WHITELEG SHRIMP CORPORATE ASK

INTRODUCTION

Approximately 6.3 million tons of whiteleg shrimp (*Penaeus vannamei*) are farmed per year (FAO, 2023), which is estimated to equate to between 300 and 620 billion individuals (Romero & Autric, 2022), making it the most farmed animal globally in terms of number of individuals (Romero & Autric, 2022). Furthermore, global production volumes have grown rapidly and steadily at an average of 300,000 tons per year over the last 2 decades (FAO, 2023). The major producing countries are China, India, Vietnam, Indonesia, and Ecuador, as well as other southeast Asian and central American countries (EUMOFA, 2023; FAO 2009). The main import markets for shrimp are China, USA, Europe, and Japan (Globefish 2023).

Whiteleg shrimp are adaptable to a wide range of salinities and tolerant of low dissolved oxygen levels, which makes them well-suited to aquaculture production from a commercial perspective. And given that they are opportunistic omnivores, well adapted to extensive and semi-intensive farming conditions, they have the potential to be produced by sustainable farming methods. However, shrimp are sentient beings capable of feeling pain and suffering, and their welfare should be protected in farming systems. Shrimp must be provided with a good quality of life in a farmed environment, and they should be humanely slaughtered by being effectively stunned, rendered insensible, and remaining unconscious until death supervenes.

This document summarises research relevant to whiteleg shrimp as a basis for our recommendations and Corporate Asks to improve shrimp welfare. This document will be divided into sections focussing on the following areas: stocking density, water quality, eyestalk ablation, feeding, and humane slaughter. Shrimp farming is practised in a variety of farming systems including ponds, tanks, and raceways, at varying levels of intensity with varying water treatment practices (FAO, 2009). The following recommendations will be applicable to all whiteleg shrimp farming contexts, regardless of the type of culture unit or water management used.

CIWF Corporate Asks for Whiteleg shrimp

Humane Slaughter

They must be killed instantaneously, or effectively stunned, rendered instantaneously insensible, and remain unconscious until death supervenes.

- A single method that both stuns and kills is recommended above other methods when it is commercially available.
- Electrical stunning is recommended followed by immersion in ice slurry.
- The use of ice slurry without previous stunning, and asphyxia, are unacceptable methods. Live selling and live cooking are also unacceptable practices.

Stocking Density

A maximum stocking density should be established to ensure that whiteleg shrimp are given adequate space to meet their physiological and behavioural needs.

- The maximum stocking density should be 30 individuals and 750g of shrimp per m^2 for farming systems that provide aeration. For systems that do not provide aeration, the maximum stocking density should be 10 individuals and 250g of shrimp per m^2.
- Stocking density for an enclosure/system should be reviewed between cycles based on performance, environmental and behavioural factors.
- Additional surface area in the form of structures such as porous fabric or mosquito mesh should be provided within culture units.

Feed and Feeding

Feeding for whiteleg shrimp should be adequate to meet their behavioural and nutritional needs. Farming methods with natural productivity are recommended.

- Avoid the use of formulated feeds, instead promoting natural productivity where this is possible.
- If formulated feeds are used, eliminate dietary Fish Meal and Fish Oil (FMFO) from wild-caught fish, and/or reduce any FMFO content via substitution for appropriate alternative ingredients, avoiding the use of ingredients edible to humans.
- Feed needs to be nutritious and of adequate quality for shrimp size and life stage, and the feeding system should ensure that all individuals have access to the feed.

Eyestalk Ablation or Mutilation

Ban the eyestalk ablation of the broodstock.

- Source exclusively from hatcheries that do not practice eyestalk ablation.
- Source from breeding programs that achieve high welfare larval production.

Water Quality

Water quality parameters should be maintained within thresholds for the shrimp to thrive, experiencing good health and wellbeing.

- Parameters should be monitored regularly with sufficient frequency to enable effective management. Dissolved oxygen, temperature, and pH should be measured at frequent intervals throughout the day, or continuously where possible. Ammonia, nitrite, salinity, and hardness should be measured at least once a day.
- Dissolved oxygen should be maintained at >5mg/l. Other parameter reference values can be found in Table 2.

SENTIENCE AND WELFARE PROTECTION

There is a body of supporting evidence for sentience in decapod crustaceans. Specific observations include the presence of nociceptors and a central nervous system capable of feeling pain, (reviewed by Elwood & Patterson, 2009), reduced pain response with analgesics (Lozada *et al*., 1988), a high level of cognitive ability (Boles & Lohmann, 2003; Elwood & Stewart, 1985), avoidance learning (Fernandez-Duque *et al*., 1992), pain-induced physiological changes (Elwood & Adams, 2015), protective motor reactions (Barr *et al*., 2008) and motivational trade-offs between pain avoidance and needs (Appel & Elwood 2009). Unfortunately, none of this research is specific to penaeid shrimps. However, Taylor *et al*. (2004) observed that the use of a topical anaesthetic prior to eyestalk ablation served to reduce the behavioural stress response to the procedure in whiteleg shrimp.

Despite the relative lack of evidence for sentience in penaeid shrimp specifically, which indicates a need for further research, it is reasonable to assume that they are similarly sentient to closely related decapod species. Indeed, reviews of the research to date have found that no evidence exists to suggest that penaeid shrimp fail to meet the criteria for sentience. (Birch *et al*., 2021; Crump *et al*., 2022)

The sheer numbers involved, as well as the prevalence of live transport, handling, and cooking, highlights the need for a precautionary approach with a mind to minimize potentially enormous levels of unnecessary suffering. Although crustacean welfare is not currently regulated by the European Union (EC 1099/2009), the European Food Safety Authority acknowledges that they feel pain and recommends that their welfare should be protected (EFSA, 2005). Indeed, movement toward the inclusion of crustaceans in animal welfare protection policies is widespread. Prominent examples include Norway, Switzerland, New Zealand (Smith *et al*., 2013), United Kingdom, and Australia (Johnston & Jungalwalla, 2005).

STOCKING DENSITY

Stocking density refers to the number or biomass of farmed animals per unit of available space within an enclosure. The concept of a minimum rearing space for aquatic animals is more complex than for terrestrial species as they occupy a three-dimensional medium (Ellis *et al.* 2002, Conte, 2004), and biomass is relatively difficult to estimate accurately. Additionally, stocking density is constantly changing as the animals grow. Nonetheless, stocking density is a critical parameter in the rearing of any aquatic species.

Stocking densities used throughout the global shrimp farming industry vary greatly according to farming system and region. Shrimp farming systems are normally categorised as extensive, semi-intensive, intensive, and super-intensive depending on stocking density among other characteristics such as feed use and water treatment. Typical reported stocking densities according to farming system vary between sources, with <5-10 individuals/m^2 being reported as typical for extensive systems, 5-30 for semi-intensive systems, 20-300 for intensive systems, and 100-450 for super-intensive systems (Boyd & Jescovitch, 2020; FAO 2009).

Stocking density in whiteleg shrimp

As shrimp are a benthic species, they primarily occupy space on and near the ground and submerged surfaces, where they spend time foraging or resting, as opposed to swimming, or being in suspension within the water column, as is the case for many species of finfish. It is therefore practical and commonplace to express shrimp stocking density as individuals/m^2.

Our recommendations assume a minimum depth of 1m within the culture units, and a maximum final weight of 25g.

Multiple environmental parameters with welfare implications are influenced by stocking density, including dissolved oxygen, nitrogenous waste, organic carbon, turbidity, and pH. Stocking density is also, however, a critical welfare parameter in and of itself, i.e. assuming all water quality parameters are optimum, stocking density must still be within a certain threshold to ensure good welfare.

Survival and growth rates are key welfare indicators, and reductions in both due to increased stocking densities have been observed in multiple studies (Arambul-Muñoz *et al.*, 2019; Araneda *et al.*, 2008; Bayot *et al.*, 2015; Esparza-Leal *et al.*, 2010; Kotiya & Vadher, 2021; Krummenauer *et al.*, 2010; Krummenauer *et al.*, 2011; Neal *et al.*, 2010; Otoshi *et al.* 2007; Roy *et al.*, 2020; Samadan, 2018). The data from these studies is summarised below in Table 1.

The causal factors behind increased mortality and reduced growth rate at higher stocking densities are likely to be multiple and interrelated. High stocking densities negatively affect water quality, however, immune system function and digestive efficiency have also been shown to be compromised at higher stocking densities (Apún-Molina *et al.* 2017; Yuan *et al.* 2023; Liu *et al.* 2017). This is likely to indicate that energy normally allocated towards digestion, immune function and growth, is allocated towards stress response and altered behaviour at high stocking densities, probably induced by the increased proximity between individuals. Indeed, Otoshi *et al.* (2007), reported that the reason behind reduced growth rates at high stocking densities in their experiment was related to behavioural alterations, although the authors were not specific regarding these. A shift in behavioural states from foraging behaviours associated with positive welfare to increased locomotion, indicating a negative impact on welfare has also been observed by da Costa *et al.* (2016) at densities over 50 individuals/m^2.

Increased mortality can be explained by compromised health status due to a weakened immune system. It can also be the result of cannibalism, where weaker shrimp and shrimp with soft shells due to moulting are more likely to be cannibalized (Schroeder *et al.*, 2010; Wu *et al.*, 2001).

Most major certification schemes primarily focussed on sustainability do not stipulate specific maximum stocking densities (Aquaculture Stewardship Council, 2023; Best Aquaculture Practices, 2023; Friend of the Sea, 2016; Global GAP, 2023). However, Naturland Organic standard sets maximum stocking density at 15 individuals/m^2, and a final biomass of 1,600kg/hectare (160g/m^2) (Naturland, 2023). Soil Association Organic sets its maximum stocking density in line with the European Commission on organic standards, at 22 individuals/m^2, and 240g/m^2 final biomass (European Commission, 2008; Soil Association, 2023). It is important to note that the limits in both of these standards apply not only to whiteleg shrimp, but to all penaeid shrimps and freshwater prawns (*Macrobrachium* spp.), the latter of which are considered an aggressive territorial species which exhibit higher density induced mortality than whiteleg shrimp (Negrini *et al.*, 2017). The FAI Farms animal agriculture consultancy group establishes a welfare protocol for farmed whiteleg shrimp, which recommends the upper limit for stocking density at 40 individuals/m^2 (Pedrazzani *et al.*, 2023). The NGO Shrimp Welfare Project, founded for the purpose of improving the welfare of farmed shrimp, recommends a stocking density of 6 – 15 individuals/m^2 (Lewit-Mendes & Boddy, 2022).

The stocking density upper limits set by both the above cited organic standards specify limits to biomass as well as numbers of individuals/m^2, which presuppose final average weights of 10.7g and 10.9g for Naturland and Soil association/European Commission respectively. These final weight figures are at the lower end of typical harvest sizes, with the largest sizes being approximately 25g (FAO, 2009). When comparing experiments cited above, the best survival rate achieved (Kotiya & Vadher, 2021) was in an experiment in which shrimp were grown at a stocking density of 30 individuals/m^2, to an average size of 26.1g. A very similar survival rate was achieved in another experiment in which shrimp were stocked at 100 individuals/m^2 but were only grown to 12.93g (Samadan, 2018). Despite the similar survival rates, the higher growth rate in the former compared to the latter experiment, of 0.22g/day compared to 0.15g/day, is likely to indicate better welfare. When comparing these two studies, it should be noted that the biomass was higher in the latter (1293 g/m^2) than the former (783 g/m^2), which explains the difference in growth rates.

It is clear upon comparing the experimental data reviewed (Table 1) that a consistent trend can be observed within each experiment towards higher mortality at higher stocking densities. Where the best survival rate, and good growth rates were achieved (Kotiya & Vadher, 2021) paddle wheels were used to ensure oxygenation. The use of oxygenation machinery also ensured a good survival rate in the experiment by Samadan (2018). In ponds with no aeration equipment, a relatively low daily mortality rate of 0.06% was achieved at a stocking density of 10 individuals/m^2, where an increase to 25 individuals/m^2 led to a 78% increase in daily mortality (Krummenauer *et al.,* 2010).

Table 1: Summary of the references that included mortality and stocking density used in this review. Stocking density and mortality were calculated from the published data for some references to allow for comparison.

Reference	Stocking density (individuals/m^2)	Mortality (%/day)	System
Arambul-Muñoz *et al.*, 2019	100	0.069	Intensive photo-heterotrophic tank system.
	300	0.088	
	500	0.265	
	700	0.35	
	900	0.452	
Araneda *et al.*, 2008	90	0.114	RAS
	130	0.148	
	180	0.162	
Bayot *et al.*, 2014	3	0.124	Earthen ponds
	6	0.119	
	9	0.164	
	12	0.265	
Esparza-Leal *et al.*, 2010	50	0.149	RAS
	100	0.149	
	150	0.201	
	200	0.196	
Kotiya & Vadher, 2021	30	0.04	Earthen ponds
	40	0.06	
	50	0.076	
	60	0.084	
	70	0.123	
	80	0.153	

Krummenauer *et al.*, 2010*	10	0.093^{ES}	0.08^{LS}	0.06^{L}	Earthen ponds
	25	0.187^{ES}	0.12^{LS}	0.107^{L}	
	40	0.24^{ES}	0.28^{LS}	0.133^{L}	
Krummenauer *et al.*, 2011	150		0.067		Biofloc
	300		0.157		
	450		0.208		
Neal *et al.*, 2010	182		0.121		Biofloc
	364		0.206		
Otoshi *et al.*, 2007	200		0.222		Biofloc
	400		0.310		
Roy *et al.*, 2020	29		0.242		Flow through tank system
	88		0.323		
	176		0.609		
	264		0.729		
Samadan, 2018	100		0.047		Ponds with sand and liner
	200		0.22		
	300		0.467		

*Krummenauer *et al*., (2010) obtained results from three different production cycles (early short-ES, late short-LS, and long-L), hence three figures for daily mortality at each density.

It is unclear how stocking densities of less than 10 individuals/m^2 would have influenced survival in the study by Krummenauer *et al*. (2010), however, in another study that tested lower stocking densities the best survival was achieved at 6 individuals/m^2, where a density of 3 individuals/m^2 yielded similar results, while densities of 9 and 12 individuals/m^2 led to slightly worse and significantly worse survival rates respectively (Bayot *et al*., 2014). The authors of this study speculate that depleted oxygen levels may have been responsible for the density correlated mortality. Indeed, during the earlier part of the experiment, when oxygen levels were within better thresholds, there was no difference in mortality between the 4 densities tested, while oxygen levels within the highest density pond were significantly lower than the other 3 densities for a prolonged period during the last 5 weeks of culture (Bayot *et al*., 2014). However, the oxygen levels that the shrimp stocked at 6 and at 9 individuals/m^2 were exposed to were the same conditions (Bayot *et al*., 2014), therefore oxygen does not explain the slightly higher mortality of the shrimp stocked at 9 individuals/m^2. Largely similar oxygen levels were observed in the study by Krummenauer *et al*. (2010), yet survival in this study, at similar and even at higher stocking densities, was significantly better.

Differences in the survival rates between these two studies may be attributable to other differences in the rearing conditions. Salinity level was different, reaching 42ppt in the study by Bayot *et al*. (2014), and ranging from 4ppt to 16ppt in the study by Krummenauer *et al*. (2010). Another difference was enclosure type, with ponds of 400m^2 and 0.8m depth being used by Bayot *et al*. (2014), and bamboo and mesh netting pens of 20m^2 x 1.5m height situated within a 3.8ha earthen pond being used by Krummenauer *et al*. (2010). Finally, feeding protocol was different, whereby shrimp were fed according to a regime via manual distribution by Bayot *et al*. (2014), and according to consumption via feeding trays by Krummenauer *et al*. (2010). According to Bayot *et al*. (2014), shrimp may have congregated in certain areas and avoided others according to varying in-pond conditions in their study. It is possible that this, along with the practice of feeding via manual distribution, could have led to density dependent competition for food resources, negatively influencing survival. The practice of feeding according to consumption, along with relatively high FCRs in the experiment by Krummenauer *et al*. (2010) suggests that feed availability was not limiting in this study. Krummenauer *et al*. (2010) also speculate that the additional surface area provided by the fences of the pens in their study may have positively influenced survival.

The contrasting results between the two studies described above highlight the need to select stocking density carefully, and in accordance with environmental conditions and culture methods used, and for the decision to be informed by the survival rates experienced in previous culture cycles. Overall mortality should be less than 10% per cycle (Pedrazzani *et al*., 2023; Krummenauer *et al*., 2010; Kotiya & Vadher, 2021), with higher mortality indicating a need to reduce stocking density or improve farming practices.

Careful attention needs to be paid to decisions regarding stocking density and feeding practice in order to meet the balance between good FCR and the avoidance of competition for food resources. Also, in a study on feeding and behavioural interactions of whiteleg shrimp by Bardera *et al*. (2021) at stocking densities of 6.2, 12.4, and 24.8 individuals/m^2, higher stocking densities were found to increase feed intake, while lower stocking densities were found to increase hierarchical behavioural interactions. This suggests that, where both culture conditions and food availability are optimum, reducing stocking density doesn't necessarily ensure better welfare as it may lead to increased aggression.

From the evidence reviewed (Table 1), it appears that at stocking densities higher than 30 individuals/m^2 density induced mortality occurs, but at 30 individuals/m^2, with the use of aeration equipment, good survival and growth rates which likely indicate positive welfare can be achieved up to final weights of 26g (Kotiya & Vadher, 2021). In the absence of aeration, low oxygen levels will limit the survival and welfare of shrimp when stocked beyond a given density, depending on the various other interdependent environmental conditions within the pond (Bayot *et al*., 2014; Krummenauer *et al*., 2010). In favourable circumstances, good survival and growth, indicative of good welfare, can be achieved at a stocking density of 10 individuals/m^2 up to final weights of approximately 15g or more (Krummenauer *et al*., 2010). Although the shrimp were only grown to approximately 15g in this experiment, it is unlikely that reaching average individual weights of 25g, and a combined biomass of 250g, would have negatively influenced survival, as the culture conditions in this experiment supported a biomass of 422.72g at the stocking density treatment of 40 individuals/m^2 (Krummenauer *et al*., 2010), and it is known that larger numbers of smaller shrimp consume more oxygen than smaller numbers of larger shrimp with the same biomass (Subrahmanyam, 1962).

Aside from the observations made by Krummenauer *et al*. (2010), there is further evidence that the provision of additional surface area can reduce the negative impact of stress related to high stocking densities (Schveitzer *et al*., 2013; Zhang *et al*., 2010). Schveitzer *et al*. (2013) used plastic mesh screens (mosquito screens) to effectively double the available surface area and found that survival rate increased from 42.5% to 93.9%, and growth improved, resulting in 314% higher final biomass. Zhang *et al.* (2010) used suspended fabric screens to increase available surface area and also observed improved survival and growth rates, averaging 81% and 0.12g/day across treatments with additional surface area compared to 54% and 0.06g/day in the control group. These studies used densities of 238, 473 and 510 individuals/m^2; densities far higher than those appropriate for shrimp welfare. Nonetheless, they clearly demonstrate the benefits of using structural enrichment for shrimp.

RECOMMENDATION ON STOCKING DENSITY

Compassion recommends that whiteleg shrimp are given adequate space to meet their physiological and behavioural needs, and that all individuals have access to adequate food and be able to avoid competition with other individuals. For systems that provide aeration, the maximum stocking density should be 30 individuals/m^2 (with a maximum biomass of 750g/m^2). For systems that do not provide aeration, the maximum stocking density should be 10 individuals/m^2 (with a maximum biomass of 250g/m^2).

Given the evidence that very low stocking densities can lead to reduced feeding and increased dominant-subordinate behavioural interactions, behaviour should be closely observed, and stocking density adjusted in order to limit such effects. Environmental factors should be regularly monitored across the enclosure and should inform the stocking densities selected. Poor welfare can occur at any given stocking density, and decisions regarding stocking density should be informed by close observation of behavioural and environmental conditions.

Given its positive impact on welfare, additional surface area in the form of structures such as porous fabric or mosquito mesh should be provided within culture units.

Research on stocking density for whiteleg shrimp is scarce and in general is not related to welfare. While there are a few indications that can guide our recommendation on maximum stocking density for whiteleg shrimp, there is insufficient information to determine a minimum stocking density. More research is needed in this area, and our recommendations will be reviewed when more information becomes available.

WATER QUALITY

One of the main concerns regarding stocking density is that a high density can lead to rapid deterioration of water quality. Poor water quality conditions, such as low oxygen or high ammonia, as well as rapid fluctuations of conditions such as water temperature or salinity are stressful for shrimp and have a negative impact on their health and immune function, increasing their susceptibility to disease. Many water quality parameters are directly interdependent in terms of the combined impact they have on health and welfare. For example, pH is affected by the concentration of CO_2, oxygen levels are dependent on temperature, and ammonia toxicity is dependent on both pH and temperature.

When shrimp are kept in poor quality water, factors can compound leading very rapidly to major problems. For example, the stress response to high concentrations of CO_2 (Furtado *et al.*, 2016) and of ammonia (Racotta & Hernández-Herrera, 2000) involves an increase in oxygen consumption, which can lead to hypoxic conditions. Hypoxic conditions impair the immune system and increase susceptibility to disease (Burgents *et al.*, 2005; Han *et al.*, 2017; Hu & Jing, 2009). Disease induced mortality, and the increased presence of dead and decaying shrimp leads to the further increase of ammonia and CO_2, and reduction in oxygen due to increased bacterial respiration (Jurtshuk, 1996), thus compounding the issue of poor water quality. Although whiteleg shrimp may be known for their ability to adapt to and endure a fairly wide range of environmental conditions, it is crucial to ensure that water quality parameters are kept within the optimum thresholds for the welfare of the animals.

Whiteleg shrimp are native to coastal areas where seawater temperatures remain above 20°C year-round (FAO, 2009). According to producers' published guidelines, the optimum temperature range for good growth and health is between 26°C and 32°C (Fonseca, 2021; Van Wyk & Scarpa, 1999).

Whiteleg shrimp are adaptable to a wide range of salinities, from 0.5ppt to full-strength seawater (35ppt) (Van Wyk & Scarpa, 1999), and even up to 40.9ppt (Pedrazzani *et al.*, 2023). This adaptability reflects their natural migratory life cycle which involves hatching in the open sea, migrating to coastal or estuarine habitats as juveniles, and returning to the sea as mature adults to spawn (FAO, 2009). Indeed, the ability to adapt to low salinity conditions is stronger at the juvenile rather than the larval stages (Laramore *et al.*, 2001). Nevertheless, at very low salinities (3ppt) susceptibility to ammonia toxicity, respiratory rate and energy spent on osmoregulation can increase significantly (Li *et al.*, 2007). Ye *et al.*, (2023) demonstrates that adaptability to low-salinity conditions is a genetically heritable trait.

According to the published production guidelines, optimum salinity is between 10 and 35 ppt (Fonseca, 2021; Pedrazzani *et al.*, 2023; Van Wyk & Scarpa, 1999; Venkateswarlu *et al.*, 2019). If shrimp are to be cultured at salinities below 10ppt, or where salinity is likely to drop below 10ppt, where possible, the shrimp used should be known to be of a lineage which performs well at low salinity. For example, it has been suggested that the Ecuadorian, as opposed to the Mexican, strain is well-adapted to low salinity conditions (Bray *et al.*, 1994).

It is possible to adapt young shrimp to low salinity water when they have previously been cultured in saline water. It is a delicate process with welfare risks to the animals, and must therefore be done with great care and according to a strict protocol. The process must be very gradual, taking place over the course of at least 100 hours (Esparza-Leal *et al.*, 2010). The procedure should not be performed until shrimp are at least 10 days past the final larval transformation (PL10) (McGraw *et al.*, 2002).

Dissolved oxygen should be maintained at 5.0 mg/l or above (Fonseca, 2021; Rojas, 2005; Van Wyk & Scarpa, 1999). pH is of particular concern to shrimp as the chemical structure of their exoskeleton is largely made up of calcium carbonate which is subject to dissolution at low pH. Reduced growth and moulting frequency have been observed in shrimp as a result of lowered pH induced by carbon dioxide (Wickins, 1984). Different authors agree that the pH should be kept within the range 7 – 8.5 (Fonseca, 2021; Pedrazzani *et al.*, 2023; Van Wyk & Scarpa, 1999; Venkateswarlu *et al.*, 2019). It is important to ensure that the respiration of excessive biomass and/or algal growth does not drive down pH. If this is the case, aeration should be applied at the end of the dark or at the beginning of the light phase. It is important that water of sufficient alkalinity ($CaCO_3$) is used to buffer against pH fluctuations. The chemical composition of seawater is such that pH is unlikely to fluctuate outside of the optimum range unless there is an excessive bio-load. In fresh or brackish water conditions however, alkalinity/hardness (CaCO3) should be at least 100ppm (Fonseca, 2021; Pedrazzani *et al.*, 2023; Van Wyk & Scarpa, 1999; Venkateswarlu *et al.*, 2019).

Ammonia toxicity is highly dependent on pH. Ammonia takes two forms in water; ionized, which is non-toxic, and unionized, which is toxic, with the relative proportions of each form being highly pH dependent, and to a lesser extent temperature dependent. The higher the pH, the greater the proportion of unionized ammonia (Thurston *et al.*, 1981). Long-term exposure to concentrations of unionized ammonia above 0.03ppm negatively affect growth and health (Van Wyk & Scarpa, 1999) and therefore welfare. Under normal circumstances, 0.1ppm of total ammonia (TAN) is an appropriate upper limit. However, in exceptional circumstances where pH exceeds 8.6, calculation must be made (see table 2 below) to ensure unionised ammonia levels are below 0.03ppm.

There is significant variation regarding the upper limit for nitrite concentration among published guidelines, which ranges from 0.4 to 1.36 ppm (Fonseca, 2021; Venkateswarlu *et al.*, 2019; Pedrazzani *et al.*, 2023; Van Wyk & Scarpa, 1999; Gross *et al.*, 2004). Given that nitrite toxicity to whiteleg shrimp is inversely correlated with salinity (Lin & Chen 2003), it is appropriate to establish upper limits according to salinity. Gross *et al.*, (2004) recommends an upper limit of 0.4ppm at 2ppt, while Valencia-Castañeda *et al.* (2019) recommends upper limits of 0.56ppm at 3ppt salinity, and Van Wyk & Scarpa (1999) recommends an over-all upper limit of 1ppm. The upper limit for nitrite (ppm) should therefore be calculated as 0.02 x salinity + 0.36.

Nitrate is toxic to shrimp and its toxicity is also inversely correlated to salinity (Kuhn *et al.*, 2010). There is some discrepancy regarding safe culture levels. Various studies at different levels of salinity propose safe upper limits for nitrate of 177ppm at 23ppt salinity (Furtado *et al.*, 2015), 127.61ppm at 10ppt salinity, 60.05ppm at 5ppt salinity (Alves *et al.*, 2019) and 45ppm at 3ppt salinity (Valencia-Castañeda *et al.*, 2019). One apparently anomalous study found that long-term exposure to levels of 220ppm had no negative survival, growth, or physiological impacts on whiteleg shrimp at 11ppt salinity, suggesting greater tolerance than other authors (Kuhn *et al.*, 2010). Despite this finding, a precautionary approach should be adopted, whereby the upper limit for nitrate (ppm) is calculated as 6.5 x salinity + 25.5.

Valencia-Castañeda *et al.* (2019) showed how the toxicity effects of TAN, nitrite and nitrate are additive, and therefore thresholds should not be considered in isolation, but in combination. Therefore, the concentration of each of these compounds should be calculated as a percentage of the upper safe limit, and the sum of the three percentages should equal less than 100.

In shrimp ponds, toxic hydrogen sulphide can be released by bacteria found in the sediment under low oxygen conditions (Ritvo *et al.*, 2000). The upper recommended limit for hydrogen sulphide is 0.001-0.002ppm (Fonseca, 2021; Van Wyk & Scarpa, 1999). Shrimp should not be reared in water containing heavy metals exceeding the thresholds detailed below (Table 2), individually or in combination (Frías-Espericueta *et al.*, 2008).

Example on nitrogen products thresholds calculation

At 8ppt salinity, the upper safe limit of TAN is 0.1ppm, that of nitrite is 0.52ppm (0.02x8+0.36), and that of nitrate is 77.7ppm (6.5x8+25.5).

Therefore, if TAN, nitrite, and nitrate levels were to measure 0.03ppm, 0.2ppm, and 20ppm, the combined levels would be within safe limits, as they equate to 30%, 38.5%, and 26% of their respective upper limits, totalling 94.5% in combination. However, if nitrate were to measure 30ppm rather than 20ppm, it would equate to 38.5% of its upper limit, and the combined levels would total to 107%. In this case, despite each level being within its safe individual limit for the given salinity, in combination, they surpass the combined safe upper limit.

Moulting

The moult state needs to be monitored closely by observing a sample of shrimp in each culture unit. The timing and regulation of moulting is complex, and, while the underlying factor is the hormonally regulated growth cycle, a wide range of nutritional, water quality, and physiological stress conditions have been reported to increase moulting frequency, while exposure to certain pesticides and pharmaceuticals have been shown to halt the process (reviewed by Lemos & Weissman, 2021). While shrimp moulting in the farming context is not a fully synchronised event within populations, a degree of synchronicity appears to exist, i.e. shrimp of all stages of the moult cycle will be present within a given culture unit, yet mass-moulting events involving the majority of the population will occur (Lemos & Weissman, 2021). Mass-moulting events can be induced by relatively sharp increases in temperature, reductions in salinity, or rapid water exchange (Lemos & Weissman, 2021), and an influence is also thought to be exerted by the lunar phase, with the new moon being associated with mass moults of around 80% of the population (Bautista-Covarrubias *et al.*, 2020). Moulting is a stressful process for shrimp, with the potential for profoundly negative consequences for welfare if the success of the process is challenged by poor conditions, because the soft-shelled post-moult shrimp are highly vulnerable to predation and cannibalism, as well as osmotic imbalance and toxicity (Lemos & Weissman, 2021; Panakorn, 2018).

Table 2: *Recommended water quality parameters.*

Parameter	CIWF Recommended range	Notes	Source(s)
Dissolved oxygen (mg/l)	>5	Should be monitored at regular intervals daily, with particular attention to dawn, which is when levels will be at their lowest	Fonseca, 2021; Rojas, 2005; Van Wyk & Scarpa, 1999; Venkateswarlu *et al.*, 2019
Temperature (°C)	26 – 32	Na	Fonseca, 2021; Van Wyk & Scarpa, 1999
Salinity (ppt / psu)	0.5 – 40	If salinity is <10 low salinity adapted post-larvae should be stocked	Pedrazzani *et al.*, 2023; Van Wyk & Scarpa, 1999
pH	7 – 8.5	Should be monitored at dawn, which is when it will be lowest, and at dusk which is when it will be highest	Fonseca, 2021; Venkateswarlu *et al.*, 2019; Pedrazzani *et al.*, 2023; Van Wyk & Scarpa, 1999
Ammonia (ppm)	<0.1 (TAN) or <0.03 (unionized)	If temperature or pH are above upper recommended limits, upper limit for ammonia concentration must be adjusted accordingly. For reference see https://www.svl.net/unionized-amonia-calculator/	Fonseca, 2021; Pedrazzani *et al.*, 2023; Van Wyk & Scarpa, 1999
Nitrite (ppm)	<1 (in seawater)	0.02 x salinity + 0.36	Van Wyk & Scarpa, 1999, Gross *et al.*, 2004
Nitrate (ppm)	<250 (in seawater)	6.5 x salinity + 25.5	Fonseca, 2021; Kuhn *et al.*, 2010; Valencia-Castañeda *et al.*, 2019
Ammonia/ nitrite/ nitrate (% of combined upper limits)	<100%	The concentration of TAN, nitrite and nitrate must be calculated as a percentage of its upper limit, and the sum of all the percentages must be <100	Valencia-Castañeda *et al.*, 2019

Hardness (ppm)	>150	Na	Van Wyk & Scarpa, 1999
Alkalinity (ppm)	>100	Na	Pedrazzani *et al.*, 2023; Van Wyk & Scarpa, 1999
Hydrogen sulphide (ppm)	<0.002	Na	Fonseca, 2021
Iron (ppm)	≤1.0	The concentration of each heavy metal must be calculated as a percentage of its upper limit, and the sum of all the percentages must be <100	Van Wyk & Scarpa, 1999; Frías-Espericueta *et al.*, 2008
Chromium; Lead (ppm)	≤0.1		
Chlorine; Cadmium (ppm)	≤0.01		
Copper (ppm)	≤0.025		
Mercury; Zinc (ppm)	≤0.0001		

Oxygen consumption increases two-fold during the moulting process (Panakorn, 2018), from the late preparatory stage to the point at which the new shell has hardened, which accounts for approximately 6-9% of the entire moult cycle (Dall *et al.*, 1990). Sensitivity to ammonia and nitrite is also greater during moulting (Lemos & Weissman, 2021). It is therefore crucial, when significant moulting events are predicted, to ensure the minimum possible ammonia and nitrite concentration (by reducing feed – see below), and to supply as much aeration as possible.

Mineral content and balance is another critical factor for successful moulting; particular care must be taken when mass moulting events are predicted, especially in fresh water or in the case of significant rainfall, to ensure sufficient hardness and balanced mineral content. This should be addressed by the application of sodium bicarbonate and commercially available mineral mixes (Panakorn, 2018).

RECOMMENDATION ON WATER QUALITY

Given the importance of water quality for whiteleg shrimp, Compassion recommends the regular monitoring of water quality parameters (dissolved oxygen, temperature, pH, ammonia, nitrite, salinity and hardness) across different points of all culture units, using as reference the ranges summarised in Table 2.

The data gathered through monitoring, and the close observation of shrimp behaviour is crucial to understanding the relationship between water quality and shrimp welfare. The use of aeration equipment, typically paddle-wheels, is encouraged to ensure good oxygen levels.

If water quality parameters are found to be outside of the recommended thresholds, remedial action must be taken immediately. Increasing aeration and short-term reduction in feeding should be the first actions taken. If water quality issues persist, or if further aeration cannot be provided, further management steps should be taken such as increased water exchange or reduction of the biomass within the culture unit.

Special care should be taken when mass moult events are expected to occur to ensure that adequate environmental conditions are provided. This is primarily involves reducing feed, increasing aeration, and ensuring sufficient hardness /mineral content.

FEED AND FEEDING

In the wild shrimp are opportunistic omnivores, at the larval stages they begin feeding on microalgae and become increasingly carnivorous consuming zooplankton. Although there is a lack of detailed scientific data regarding the diets of whiteleg shrimp in the wild, Rothlisberg (1998) reviews that juveniles and adults eat a wide variety of macroinvertebrates (gastropods, bivalves, crustaceans, and polychaetes) and plant material. Van Wyk (1999) reports the dietary requirements for shrimp according to production performance in closed systems based entirely on artificial feeds (Table 3).

__Table 3:__ Recommended protein and lipid content (%) according to shrimp size (Van Wyk, 1999).

Shrimp size (g)	Protein	Lipid
0.002 – 0.25	50%	15%
0.25 – 1.0	45%	9%
1.0 – 3.0	40%	7.5%
<3.0	35%	6.5%

Vitamins D_3 and B_6 are of particular importance (Ayisi *et al.*, 2017), and should be present in the diet at 0.159mg/kg (6366IU x 0.025) and 151.92mg/k respectively (Li *et al.*, 2010; Wen *et al.*, 2015). Vitamins C and E should also be present in the diet at 90mg/kg and 99mg/kg respectively (He & Lawrence, 1993a; b). Vitamin requirements vary according to size, salinity, and farm system intensity (Van Wyk, 1999). The greater the contribution of natural productivity to the diet, the more likely vitamin requirements are to be met, while the more a system relies on manufactured feeds the more carefully fortified with vitamins the feeds will need to be (Van Wyk, 1999). Feed manufacturers normally overfortify feeds to ensure requirements are met, and if health problems arise which are indicative of a vitamin deficiency, a more "complete" feed, appropriate for the size of the shrimp, should be used (Van Wyk, 1999).

Calcium is of major significance to shrimp given its involvement in exoskeletal formation, and it is directly absorbed from the surrounding water (Li & Cheng, 2012). Seawater contains sufficient calcium levels for shrimp health, but freshwater sources may vary, as well as brackish water sources to a degree. Where water hardness is inadequate (see previous section on water quality), calcium will be lacking, and dietary supplementation is possible, however, dietary calcium inhibits dietary phosphorous uptake, and should not exceed 50% of dietary phosphorous levels (Cheng *et al.*, 2006).

Phosphorous should be supplemented at least at 0.34% of feed (Van Wyk, 1999), with 0.93% being preferable (Cheng *et al.*, 2006). Magnesium should also be supplemented; 0.26–0.346% of feed is sufficient (Cheng *et al.*, 2005). Potassium should also be supplemented at 0.096-0.126% (Ayisi *et al.*, 2017). Trace minerals including iron, iodine, manganese, copper, cobalt, zinc, selenium, molybdenum, fluorine, aluminium, nickel, vanadium, silicon, tin and chromium should be included in diets via a premix (Van Wyk, 1999).

Shrimp are slow feeders, using chemosensory rather than visual detection, and external mastication before ingestion of the masticated food particles (Obaldo & Masuda, 2006). Feed pellets should be hydro-stable, and an appropriate size for the size of the shrimp. Obaldo & Masuda (2006) found that large pellets (3mm diameter) led to greater competition and aggressive behaviour between shrimp.

Recommended feed rates for shrimp are dependent on their size. They are also dependent on temperature and salinity and will also be highly variable according to the availability of natural productivity as a food source within the culture unit. Roy *et al.* (2012) found that where natural productivity was available it would account for a 60% reduction of fed ration with no implication for growth rate. Table 4 gives an approximate indication of recommended feed rate according to shrimp size with and without natural productivity.

Table 4: Recommended feed rate according to shrimp size in the absence of, and accounting for the availability of natural productivity.

Shrimp size (g)		**<1**	**1-4**	**4-7**	**7-10**	**10-13**	**13-16**	**16-19**	**19+**
Daily feed rate (% body weight)	With no natural productivity (from Van Wyk, 1999)	35 – 11	11 – 6	6 – 4.5	4.5 – 3.75	3.75 – 3	3 – 2.3	2.3 – 1.9	1.9 – 1.7
	Accounting for natural productivity (from Van Wyk, (1999), - 60% following Roy *et al.*, (2012))	21 – 6.6	6.6 – 3.6	3.6 – 2.7	2.7 – 2.25	2.25 – 1.8	1.8 – 1.38	1.38 – 1.14	1.14 – 1.02

Care must be taken to find a balance at which the presence of excessive quantities of degrading feed in the water is avoided, while sufficient access to feed is provided to ensure shrimp are not hungry, or in competition with each other. Feeding should be during daylight hours (Pontes & Arruda 2005), and at least 2 feeds daily is optimum (Carvalho & Nunes 2006), while 4 to 6 is preferable (Nunes, 2001). Where feeding trays are used, 25 – 30 feeding trays should be used per hectare of pond area to ensure access to all individuals (Nunes, 2001; ABCC, 2012). If feed is broadcasted, feed should reach 75% of the culture unit area (Pedrazzani *et al.* 2023). Automatic demand feeders may be used but should be carefully monitored to ensure their proper functioning. Effects on shrimp feeding behaviour, and impacts on dissolved oxygen levels, should also be closely monitored, and addressed where necessary (Davis *et al.*, 2018).

Feeding methods

Various methods exist for shrimp feeding, and the method used can significantly influence the efficiency of feed use. Methods include the use of feed trays, the manual or mechanical broadcasting of feed over the surface of the ponds, or the use of relatively sophisticated demand feeders based on acoustic sensing.

Shrimp reduce and eventually cease feeding in the last stage of preparation for moulting, and do not resume feeding until the new shell has hardened, with the duration of non-feeding lasting approximately 6-9% of the entire moult cycle (Dall *et al.*, 1990). The actual moment of moulting (ecdysis), when the shrimp escapes its old shell, mostly occurs at night, to reduce the risk of predation given that they are immobile and vulnerable for several hours after the procedure, and normal feeding activity typically resumes on the following night (Lemos & Weissman, 2021). It is important that feed is reduced by between 10 and 30% on days when moulting is expected, and up to 50% on days when mass-moulting is expected (Lemos & Weissman, 2021; Panakorn, 2018).

Shrimp farming methods by intensity

In extensive systems stocking is at very low density, and sometimes based on natural recruitment, and no manufactured feed is used.

Semi intensive pond systems are stocked with larvae, but densities remain relatively low, and shrimp consume both manufactured feeds and natural productivity within the pond, the growth of which is promoted to a varying degree. Mechanical aeration is usually practised ensuring adequate water quality.

Intensive systems are operated at high stocking densities. Culture units include ponds, tanks and raceways. In these systems shrimp rely entirely on manufactured feeds for nutrition, and significant aeration or oxygenation is required, as well as water exchange or treatment, as in recirculating or biofloc systems, to maintain adequate water quality.

Systems where natural productivity forms at least a percentage of the diet of the shrimp are preferable, as this provides the shrimp with opportunity to forage on a variety of organisms, and thereby express natural behaviour. Furthermore, since natural productivity reduces reliance on manufactured feeds, it is more sustainable, and avoids potential secondary impacts to animal welfare.

The protein content of feeds can be met using plant-based ingredients or byproducts from meat processing industries with no negative effect on performance compared with fishmeal (Amaya *et al.*, 2007). The lipid fraction can also be provided using algae-based ingredients (Araújo *et al.*, 2019; Kumar *et al.*, 2018), or byproduct from fish processing industries (Soller *et al.*, 2019), with no negative impact on performance. Natural productivity also provides shrimp with essential highly unsaturated fatty acids (Izquierdo *et al.*, 2006), including at low salinity (Soller *et al.*, 2019), reducing the need to include these fatty acids in the feed. Indeed, improved shrimp performance has been observed in ponds where natural productivity is promoted (Porchas-Cornejo *et al.*, 2011).

RECOMMENDATION ON FEED AND FEEDING

Compassion recommends adopting extensive systems to rear whiteleg shrimp where natural productivity is the source of feed. Whiteleg shrimp are omnivorous grazers, and can feed on natural productivity within ponds, which can be promoted through the application of fertilisers prior to stocking. Using an external source of feed increases the environmental impact of shrimp farming.

When an external source of feed needs to be used, Compassion recommends avoiding the use of ingredients edible to humans. Compassion recommends that the amount of fishmeal in the feed be eliminated or minimised as much as is feasible while still providing for the nutritional needs of the farmed shrimp. Using ingredients that are edible for humans increases the environmental impact of rearing animals in captivity and reduces the efficiency of the food system. Shrimp can thrive on diets with plant-based proteins with little to no content of fish meal or fish oil. Feed ingredients used should be plant-based or sourced from agricultural or fishery and fish processing byproducts.

Compassion recommends that feed for shrimp be of adequate quality and nutrition for the life stage and size of the shrimp. The feed used must have a composition adequate to the life stage, as smaller shrimp require a higher proportion of protein compared to larger shrimp.

Compassion recommends adapting the feeding to the biology and behaviour of the shrimp, ensuring that all individuals have access to the feed. When using feeding trays there should be 25 to 30 per hectare, and if feed is broadcasted it is recommended that it reaches 75% of the culture unit. When mass moulting events are expected or observed, feed should be significantly reduced.

EYESTALK ABLATION

Experiments aimed at establishing hatchery production of various species of shrimp considered promising for aquaculture in the 1970s revealed that eyestalk ablation, whereby one of the eyestalks is removed, could be practised as hatchery protocol to induce female shrimp to spawn (Aquacop, 1975; Arnstein & Beard, 1975; Lawrence *et al.*, 1980). It has been standard practice within the shrimp hatchery industry for the major cultivated species *Penaeus monodon* since 1977 (Santiago Jr, 1977), and subsequently *P. vannamei* since 1989 (Rankin *et al.*, 1989) facilitating the development of the global industry.

It is still cited as industry standard by the FAO (FAO, 2009) with no discussion relating to the profound negative impact that the procedure has on the individuals upon which it is practised. Eyestalk ablation results in copious spawning and moulting, as the eyestalk houses a gland from which gonad- and moult-inhibiting hormone is produced and secreted (Primavera, 1988). When one eyestalk is missing, the cycles of moulting and breeding are not regulated and occur more frequently, it can no longer be understood as a cycle, but rather as precocious moulting and spawning on a continuous basis. It alters haemolymph content; reduced glucose in females, increased glucose in males, reduced lactate in both sexes, reduced triglycerides in females, reduced protein in females, increased protein in males, and reduced haemocytes in both sexes

(Sainz-Hernández *et al.* 2008) leading to a loss of control of immune function, and eventual death (Benzie 1998). This procedure has a profound and negative impact on shrimp welfare, and it is completely unacceptable.

Larvae produced through this procedure are of poorer quality in terms of survival and growth rate, due to the reproductive exhaustion of the mother (Palacios, *et al.* 1999). Also, larvae obtained through this method have been observed to be less resilient to salinity stress (Zacarias *et al.,* 2019) and common pathogens (Zacarias *et al.,* 2021). Thus, not only do the female broodstock suffer as a result of the procedure, but the progeny also has reduced welfare potential. Breeding programs have achieved greater readiness to spawn in captivity as a heritable trait without the need of relying on eyestalk ablation (Zacarias *et al.,* 2019).

RECOMMENDATION ON EYESTALK ABLATION

Eyestalk ablation has a profound and negative impact on shrimp welfare, and it is completely unacceptable. Compassion recommends banning the use of this practice.

This procedure not only negatively impacts the welfare of the broodstock on which it is practised, but also their progeny. Furthermore, it has been demonstrated that it is unnecessary, and it is also disadvantageous from a production perspective.

HUMANE SLAUGHTER

The commonplace methods reported to be used in harvesting procedures of farmed shrimp are immersion in a mix of ice and water, or simply live stacking in crates with or without ice, the latter of which will result in the death of the animal by asphyxiation or crushing, and the former of which has consequences not yet fully understood, and which are likely to involve prolonged suffering (Khire, 2023; Shrimp Welfare Project, no date). Given the evidence that shrimp can experience pain (Taylor *et al.* 2004), and as is reviewed in the "Sentience and Welfare Protection" section of this document, they should be slaughtered as humanely and as painlessly as possible. Humane slaughter means killing an animal instantaneously or rendering it instantly unconscious and killing it while it is unconscious.

Weineck *et al.* (2018) maintains that immersion in ice slurry alone may reduce the duration of suffering for harvested shrimp when compared to live stacking with or without ice (Weineck *et al.*, 2018), but this represents a marginal improvement for welfare as compared to these methods. It is likely that they feel pain or discomfort from cold shock, and they are likely to recover upon re-exposure to warmer temperatures after immersion in ice slurry for up to 5.5 minutes and possibly longer (Weineck *et al.*, 2018). Where ice slurry is prepared using ice and water of a different salinity level to the culture water, it is also possible that shrimp will suffer pain and discomfort caused by osmotic shock (Mood, 2021).

It is common for many species of crustaceans to be marketed alive. Maintaining crabs and lobsters alive until they are cooked is commonplace in many parts of the world, where they are killed by the cooking process itself. Electrical stunning machines aimed at larger crustaceans are commercially available, including one named Crustastun designed for use on crabs and lobsters in the catering industry (Crustastun, no date; Yue, 2008).

Electrical stunning has been investigated as a method of humane slaughter in other decapods. Roth and Grimsbø (2016), found that edible crabs could be rendered unconscious within one second by an electric shock of 50-60Hz and 220 V. Weineck *et al.* (2018) also found that electrical stunning with the parameters: 60 Hz, 120 Volts, 20 amps, can immediately stop the heartbeat in shrimp. An electrical dry stunning machine was tested in a production setting and is in use for shrimp. The recovery from the stun administered by this machine when operated using 60-75 volts at 45 Hertz (operational amperage = 0-0.015 mA) was less than 3%. The stun was followed by stacking in layers of crushed ice to ensure the non-recovery of the shrimp prior to death (Compassion in World Farming, 2020). While electrical methods are the only practical methods that currently exist that can be considered humane, shrimp are able to recover from the stun (Weineck *et al.*, 2018), therefore, a follow-up method is required that either kills them, or maintains them unconscious until death supervenes.

RECOMMENDATION ON HUMANE SLAUGHTER

Whiteleg shrimp should be effectively stunned, rendered instantaneously insensible, and remain unconscious until death supervenes.

If a single method that both stuns and kills is available, it should be used. Compassion recommends the use of electrical stunning followed by another method that kills the shrimp, or maintains them unconscious until death supervenes, such as the use of ice layering or immersion in ice slurry.

The use of ice slurry without previous stunning, and asphyxia, are unacceptable methods. Live selling and live cooking are also unacceptable practices.

REFERENCES

ABCC (2012) Boas Práticas de Manejoe e Biossegurança para a Carcinicultura Marinha Nacional. https://abccam.com.br/wp-content/uploads/2012/02/BPMS_E_BIOSSEGURANA_-_ABCC_FEVEREIRO_2012.pdf

Alves Neto, I., Brandão, H., Furtado, P. S., & Wasielesky Jr, W. (2019). Acute toxicity of nitrate in *Litopenaeus vannamei* juveniles at low salinity levels. Ciência Rural, 49, e20180439. https://www.scielo.br/j/cr/a/SrCF7KGrXy3DDLJvz4Mf9kS/

Amaya, E., Davis, D. A., & Rouse, D. B. (2007). Alternative diets for the Pacific white shrimp *Litopenaeus vannamei*. Aquaculture, 262(2-4), 419-425. https://www.academia.edu/13189734/Alternative_diets_for_the_Pacific_white_shrimp_Litopenaeus_vannamei

Appel, M., & Elwood, R. W. (2009). Gender differences, responsiveness and memory of a potentially painful event in hermit crabs. Animal Behaviour, 78(6), 1373-1379. https://doi.org/10.1016/j.anbehav.2009.09.008

Apún-Molina, J. P., Robles-Romo, A., Alvarez-Ruiz, P., Santamaria-Miranda, A., Arjona, O., & Racotta, I. S. (2017). Influence of stocking density and exposure to white spot syndrome virus in biological performance, metabolic, immune, and bioenergetics response of whiteleg shrimp *Litopenaeus vannamei*. *Aquaculture*, *479*, 528-537.Aquaculture, Volume 479, Pages 528-537, ISSN 0044-8486, https://doi.org/10.1016/j.aquaculture.2017.06.027

Aquacop (1975). Maturation and Spawning in Captivity of Penaeid Shrimp: *Penaeus merguiensis* de Man *Penaeus japonicus* Bate *Penaeus aztecus* Ives *Metapenaeus ensis* de Hann *Penaeus semisulcatus* de Haan. In Proceedings of the annual meeting-World Mariculture Society (Vol. 6, No. 1-4, pp. 123-132). https://doi.org/10.1111/j.1749-7345.1975.tb00011.x

Aquaculture Stewardship Council (2023) ASC Shrimp Standard. Version 1.2.1. https://asc-aqua.org/wp-content/uploads/2023/07/ASC-Shrimp-Standard_v1.2.1.pdf

Arambul-Muñoz, E., Ponce-Palafox, J. T., Claro De Los Santos, R., Aragón-Noriega, E. A., Rodríguez-Domínguez, G., & Castillo-Vargasmachuca, S. G. (2019). Influence of stocking density on production and water quality of a photoheterotrophic intensive system of white shrimp (*Penaeus vannamei*) in circular lined grow-out ponds, with minimal water replacement. Latin american journal of aquatic research, 47(3), 449-455. https://doi.org/10.3856/vol47-issue3-fulltext-7

Araneda, M., Pérez, E. P., & Gasca-Leyva, E. (2008). White shrimp *Penaeus vannamei* culture in freshwater at three densities: condition state based on length and weight. Aquaculture, 283(1-4), 13-18. https://doi.org/10.1016/j.aquaculture.2008.06.030

Araújo, B. C., Mata-Sotres, J. A., Viana, M. T., Tinajero, A., & Braga, A. (2019). Fish oil-free diets for Pacific white shrimp *Litopenaeus vannamei*: The effects of DHA-EPA supplementation on juvenile growth performance and muscle fatty acid profile. Aquaculture, 511, 734276. https://doi.org/10.1016/j.aquaculture.2019.734276

Arnstein, D. R., & Beard, T. W. (1975). Induced maturation of the prawn *Penaeus orientalis* Kishinouye in the laboratory by means of eyestalk removal. Aquaculture, 5(4), 411-412. https://doi.org/10.1016/0044-8486(75)90060-5

Ayisi, C. L., Hua, X., Apraku, A., Afriyie, G., & Kyei, B. A. (2017). Recent studies toward the development of practical diets for shrimp and their nutritional requirements. HAYATI Journal of Biosciences, 24(3), 109-117. https://www.sciencedirect.com/science/article/pii/S1978301917301833

Bardera, G., Owen, M. A., Façanha, F. N., Alcaraz-Calero, J. M., Alexander, M. E., & Sloman, K. A. (2021). The influence of density and dominance on Pacific white shrimp (*Litopenaeus vannamei*) feeding behaviour. Aquaculture, 531, 735949. https://doi.org/10.1016/j.aquaculture.2020.735949

Barr, S., Laming, P. R., Dick, J. T., & Elwood, R. W. (2008). Nociception or pain in a decapod crustacean?. Animal Behaviour, 75(3), 745-751. https://doi.org/10.1016/j.anbehav.2007.07.004

Bautista-Covarrubias, J. C., Zamora-Ibarra, P. A., Apreza-Burgos, E., Rodríguez-Ocampo, A. N., Peraza-Gómez, V., López-Sánchez, J. A., ... & Frías-Espericueta, M. G. (2020). Immune response and oxidative stress of shrimp *Litopenaeus vannamei* at different moon phases. Fish & Shellfish Immunology, 106, 591-595. https://doi.org/10.1016/j.fsi.2020.08.040

Bayot, B., Rodríguez, J., Arguello, W., Cornejo-Rodríguez, M. H., & Sonnenholzner, S. (2014). An evaluation of intraspecific competition for Pacific white shrimp *Penaeus vannamei* (Boone) in extensive/semi-intensive ponds. Aquaculture international, 22, 1025-1039. http://dx.doi.org/10.1007/s10499-013-9724-8

Benzie, J.A.H. (1998) Penaeid genetics and biotechnology in Aquaculture 164 1998 23–47 https://doi.org/10.1016/S0044-8486(98)00175-6

Best Aquaculture Practices (2023) Farm Standard. Issue 3.1 https://www.bapcertification.org/Downloadables/pdf/BAP%20-%20BAP%20Farm%20Standard%20-%20Issue%203.1%20-%2007-February-2023.pdf

Birch, J., Burn, C., Schnell, A., Browning, H., & Crump, A. (2021). Review of the evidence of sentience in cephalopod molluscs and decapod crustaceans. https://www.wellbeingintlstudiesrepository.org/af_gen/2/

Boles, L. C., & Lohmann, K. J. (2003). True navigation and magnetic maps in spiny lobsters. Nature, 421(6918), 60-63. https://www.nature.com/articles/nature01226

Boyd, C. E., & Jescovitch, L. N. (2020). Penaeid shrimp aquaculture. Fisheries and Aquaculture, 9, 233. https://books.google.co.uk/books?hl=en&lr=&id=yvPuDwAAQBAJ&oi=fnd&pg=PA233&dq=shrimp+stocking+practices+global&ots=UtU2RNlJNu&sig=3zVdUXXxrGU5pSoBi4eWgqQtg30

Bray, W. A., Lawrence, A. L., & Leung-Trujillo, J. R. (1994). The effect of salinity on growth and survival of *Penaeus vannamei*, with observations on the interaction of IHHN virus and salinity. Aquaculture, 122(2-3), 133-146. https://www.ecowin.org/pdf/documents/Bray%201994%20vannamei%20salinity%20growth.pdf

Burge, E. J., Madigan, D. J., Burnett, L. E., & Burnett, K. G. (2007). Lysozyme gene expression by hemocytes of Pacific white shrimp, *Litopenaeus vannamei*, after injection with Vibrio. Fish & Shellfish Immunology, 22(4), 327-339. https://doi.org/10.1016/j.fsi.2006.06.004

Burgents, J. E., Burnett, K. G., & Burnett, L. E. (2005). Effects of hypoxia and hypercapnic hypoxia on the localization and the elimination of *Vibrio campbellii* in *Litopenaeus vannamei*, the Pacific white shrimp. The Biological Bulletin, 208(3), 159-168. https://www.journals.uchicago.edu/doi/abs/10.2307/3593148

Carvalho, E. A., & Nunes, A. J. (2006). Effects of feeding frequency on feed leaching loss and grow-out patterns of the white shrimp *Litopenaeus vannamei* fed under a diurnal feeding regime in pond enclosures. Aquaculture, 252(2-4), 494-502. https://doi.org/10.1016/j.aquaculture.2005.07.013

Cheng, K. M., Hu, C. Q., Liu, Y. N., Zheng, S. X., & Qi, X. J. (2005). Dietary magnesium requirement and physiological responses of marine shrimp *Litopenaeus vannamei* reared in low salinity water. Aquaculture Nutrition, 11(5), 385-393. https://doi.org/10.1111/j.1365-2095.2005.00364.x

Cheng, K. M., Hu, C. Q., Liu, Y. N., Zheng, S. X., & Qi, X. J. (2006). Effects of dietary calcium, phosphorus and calcium/phosphorus ratio on the growth and tissue mineralization of *Litopenaeus vannamei* reared in low-salinity water. Aquaculture, 251(2-4), 472-483. https://doi.org/10.1016/j.aquaculture.2005.06.022

Compassion in World Farming (2020) Tesco and Hilton Seafood – Improving the welfare of whiteleg shrimp (*Pennaeus vannamei*) at harvest. https://www.compassioninfoodbusiness.com/media/7444897/tesco-and-hilton-seafood-case-study-improving-the-welfare-of-whiteleg-shrimp-at-harvest.pdf

Conte, F. S. (2004). Stress and the welfare of cultured fish. Applied Animal Behaviour Science, 86(3-4), 205-223. https://doi.org/10.1016/j.applanim.2004.02.003

Crump, A., Browning, H., Schnell, A., Burn, C., & Birch, J. (2022). Sentience in decapod crustaceans: A general framework and review of the evidence. Animal Sentience, 7(32), 1. https://www.wellbeingintlstudiesrepository.org/animsent/vol7/iss32/1/

da Costa, F. P., Gomes, B. S. F. D. F., Pereira, S. D. D. N. A., & de Fátima Arruda, M. (2016). Influence of stocking density on the behaviour of juvenile *Litopenaeus vannamei* (Boone, 1931). *Aquaculture Research*, *47*(3), 912-924. https://doi.org/10.1111/are.12550

Dall, W. H. B. J., Hill, B. J., Rothlisberg, P. C., & Sharples, D. J. (1990). The biology of the Penaeidae. The biology of the Penaeidae., 27. https://www.cabdirect.org/cabdirect/abstract/19910192312

Davis, D. A., Ullman, C., Rhodes, M., Novriadi, R., & Swanepoel, A. (2018). Automated feeding systems in pond production of Pacific white shrimp. https://www.researchgate.net/publication/330566608_Automated_feeding_systems_in_pond_production_of_Pacific_white_shrimp

EFSA (2005) Aspects of the Biology and Welfare of Animals Used for Experimental and Other Scientific Purposes. EFSA-Q-2004-105. EFSA J. 2005, 292, 1–46. https://efsa.onlinelibrary.wiley.com/doi/pdf/10.2903/j.efsa.2005.292

Ellis, T., North, B., Scott, A. P., Bromage, N. R., Porter, M., & Gadd, D. (2002). The relationships between stocking density and welfare in farmed rainbow trout. Journal of fish biology, 61(3), 493-531. https://doi.org/10.1111/j.1095-8649.2002.tb00893.x

Elwood, R. W. (2012). Evidence for pain in decapod crustaceans. Animal Welfare, 21(S2), 23-27. https://doi.org/10.7120/096272812X13353700593365

Elwood, R. W., & Adams, L. (2015). Electric shock causes physiological stress responses in shore crabs, consistent with prediction of pain. Biology Letters, 11(11), 20150800. https://doi.org/10.1098/rsbl.2015.0800

Elwood, R. W., & Stewart, A. (1985). The timing of decisions during shell investigation by the hermit crab, *Pagurus bernhardus*. Animal behaviour, 33(2), 620-627. https://doi.org/10.1016/S0003-3472(85)80086-5

Elwood, R. W., Barr, S., & Patterson, L. (2009). Pain and stress in crustaceans?. Applied Animal Behaviour Science, 118(3-4), 128-136. https://doi.org/10.1016/j.applanim.2009.02.018

Esparza-Leal, H. M., Ponce-Palafox, J. T., Aragón-Noriega, E. A., Arredondo-Figueroa, J. L., García-Ulloa Gómez, M., & Valenzuela-Quiñonez, W. (2010). Growth and performance of the whiteleg shrimp *Penaeus vannamei* (Boone) cultured in low-salinity water with different stocking densities and acclimation times. Aquaculture Research, 41(6), 878-883. https://doi.org/10.1111/j.1365-2109.2009.02367.x

EUMOFA (2023) Shrimp Penaeus. https://eumofa.eu/documents/20124/35695/Shrimp+Penaeus_31-1.pdf/08a99cec-ac32-4d14-a2ba-c5483d9e8591?t=1670841656677

European Commission (2008) Commission Regulation (EC) No 889/2008. https://www.legislation.gov.uk/eur/2008/889/annex/XIIIa

FAO (2009) *Penaeus vannamei*. In Cultured aquatic species fact sheets. Text by Briggs, M. Edited and compiled by Valerio Crespi and Michael New. CD-ROM (multilingual). https://www.fao.org/fishery/docs/DOCUMENT/aquaculture/CulturedSpecies/file/en/en_whitelegshrimp.htm

FAO (2023) Fishery and Aquaculture Statistics. Global aquaculture production 1950-2021 (FishStatJ). In: FAO Fisheries and Aquaculture Division [online]. Rome. Updated 2023. www.fao.org/fishery/en/statistics/software/fishstatj

Fernandez-Duque, E., Valeggia, C., & Maldonado, H. (1992). Multitrial inhibitory avoidance learning in the crab *Chasmagnathus*. Behavioural and neural biology, 57(3), 189-197. https://doi.org/10.1016/0163-1047(92)90136-R

Fonseca, C. S. (2021). Manual de Boas Práticas de Manejo e de Biossegurança Para a Carcinicultura Brasileira; Associação Brasileira de Criadores de Camarão: Candelária. *RN, Brasil*. https://abccam.com.br/2021/09/manual-de-boas-praticas-de-manejo-e-de-biosseguranca-para-a-carcinicultura-brasileira-junho-2021/

Frías-Espericueta, M. G., Abad-Rosales, S., Nevárez-Velázquez, A. C., Osuna-López, I., Páez-Osuna, F., Lozano-Olvera, R., & Voltolina, D. (2008). Histological effects of a combination of heavy metals on Pacific white shrimp *Litopenaeus vannamei* juveniles. *Aquatic toxicology*, *89*(3), 152-157. (1) Histological effects of a combination of heavy metals on Pacific white shrimp *Litopenaeus vannamei* juveniles | METALES DE SINALOA – Academia.edu

Friend of the Sea (2016) Friend of the Sea Standard. FOS-Aqua – Prawns Criteria and indicators for the Certification of sustainable farmed crustaceans https://friendofthesea.org/wp-content/uploads/FOS-Aqua-Prawns-03112014_EN_edited_2020.pdf

Furtado, P. S., Campos, B. R., Serra, F. P., Klosterhoff, M., Romano, L. A., & Wasielesky, W. (2015). Effects of nitrate toxicity in the Pacific white shrimp, *Litopenaeus vannamei*, reared with biofloc technology (BFT). Aquaculture international, 23, 315-327. https://link.springer.com/article/10.1007/s10499-014-9817-z

Furtado, P. S., Valenzuela, M. A., Badillo, M. A., Gaxiola, G., & Wasielesky Jr, W. (2016). Effect of dissolved carbon dioxide on oxygen consumption in the Pacific white shrimp, *Litopenaeus vannamei* (Boone 1931). Marine and freshwater behaviour and physiology, 49(5), 337-346. https://doi.org/10.1080/10236244.2016.1213568

Global GAP (2023) IFA Smart/GFS – Aquaculture. Principles and criteria. https://documents.globalgap.org/documents/231215_IFA_Smart_GFS_P&Cs_AQ_v6_0_Dec23_en.pdf

Globefish (2023) China becomes the world's top shrimp importer | GLOBEFISH | Food and Agriculture Organization of the United Nations (fao.org) https://www.fao.org/in-action/globefish/market-reports/resource-detail/en/c/1633618/

Gross, A., Abutbul, S., & Zilberg, D. (2004). Acute and chronic effects of nitrite on white shrimp, *Litopenaeus vannamei*, cultured in low-salinity brackish water. Journal of the world aquaculture society, 35(3), 315-321. https://doi.org/10.1111/j.1749-7345.2004.tb00095.x

Han, S. Y., Wang, B. J., Liu, M., Wang, M. Q., Jiang, K. Y., Qi, C. C., & Wang, L. (2017). Effect of cyclic serious/medium hypoxia stress on the survival, growth performance and resistance against *Vibrio parahemolyticus* of white shrimp *Litopenaeus vannamei*. Invertebrate Survival Journal, 14(1), 259-270. https://www.isj.unimore.it/index.php/ISJ/article/view/50

He, H., & Lawrence, A. L. (1993a). Vitamin C requirements of the shrimp *Penaeus vannamei*. Aquaculture, 114(3-4), 305-316. https://www.sciencedirect.com/science/article/pii/004484869390305I

He, H., & Lawrence, A. L. (1993b). Vitamin E requirement of *Penaeus vannamei*. Aquaculture, 118(3-4), 245-255. https://www.sciencedirect.com/science/article/pii/004484869390460G

Hu, F., Pan, L., & Jing, F. (2009). Effects of hypoxia on dopamine concentration and the immune response of white shrimp (*Litopenaeus vannamei*). Journal of Ocean University of China, 8, 77-82. https://link.springer.com/article/10.1007/s11802-009-0077-x

Izquierdo, M., Forster, I., Divakaran, S., Conquest, L., Decamp, O., & Tacon, A. (2006). Effect of green and clear water and lipid source on survival, growth and biochemical composition of Pacific white shrimp *Litopenaeus vannamei*. Aquaculture nutrition, 12(3), 192-202. https://doi.org/10.1111/j.1365-2095.2006.00385.x

Johnston, C., & Jungalwalla, P. (2005). Aquatic animal welfare guidelines: guidelines on welfare of fish and crustaceans in aquaculture and/or in live holding systems for human consumption. National Aquaculture Council.

Jurtshuk, P. (1996). Bacterial metabolism. Medical microbiology, 4. https://cidta.usal.es/cursos/enfermedades/modulos/libros/UNIDAD4/Bacterial%20Metabolism%20Baron.pdf

Khire., I, (2023). Overview of Shrimp Farming and Questions Surrounding it. https://ishankhire.blogspot.com/2023/04/overview-of-shrimp-farming-and.html

Kotiya, A. S., & Vadher, K. H. (2021). Effect of different stocking density on growth and survival of *Litopenaeus vannamei* (boone, 1931) in summer crop in province of Gujarat state, India. Journal of Experimental Zoology India, 24(1). https://connectjournals.com/03895.2021.24.261

Krummenauer, D., Cavalli, R. O., Ballester, E. L., & Wasielesky Jr, W. (2010). Feasibility of pacific white shrimp *Litopenaeus vannamei* culture in southern Brazil: effects of stocking density and a single or a double CROP management strategy in earthen ponds. Aquaculture Research, 41(2), 240-248. https://doi.org/10.1111/j.1365-2109.2009.02326.x

Krummenauer, D., Peixoto, S., Cavalli, R. O., Poersch, L. H., & Wasielesky Jr, W. (2011). Superintensive culture of white shrimp, *Litopenaeus vannamei*, in a biofloc technology system in southern Brazil at different stocking densities. Journal of the world aquaculture society, 42(5), 726-733. https://doi.org/10.1111/j.1749-7345.2011.00507.x

Kuhn, D. D., Smith, S. A., Boardman, G. D., Angier, M. W., Marsh, L., & Flick Jr, G. J. (2010). Chronic toxicity of nitrate to Pacific white shrimp, *Litopenaeus vannamei*: impacts on survival, growth, antennae length, and pathology. Aquaculture, 309(1-4), 109-114. https://www.sciencedirect.com/science/article/pii/S0044848610006198

Kumar, V., Habte-Tsion, H. M., Allen, K. M., Bowman, B. A., Thompson, K. R., El-Haroun, E., … & Tidwell, J. H. (2018). Replacement of fish oil with *Schizochytrium* meal and its impacts on the growth and lipid metabolism of Pacific white shrimp (*Litopenaeus vannamei*). Aquaculture nutrition, 24(6), 1769-1781. https://doi.org/10.1111/anu.12816

Laramore, S., Laramore, C. R., & Scarpa, J. (2001). Effect of low salinity on growth and survival of postlarvae and juvenile *Litopenaeus vannamei*. Journal of the World Aquaculture Society, 32(4), 385-392. https://doi.org/10.1111/j.1749-7345.2001.tb00464.x

Lawrence, A. L., Akamine, Y., Middleditch, B. S., Chamberlain, G., & Hutchins, D. (1980). Maturation and reproduction of *Penaeus setiferus* in captivity. In Proceedings of the World Mariculture Society (Vol. 11, No. 1-4, pp. 479-487). Oxford, UK: Blackwell Publishing Ltd. https://doi.org/10.1111/j.1749-7345.1980.tb00143.x

Lemos, D., & Weissman, D. (2021). Moulting in the grow-out of farmed shrimp: a review. Reviews in aquaculture, 13(1), 5-17. https://doi.org/10.1111/raq.12461

Lewit-Mendes, L. & Boddy, A., (2022) What matters to shrimps? Factors affecting shrimp welfare in aquaculture. In Effective Altruism Forum. https://forum.effectivealtruism.org/posts/nGrmemHzQvBpnXkNX/what-matters-to-shrimps-factors-affecting-shrimp-welfare-in

Li, C. H., & Cheng, S. Y. (2012). Variation of calcium levels in the tissues and hemolymph of *Litopenaeus vannamei* at various molting stages and salinities. Journal of Crustacean Biology, 32(1), 101-108. https://academic.oup.com/jcb/article-pdf/32/1/101/10336102/jcb0101.pdf

Li, E., Chen, L., Zeng, C., Chen, X., Yu, N., Lai, Q., & Qin, J. G. (2007). Growth, body composition, respiration and ambient ammonia nitrogen tolerance of the juvenile white shrimp, *Litopenaeus vannamei*, at different salinities. Aquaculture, 265(1-4), 385-390. https://doi.org/10.1016/j.aquaculture.2007.02.018

Li, E., Yu, N., Chen, L., Zeng, C., Liu, L., & Qin, J. G. (2010). Dietary vitamin B6 requirement of the Pacific white shrimp, *Litopenaeus vannamei*, at low salinity. Journal of the World Aquaculture Society, 41(5), 756-763.

Lin, Y. C., & Chen, J. C. (2003). Acute toxicity of nitrite on *Litopenaeus vannamei* (Boone) juveniles at different salinity levels. Aquaculture, 224(1-4), 193-201. https://doi.org/10.1016/S0044-8486(03)00220-5

Liu, G., Zhu, S., Liu, D., Guo, X., & Ye, Z. (2017). Effects of stocking density of the white shrimp *Litopenaeus vannamei* (Boone) on immunities, antioxidant status, and resistance against *Vibrio harveyi* in a biofloc system. Fish & Shellfish Immunology, 67, 19-26. https://doi.org/10.1016/j.fsi.2017.05.038

Lozada, M., Romano, A., & Maldonado, H. (1988). Effect of morphine and naloxone on a defensive response of the crab *Chasmagnathus granulatus*. Pharmacology Biochemistry and Behavior, 30(3), 635-640. https://doi.org/10.1016/0091-3057(88)90076-7

McGraw, W. J., Davis, D. A., Teichert-Coddington, D., & Rouse, D. B. (2002). Acclimation of *Litopenaeus vannamei* postlarvae to low salinity: influence of age, salinity endpoint, and rate of salinity reduction. Journal of the World Aquaculture Society, 33(1), 78-84. https://doi.org/10.1111/j.1749-7345.2002.tb00481.x

Mood, A. (2014). Welfare during killing of crabs, lobsters and crayfish. https://fishcount.org.uk/welfare-of-crustaceans/welfare-during-killing-of-crabs-lobsters-and-crayfish

Naturland (2023) Naturland Standards Organic Aquaculture. https://www.naturland.de/images/01_naturland/_en/Standards/Naturland-Standards_Aquaculture.pdf

Neal, R. S., Coyle, S. D., Tidwell, J. H., & Boudreau, B. M. (2010). Evaluation of stocking density and light level on the growth and survival of the Pacific white shrimp, *Litopenaeus vannamei*, reared in zero-exchange systems. *Journal of the World Aquaculture Society*, *41*(4), 533-544. https://doi.org/10.1111/j.1749-7345.2010.00393.x

Negrini, C., Castro, C. S. D., Bittencourt-Guimarães, A. T., Frozza, A., Ortiz-Kracizy, R., & Cupertino-Ballester, E. L. (2017). Stocking density for freshwater prawn *Macrobrachium rosenbergii* (Decapoda, Palaemonidae) in biofloc system. Latin american journal of aquatic research, 45(5), 891-899. https://scholar.archive.org/work/auee2bf3jvgylgsjcxziq6gxtq/access/wayback/http://www.lajar.cl/pdf/imar/v45n5/Art%C3%ADculo_45_5_03.pdf

Nunes, A. J. P. (2001). Nunes, A. J. P. (2001). Alimentação para camarões marinhos–Parte II. Panorama da Aqüicultura, 11(63), 13-23. https://panoramadaaquicultura.com.br/alimentacao-para-camaroes-marinhos-parte-ii/

Obaldo, L. G., & Masuda, R. (2006). Effect of diet size on feeding behavior and growth of Pacific white shrimp, *Litopenaeus vannamei*. Journal of Applied Aquaculture, 18(1), 101-110. https://doi.org/10.1300/J028v18n01_07

Otoshi, C.A. & Naguwa, S.S. & Falesch, F.C. & Moss, Shaun. (2007). Shrimp behavior may affect culture performance at super-intensive stocking densities. Global Aquaculture Advocate. 2. 67-69. https://www.globalseafood.org/advocate/shrimp-behavior-may-affect-culture-performance-at-super-intensive-stocking-densities/

Palacios, E., Perez-Rostro, C.I., Ramirez, J.L., Ibarra, A.M., Racotta, I.S. (1999) Reproductive exhaustion in shrimp (*Penaeus vannamei*) reflected in larval biochemical composition, survival and growth in Aquaculture, Volume 171, Issues 3–4, Pages 309-321 https://doi.org/10.1016/S0044-8486(98)00393-7

Panakorn, S. (2018). Managing shrimp moulting. Aquacult Asia Pac, 14, 18-21. https://aquaasiapac.com/issue/may-june-2018/

Pedrazzani, A. S., Cozer, N., Quintiliano, M. H., Tavares, C. P. D. S., da Silva, U. D. A. T., & Ostrensky, A. (2023). Non-invasive methods for assessing the welfare of farmed White-leg Shrimp (*Penaeus vannamei*). *Animals*, *13*(5), 807. https://www.mdpi.com/2076-2615/13/5/807

Pontes, C. S., & Arruda, M. D. F. (2005). Behavior of *Litopenaeus vannamei* (Boone)(Crustacea, Decapoda, Penaeidae) in relation to artificial food offer along light and dark phases in a 24 h period. Revista Brasileira de Zoologia, 22, 648-652. https://doi.org/10.1590/S0101-81752005000300019

Porchas-Cornejo, M. A., Martínez-Córdova, L. R., Ramos-Trujillo, L., Hernández-López, J., Martínez-Porchas, M., & Mendoza-Cano, F. (2011). Effect of promoted natural feed on the production, nutritional, and immunological parameters of *Litopenaeus vannamei* (Boone, 1931) semi-intensively farmed. Aquaculture Nutrition, 17(2), e622-e628. https://doi.org/10.1111/j.1365-2095.2010.00809.x

Primavera, J. H. (1988) Maturation, reproduction, and broodstock technology in Biology and culture of *Penaeus monodon* pp. 37-57 Tigbauan, Iloilo, Philippines: SEAFDEC Aquaculture Department [online] available at: https://repository.seafdec.org.ph/bitstream/handle/10862/865/biol.monodon_p037-057.pdf

Racotta, I. S., & Hernández-Herrera, R. (2000). Metabolic responses of the white shrimp, *Penaeus vannamei*, to ambient ammonia. Comparative Biochemistry and Physiology Part A: Molecular & Integrative Physiology, 125(4), 437-443. https://doi.org/10.1016/S1095-6433(00)00171-9

Rankin, S., Bradfield, J., & Keeley, L. (1989). Ovarian protein synthesis in the South American white shrimp, *Penaeus vannamei*, during the reproductive cycle. International journal of invertebrate reproduction and development, 15(1), 27-33. https://doi.org/10.1080/07924259.1989.9672018

Ritvo, G., Dixon, J. B., Neill, W. H., Samocha, T. M., & Lawrence, A. L. (2000). The effect of controlled soil sulfur concentration on growth and survival of *Litopenaeus vannamei*. Journal of the World Aquaculture Society, 31(3), 381-389. https://doi.org/10.1111/j.1749-7345.2000.tb00888.x

Rojas, A. A. (2005). *Buenas prácticas de manejo para el cultivo de camarón*. The David and Lucile Packard Foundation. Buenas Prácticas de Manejo Para el Cultivo de Camarón (uri.edu) https://www.crc.uri.edu/download/PKD_good_mgt_field_manual.pdf

Romero Waldhorn, D., & Autric, E. (2022) Shrimp: The animals most commonly used and killed for food production. https://osf.io/b8n3t/

Roth, B., & Grimsbø, E. (2016). Electrical stunning of edible crabs (*Cancer pagurus*): From single experiments to commercial practice. Animal Welfare, 25(4), 489-497. https://doi.org/10.7120/09627286.25.4.489

Rothlisberg, P. C. (1998). Aspects of penaeid biology and ecology of relevance to aquaculture: a review. Aquaculture, 164(1-4), 49-65. http://dx.doi.org/10.1016/S0044-8486(98)00176-8

Roy, L. A., Davis, D. A., & Whitis, G. N. (2012). Effect of feeding rate and pond primary productivity on growth of *Litopenaeus vannamei* reared in inland saline waters of West Alabama. North American Journal of Aquaculture, 74(1), 20-26. http://dx.doi.org/10.1080/15222055.2011.638416

Roy, L. A., Teichert-Coddington, D., Beck, B. H., Dahl, S., James, J., Guo, J., & Davis, D. A. (2020). Evaluation of Stocking Density and Dietary Fish Meal Inclusion for Intensive Tank Production of Pacific White Shrimp *Litopenaeus vannamei* Cultured in Low-Salinity Waters of Western Alabama. *North American Journal of Aquaculture*, *82*(3), 345-353. https://doi.org/10.1002/naaq.10150

Sainz-Hernández, Juan Carlos., Racotta, Ilie S., Dumas, Silvie., Hernández-López, Jorge. (2008) Effect of unilateral and bilateral eyestalk ablation in *Litopenaeus vannamei* male and female on several metabolic and immunologic variables in Aquaculture, Volume 283, Issues 1–4 https://doi.org/10.1016/j.aquaculture.2008.07.002

Samadan, G. M. (2018). Production performance of whiteleg shrimp *Litopenaeus vannamei* at different stocking densities reared in sand ponds using plastic mulch. *Aquaculture, Aquarium, Conservation & Legislation*, *11*(4), 1213-1221. https://www.cabidigitallibrary.org/doi/full/10.5555/20183343170

Santiago Jr, A. C. (1977). Successful spawning of cultured *Penaeus monodon* Fabricius after eyestalk ablation. Aquaculture, 11(3), 185-196. https://doi.org/10.1016/0044-8486(77)90111-9

Schroeder, J. P., Gärtner, A., Waller, U., & Hanel, R. (2010). The toxicity of ozone-produced oxidants to the Pacific white shrimp *Litopenaeus vannamei*. Aquaculture, 305(1-4), 6-11. https://doi.org/10.1016/j.aquaculture.2010.03.030

Schveitzer, R., Arantes, R., Baloi, M. F., Costódio, P. F. S., Arana, L. V., Seiffert, W. Q., & Andreatta, E. R. (2013). Use of artificial substrates in the culture of *Litopenaeus vannamei* (Biofloc System) at different stocking densities: Effects on microbial activity, water quality and production rates. Aquacultural Engineering, 54, 93-103. https://doi.org/10.1016/j.aquaeng.2012.12.003

Shrimp Welfare Project (no date) The Shrimp Supply Chain. https://www.shrimpwelfareproject.org/the-shrimp-supply-chain

Smith, J. A., Andrews, P. L., Hawkins, P., Louhimies, S., Ponte, G., & Dickel, L. (2013). Cephalopod research and EU Directive 2010/63/EU: Requirements, impacts and ethical review. Journal of Experimental Marine Biology and Ecology, 447, 31-45. https://www.sciencedirect.com/science/article/abs/pii/S0022098113000610

Soil Association (2023) Organic Standards for Great Britain Aquaculture. https://www.soilassociation.org/media/23377/gb-aquaculture.pdf

Soller, F., Roy, L. A., & Davis, D. A. (2019). Replacement of fish oil in plant-based diets for Pacific white shrimp, *Litopenaeus vannamei*, by stearine fish oil and palm oil. Journal of the World Aquaculture Society, 50(1), 186-203. https://onlinelibrary.wiley.com/doi/epdf/10.1111/jwas.12571

Taylor, J., Vinatea, L., Ozorio, R., Schuweitzer, R., & Andreatta, E. R. (2004). Minimizing the effects of stress during eyestalk ablation of *Litopenaeus vannamei* females with topical anesthetic and a coagulating agent. Aquaculture, 233(1-4), 173-179. https://doi.org/10.1016/j.aquaculture.2003.09.034

Thurston, R. V., Russo, R. C., & Vinogradov, G. A. (1981). Ammonia toxicity to fishes. Effect of pH on the toxicity of the unionized ammonia species. Environmental science & technology, 15(7), 837-840. https://pubs.acs.org/doi/pdf/10.1021/es00089a012

Valencia-Castañeda, G., Frías-Espericueta, M. G., Vanegas-Pérez, R. C., Chávez-Sánchez, M. C., & Páez-Osuna, F. (2019). Toxicity of ammonia, nitrite and nitrate to *Litopenaeus vannamei* juveniles in low-salinity water in single and ternary exposure experiments and their environmental implications. Environmental toxicology and pharmacology, 70, 103193. https://www.sciencedirect.com/science/article/pii/S1382668919300602

Van Wyk, P. (1999). Nutrition and Feeding of *Litopenaeus vannamei* in Intensive Culture Systems. *Farming marine shrimp in recirculating freshwater systems*, *4520*, 141-161. https://www.researchgate.net/profile/John-Scarpa/publication/242621708_Farming_Marine_Shrimp_in_Recirculating_Fresh_Water_Systems/links/574c4f0508ae8d6e6a7b678c/Farming-Marine-Shrimp-in-Recirculating-Fresh-Water-Systems.pdf?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19

Van Wyk, P., & Scarpa, J. (1999). Water quality requirements and management. *Farming marine shrimp in recirculating freshwater systems*, *4520*, 141-161. https://www.researchgate.net/profile/John-Scarpa/publication/242621708_Farming_Marine_Shrimp_in_Recirculating_Fresh_Water_Systems/links/574c4f0508ae8d6e6a7b678c/Farming-Marine-Shrimp-in-Recirculating-Fresh-Water-Systems.pdf?_tp=eyJjb250ZXh0Ijp7ImZpcnN0UGFnZSI6InB1YmxpY2F0aW9uIiwicGFnZSI6InB1YmxpY2F0aW9uIn19

Venkateswarlu, V., Seshaiah, P. V., Arun, P., & Behra, P. C. (2019). A study on water quality parameters in shrimp *L. vannamei* semi-intensive grow out culture farms in coastal districts of Andhra Pradesh, India. International Journal of Fisheries and Aquatic Studies, 7(4), 394-399. https://www.fisheriesjournal.com/archives/?year=2019&vol=7&issue=4&part=F&ArticleId=1955

Weineck, K., Ray, A. J., Fleckenstein, L. J., Medley, M., Dzubuk, N., Piana, E., & Cooper, R. L. (2018). Physiological changes as a measure of crustacean welfare under different standardized stunning techniques: Cooling and electroshock. Animals, 8(9), 158. https://www.mdpi.com/2076-2615/8/9/158

Wen, M., Liu, Y. J., Tian, L. X., & Wang, S. (2015). Vitamin D3 requirement in practical diet of white shrimp, *Litopenaeus vannamei*, at low salinity rearing conditions. Journal of the World Aquaculture Society, 46(5), 531-538. https://doi.org/10.1111/jwas.12209

Wickins, J. F. (1984). The effect of hypercapnic sea water on growth and mineralization penaeid prawns. Aquaculture, 41(1), 37-48. https://doi.org/10.1016/0044-8486(84)90388-0

Wu, J. L., Namikoshi, A., Nishizawa, T., Mushiake, K., Teruya, K., & Muroga, K. (2001). Effects of shrimp density on transmission of penaeid acute viremia in *Penaeus japonicus* by cannibalism and the waterborne route. Diseases of aquatic organisms, 47(2), 129-135. https://www.int-res.com/abstracts/dao/v47/n2/p129-135/

Ye, Y., Zhu, B., Yun, J., Yang, Y., Tian, J., Xu, W., … & Li, Y. (2023). Comparison of antioxidant capacity and immune response between low salinity tolerant hybrid and normal variety of Pacific white shrimp (*Litopenaeus vannamei*). Aquaculture International, 1-16. https://link.springer.com/article/10.1007/s10499-023-01248-8

Yuan, H., Xie, M., Hu, N., Zheng, Y., Hou, C., Tan, B., ... & Zhang, S. (2023). Growth, immunity and transcriptome response to different stocking densities in *Litopenaeus vannamei*. Fish & Shellfish Immunology, 139, 108924. https://doi.org/10.1016/j.fsi.2023.108924.

Yue, S. (2008). The welfare of crustaceans at slaughter. Agribusiness Reports, 2008(2008), 5. https://www.wellbeingintlstudiesrepository.org/agreports/vol2008/iss2008/5/

Zacarias, S., Fegan, D., Wangsoontorn, S., Yamuen, N., Limakom, T., Carboni, S., ... & Shinn, A. P. (2021). Increased robustness of postlarvae and juveniles from non-ablated Pacific whiteleg shrimp, *Penaeus vannamei*, broodstock post-challenged with pathogenic isolates of Vibrio parahaemolyticus (VpAHPND) and white spot disease (WSD). Aquaculture, 532, 736033. https://doi.org/10.1016/j.aquaculture.2020.736033

Zacarias, Simão., Carboni, Stefano., Davie, Andrew., Little, David C. (2019) Reproductive performance and offspring quality of non-ablated Pacific white shrimp (*Litopenaeus vannamei*) under intensive commercial scale conditions in Aquaculture, Volume 503, , Pages 460-466 https://doi.org/10.1016/j.aquaculture.2019.01.018

Zhang, B., Lin, W., Huang, J., Wang, Y., & Xu, R. (2010). Effects of artificial substrates on the growth, survival and spatial distribution of *Litopenaeus vannamei* in the intensive culture condition. https://www.sid.ir/en/VEWSSID/J_pdf/101220100209.pdf