis and encrustations are sometimes noted on the shrimp exoskeleton (Figure 8). In the case of melanosis, however, it may also represent a defensive response to an external microbial agent.

The musculature, being the part intended for human consumption, rarely shows quality degradation. Following euthanasia, black spots or melanosis are seldom observed (Figure 7). However, on sampling days or at the commercial scale, muscle discoloration—ranging from translucent to opaque – along with cramping and occasional mortalities, can be detected (Figure 9). This condition appears to be unrelated to changes in water mineral profiles and may instead result from environmental

Figure 10. Optimal gill condition (left, Photo: Mirko Bögner). Slight gill discolouration (middle, Photo: Mirko Bögner) and severe dark discolouration (right, Photo: Paolo Gamberoni).

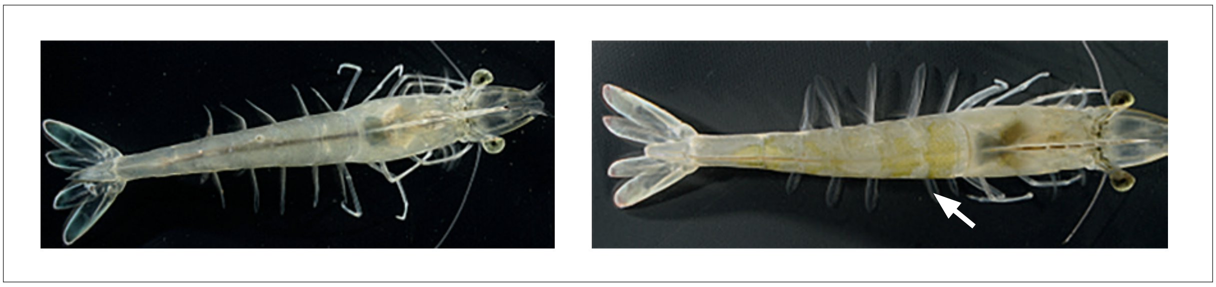

Figure 11. Whiteleg shrimp displaying intestine fullness (top, Photo: Paolo Gamberoni) and one with empty intestine (bottom, Photo: Paolo Gamberoni).

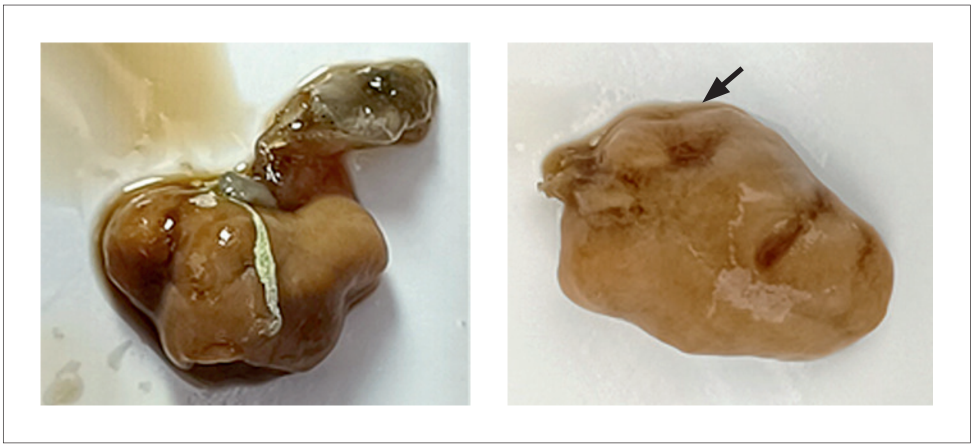

Figure 12. Dark and solid hepatopancreas in dark brown optimal condition (left, Photo: Paolo Gamberoni) and light brown (right, Photo: Paolo Gamberoni).

stress or specific microbial factors, such as elevated *Vibrio* loads.

Gills are generally observed to be in good condition in indoor systems. Clogged gills, black dots or slight discoloration from particulate or microalgal deposits may be detected, though such alterations may also result from pathogen infection (Figure 10).

At commercial-scale, careful and constant feeding is maintained using automatic feeders, resulting in intestine and stomachs that are generally full and dark brown in color. An empty stomach or intestine (Figure 11) may reflect normal physiological processes associated with molting or could indicate inappetence due to environmental stress or pathogen infection.

As illustated in Figure 12, the hepatopancreas quality can vary in colouration, consistence and size, according to the phenotypic scale described by Zhang et al. (2023) and Lozano-Olvera & Abad-Rosales (2024).

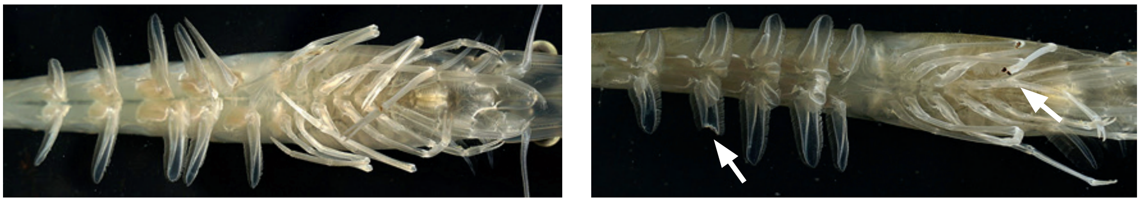

Figure 13. Whiteleg shrimp displaying all pleopods and pereiopods intact (on the left, Photo: Mirko Bögner). Shrimp with one pleopod and two pereiopods damaged (right, Photo: Mirko Bögner).

Figure 14. Intact uropods (left, Photo: Paolo Gamberoni) and damaged uropod (right, Photo: Paolo Gamberoni).

A healthy hepatopancreas is typically dark in colour and firm, whereas lightening and a very soft texture may indicate underlying problems.

Similar to antennae, broken legs are frequently observed, likely resulting from friction with tank structures or antagonistic interactions (Figure 13). Damage to uropods included loss of external setae, structural cracks, missing fragments, and in some cases damage to the telson, with causes analogous to those affecting antennae (Figure 14). Unfortunately, no clear relationship between stressfull cultivation conditions and tail coloration has yet been established, due to the large number of variables involved in this process.

Morphological welfare index

To consolidate this information, a morphological index has been developed to assess shrimp health conditions in aquaculture systems. You can download copies of the index for printing and field use at igb-berlin.de/en/downloads. The index integrates the authors' own findings with results from previous studies and provides detailed descriptions and photographic evidence to support consistent evaluation (Table 2). The Morphological Welfare Index focuses on easily identifiable external and internal shrimp characteristics. A simple, four-level scoring system is used here to record the severity of damage to each body part, with 0 indicating no recognizable damage and 3 representing the most severe damage (Table 2). Moreover, the index has practical applications for the aquaculture industry, enabeling shrimp farmers to monitor animal condition over time and potentially improve welfare. The index could also serve as a tool for certification or

Table 2. List of scores and corresponding descriptions used to evaluate shrimp health for each body part.

Body part	Score	Description
Antennae	0	Antennae completely developed with thinner termination
	1	1 antenna slightly shortened (lack of thinner terminations). Length about or > than 50% of total shrimp length
	2	Both antennae slightly shortened. Or 1 antenna fine and another considerably damaged (< 50% body length)
	3	1 antenna several damaged and 1 mild damaged or worse
Eyes	0	Both eyes black, in healthy appearance and no deformations
	1	1 eye with mild lightening or erosion
	2	Relevant lightening or erosion, on an eye or 2 mild erosions/lightening
	3	Complete lightening or erosion, missing eye, or abnormal eye position (even 1 eye if lesion is very bad) or 1 relevant erosions/lightening and 1 mild
Rostrum and Telson	0	Thick, strong, long and straight rostrum and telson. Rostrum ending well beyond the eye
	1	Rostrum/telson edge inflamed, slightly crooked, bent, or twisted
	2	1 between telson/rostrum slightly shortened or relevantly crooked or both with minor impairments
	3	Damages to both with one damage not mild, or worse
Exoskeleton	0	Healthy appearance, no lesions neither melanosis
	1	Slight lesion or encrusting, few black spots due to melanosis
	2	Focal melanosis, encrusting or lesions.
	3	Loss of tissue, generalized melanosis, crusting and deformity
Musculature	0	Healthy appearance, no lesions, nor deep melanosis
	1	Small imperfection as melanosis
	2	A few imperfections or limited opacity muscle
	3	Generalised necrosis/ melanosis, or white opaque muscle. Muscled cramped
Hepatopancreas	0	Dark brown and firm.
	1	Brown and slightly aqueous.
	2	Light brown and aqueous.
	3	Pale, considerably atrophied, aqueos
Stomach/ Intestine Fullness	0	Dark brown and full intestine and stomach
	1	Intestine or stomach (only 1) fullness not clear
	2	Intestine and stomach fullness not clear or 1 full and 1 empty
	3	Intestine and stomach are clearly empty
Gills	0	Healthy appearance, no changes and white
	1	Focal lesion or colour change on 1 side
	2	Focal lesion on both sides
	3	Multiple lesions. Pale, general redness or darkening, erosion (even 1 very bad gill is enough)
Legs	0	Healthy appearance, no changes and no injuries
	1	Focal lesion or darkening (1 per side) or two total
	2	Some lesions or darkening (2 per sides) or 4 total
	3	Generalised lesions or darkenings (more than 4 modifications)
Uropods	0	Uniform shape setae clear and visible
	1	Local deformities or missing setae
	2	Small damage to at uropod level, or bad setae condition
	3	Multiple uropod damages or general relevant damage

standardisation bodies as a tool to support the assessment of shrimp farms worldwide. Finally, this index can be integrated into scientific experiments to complement analysis in studies on nutrition, stress or other aquaculture innovations.

Practical application and informative value of morphological indices

Morphological indices in aquaculture

Operational welfare indicators (OWIs) based on external appearance are not unique to Whiteleg shrimp and have already been developed and applied in several aquaculture species, including Atlantic salmon, rainbow trout, lumpfish, and common carp[10,11,12,13]. These welfare assessment tools differ in the number of indicators they include and in the methods used to score them.

Changes in body condition, such as deformities, injuries, or lesions, can indicate poor welfare because they may be linked to stress, pain, or discomfort. However, the relationship between these visible signs and physiological stress responses is not always straight forward. One of the main challenges of morphology-based assessments is observer variability, as different people may score the same animal differently. Other factors, such as farming conditions, environmental variation, the timing of injuries, and differences in healing rates, can also influence the results.

These challenges are even greater in crustaceans, whose welfare biology is less well understood than that of finfish. In shrimp, moulting is a particularly important process because it affects tissue repair and the regeneration of damaged appendages. However, accurately determining moult stage requires specialised equipment, such as a stereomicroscope, and is not practical during routine harvest assessments.

Despite these limitations, evidence from aquaculture species suggests that morphological indicators can provide meaningful information about animal welfare. For example, Weirup et al. (2022)[13] found that fin damage in rainbow trout was associated with elevated plasma cortisol levels, while Zhang et al. (2023)[14] showed that changes in shrimp hepatopancreas appearance were related to both the presence and load of *Vibrio parahaemolyticus*. These studies highlight the potential of morphology-based indicators as rapid and practical welfare assessment tools.

A comparable approach is used in Atlantic salmon farming, where gill condition is first evaluated through visual scoring and, when abnormalities are detected, followed by more detailed diagnostic analyses such as light microscopy, histopathology, and PCR. For shrimp, an important remaining challenge is determining how much damage to fragile structures, such as antennae and other appendages, can be considered acceptable before welfare is compromised. One possible solution is to focus on functional impairment rather than minor structural damage, allowing welfare assessments to distinguish between cosmetic abnormalities and changes that are likely to affect the animal's well-being.

Data from farm observations

Across three studies conducted at commercial shrimp farms, a total of 129 shrimp weighing between 10 and 25 g were assessed. Antennae damage was the most common finding, affecting more than 95% of individuals, with over half of the shrimp showing severe damage.

Shrimp reared in the biofloc system generally exhibited better eye condition than those from the other farms. Approximately 50% of shrimp in the biofloc system showed some degree of eye damage, but no severe cases were observed. In contrast, around 80% of shrimp from the other farms displayed eye damage, including 5% with severe symptoms. Nutritional deficiencies may contribute to these differences and could potentially offset by the ingestion of flocs in biofloc systems. However, no scientific evidence currently exists to support this hypothesis.

Damage to the rostrum and telson was also common, affecting more than 50% of shrimp, although only about 5% of cases were classified as severe. One farm recorded a higher prevalence of exoskeleton damage, mainly associated with contact with enrichment structures. In the other two farms, exoskeleton damage was observed in roughly 30% of shrimp and was limited to mild impairments.

Assessment of the digestive tract showed that approximately 30% of shrimp had partially empty stomachs or intestines. In contrast, muscle condition was generally good, with fewer than 5% of shrimp exhibiting any signs of muscular damage.

Leg damage was consistently observed across all three farms, affecting around 70% of shrimp, with approximately 10% showing severe impairment. Evaluation of the uropods was more challenging because of the high variability among individuals. Overall, about half of the shrimp displayed some degree of uropod damage, while severe damage was relatively uncommon and observed in fewer than 10% of cases.

Nevertheless, data from wild individuals or from capture fisheries are missing to support further conclusions.

Considerations of importance of each body part

As discussed earlier, morphological damage is commonly observed in shrimp appendages, including antennae, uropods, legs, and body margins such as the rostrum and telson. Moderate levels of damage to these structures may be considered acceptable under commercial farming conditions. However, the presence of severe impairments should not be overlooked, as they have been directly associated with reduced growth and survival[13]. Similarly, mild eye lesions are relatively common, but more severe damage deserves particular attention because the eyes are essential sensory organs and play an important role in hormonal regulation.

Structures involved in critical biological functions require especially careful assessment. This includes organs associated with digestion and respiration, which are often affected during disease outbreaks. For example, gill discoloration may be an indicator of Black Gill Disease, while abnormalities in the hepatopancreas are frequently associated with Acute Hepatopancreatic Necrosis Disease. Muscular and exoskeletal alterations, including muscle necrosis, melanosis, and encrustations, have also been reported in shrimp affected by Taura Syndrome, White Tail Disease, and White Spot Syndrome[6].

Despite these observations, the available evidence remains limited and sometimes inconsistent. Attempts to assign different levels of importance to specific impairments should therefore be approached with caution, as the lack of objective and standardized evaluation criteria may lead to misinterpretation and criticism. Consequently, this section should be regarded as a interim state and work in progress.

Further data from both controlled laboratory studies and commercial farming operations are needed to improve the understanding of the welfare significance of different impairments. Input from industry stakeholders will be particularly valuable in this process. The collection and sharing of welfare assessment data, together with key water quality and management parameters, could help identify robust patterns and support the development of more reliable welfare assessment tools for shrimp farming.

Results from the CrustaWohl project

As part of the CrustaWohl project, carried out by the Alfred Wegener Institute, Helmholtz Centre for Polar and Marine Research (AWI) and IGB and funded by the German Federal Environmental Foundation (DBU), three laboratory-scale experiments were conducted to evaluate how different stressors affect the welfare of *L. vannamei.* The studies examined the effects of crowding, elevated nitrate concentrations, and magnesium deficiency on both physiological stress responses and operational welfare indicators (OWIs). Overall, crowding produced the clearest and most consistent stress response, whereas the effects of nitrate and magnesium deficiency were weaker and depended on the intensity of the stressor [9,15,16].

Among the physiological measures tested, gene expression analysis proved to be more sensitive than conventional biochemical assays. In particular, heat shock proteins 70 and 90 (HSP70 and HSP90), glutathione peroxidase (GPx), and, to a lesser extent, lysozyme (Lys), emerged as promising molecular indicators of stress.

In the crowding experiment, the expression levels of GPx, HSP70, and Lys were positively associated with uropod damage. HSP70 expression was also positively correlated with antennae damage and with the overall welfare score derived from a simplified version of the morphological index presented in this *IGB Manual.* Similar patterns were observed under commercial farming conditions. At the farm scale, GPx expression showed a significant positive correlation with both uropod damage and the overall morphological index score. In addition, HSP70 expression was negatively correlated with leg condition, while HSP90 expression was negatively correlated with stomach and intestinal fullness.

Taken together, these results suggest that molecular stress markers and morphological welfare indicators may be linked and could provide complementary information about shrimp condition and welfare. However, the relationships identified so far should be considered preliminary. Further research involving additional molecular markers, larger sample sizes, and a wider range of farming conditions will be necessary to strengthen these findings and improve the robustness of the analysis.

Economic considerations

From both a biological and commercial perspective, shrimp raised under optimal conditions and supported by regular monitoring are more likely to achieve higher production performance. Better survival rates, faster growth, and improved overall condition can increase yields and shorten production cycles. Consistent monitoring also helps farmers identify and address problems early, leading to more stable production and more efficient use of feed, materials, labor, and other resources.

Shrimp with good external condition and minimal physical damage can often be sold as whole fresh products directly to restaurants, local retailers, or consumers. This reduces the need for additional processing steps, such as peeling, and lowers associated costs for equipment, labor, and processing time. As a result, maintaining good shrimp condition can provide direct economic benefits throughout the production chain.

At the same time, the aquaculture industry is increasingly adopting certification schemes and sustainability standards. Products certified under these schemes can benefit from greater market recognition and increased value, reflecting growing consumer interest in responsibly and sustainably produced seafood.

Outlook

As outlined in this *IGB Manual,* sustainable shrimp aquaculture adequately adressing animal welfare remains a complex task. The conclusions drawn and practical welfare indicators developed are intended to provide a foundation for their own continued development, contributing to improved shrimp welfare, stronger farm performance, and more evidence-based consumer confidence in shrimp aquaculture.

	Date	Operator	SENSORY SYSTEM		MUSCULOSKELETAL SYSTEM			DIGESTIVE SYSTEM		RESPIRATORY SYSTEM	APPENDICES	
Shrimp ID	Weight (g)	Length (cm)	Antennas (0-1-2-3)	Eyes (0-1-2-3)	Rostrum/ Telson (0-1-2-3)	Exoskeleton (0-1-2-3)	Musculature (0-1-2-3)	Hepato-pancreas (0-1-2-3)	Intestine/ stomach fullness (0-1-2-3)	Gills (0-1-2-3)	Legs (0-1-2-3)	Uropods (0-1-2-3)
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	Water parameters	Ammonia (mg/L NH_3-N)	Nitrites (mg/L NO_2-N)	Nitrates (mg/L NO_3-N)	Oxygen (% saturation)	pH	Salinity (ppt)	Temperature (° C)	Alkalinity (mg/L $CaCO_3$)	CO_2 (mg/L)	Stocking density (kg/m²)	

Table 3. Template of morphological shrimp index

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