

Water Quality Dynamics and Survival of Pacific White Shrimp in Inland Saline Ponds

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ABSTRACT

The Pacific white shrimp, Litopenaeus vannamei, is now farmed far from the coast, in ponds filled with saline groundwater or irrigation drainage that has little in common with seawater except the presence of salt. Producers often assume that bringing such water to a suitable salinity is enough, yet reports of poor survival from inland farms are common. This narrative review asks what the published literature says about water quality dynamics in inland saline ponds and about the factors that govern survival of the shrimp stocked in them. It draws on work on the ionic composition of inland waters, on crustacean osmoregulation, on acclimation of postlarvae, on nitrogen and alkalinity management in ponds, and on shrimp disease and biosecurity, and it reports no new data. The central point is that the proportions of potassium, magnesium and calcium relative to sodium and chloride matter at least as much as total salinity, and that these proportions differ from one site to the next. Acclimation practice, nitrogenous wastes, pond management and disease add further layers, and most of the experimental evidence comes from small tank or short pond trials. The review concludes that a site-specific analysis of the water, followed by a modest pilot, is a better basis for stocking decisions than a salinity reading alone, and it outlines what better studies would report.

Keywords: Litopenaeus vannamei; Inland saline ponds; Ionic composition; Water quality; Survival; Biosecurity; Narrative review

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1. Introduction

Shrimp farming used to mean the coast. Ponds were dug in tidal flats and mangrove margins, filled with brackish water pumped from an estuary, and drained back when the crop was done. The Pacific white shrimp, *Litopenaeus vannamei*, changed that picture because it tolerates a wide range of salinity, and farmers in several countries began to stock it in ponds far from the sea, filled with saline groundwater, well water or irrigation drainage [1, 2]. For a

landholder with salt-affected soil that will no longer grow a conventional crop, the idea is appealing.

The difficulty is that saline water is not seawater diluted or concentrated to taste. Inland waters carry the signature of the rocks and soils they have passed through, and their mix of ions can differ sharply from that of the sea even when the salinity reading is the same [2, 3]. A shrimp that regulates the ionic make-up of its blood against the medium around it meets that medium one ion at a time, and

a shortage of a single ion can matter more than the total. Add to this the usual troubles of any pond (nitrogen wastes, swings in pH and oxygen, disease) and it is unsurprising that survival at inland farms is sometimes poor and often unpredictable (Figure 1).

This review asks what the published literature says about water quality dynamics in inland saline ponds and about the factors that govern the survival of shrimp stocked in them. The question has practical weight: a producer who treats salinity as the only variable may invest in ponds, pumps and postlarvae and discover only at harvest that the water lacked something the animals needed. It also has an honest complication. Much of what is known comes from small trials in tanks or short pond cycles, at a limited set of sites, and the water at one site cannot be assumed to behave like the water at another. The aim is a fair account of what is known, and of what has simply been repeated.

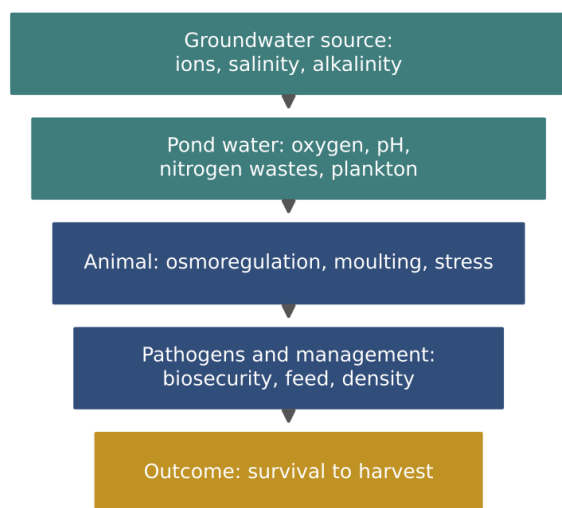


Figure 1. Layers between a groundwater source and shrimp survival (schematic, not data).

The article is a narrative review. It draws on work about the ionic composition of inland waters, crustacean osmoregulation, acclimation, pond water chemistry and shrimp disease, and it deliberately reports no new data. Where evidence is thin we say so, and we avoid quoting figures we cannot check against their sources.

2. Literature Review

2.1 Inland Saline Waters Compared with Seawater

Seawater has a remarkably constant composition: sodium and chloride dominate, with magnesium, sulfate, calcium and potassium in fairly stable proportions to one another. Inland saline waters

have no such constancy. A survey of waters from inland shrimp farms in several countries found that the proportions of the major ions differed from those of seawater diluted to the same salinity, and that the differences were not the same from one farm to the next [2]. Studies of well waters in the southern United States reached a similar conclusion, noting that some wells were short of particular ions even when their salinity looked suitable [1, 3].

The reasons are geological. Groundwater that has moved slowly through marine sediments, evaporite deposits or weathered rock picks up some ions and leaves others behind, and irrigation drainage reflects both the aquifer and the soil it has crossed. The standard texts on pond water quality describe how dissolved ions, alkalinity and hardness arise and why they differ between sources [4, 5]. For the shrimp farmer the practical point is plain: a salinity reading says how much dissolved salt there is and nothing about what the salt is made of.

This has long been recognised in the review literature on culture in inland low-salinity waters, which treats ionic composition as a first-order concern and reports that success with the species depends on matching the water to the animal, not simply on reaching a target salinity [1]. It is an easy lesson to state and a harder one to act on, since few farms routinely analyse their water beyond salinity, pH and a handful of nutrients.

2.2 How a Shrimp Handles Low-Salinity Water

Penaeid shrimp are strong osmoregulators. In dilute media the animal keeps the osmotic pressure of its blood well above that of the water by taking up ions across the gill and excreting dilute urine, and the gill is the central organ in this work [6, 7]. Detailed structure-function studies of crustacean gills and excretory organs describe pumps and transporters that move sodium, potassium, chloride and other ions, and their activity changes as an animal moves between salinities [8, 9].

L. vannamei copes with a wide salinity range, which is the basis of inland culture, and early work established that growth and survival respond to salinity and to temperature together rather than to either alone [10, 11]. Later studies of postlarvae and juveniles in low-salinity water showed that survival and growth depend on the age of the animal and on the salinity to which it is exposed [12], and that the osmotic response of the animal, together with growth, shifts across a salinity range [13]. Tolerance is therefore real but conditional.

Because regulation depends on specific transporters, it also depends on the ions available to them. Potassium has drawn most attention, since the sodium-to-potassium balance of the medium influences the ion-transport machinery, and work with the species at different sodium-to-potassium ratios reported effects on growth and energy use [14]. Experiments with related species in potassium-fortified inland saline water made the same point from the opposite side: where the water was short of potassium, adding it changed how the animals regulated their blood [15]. Table 1 summarises the ions that recur in this literature.

Table 1. Ions that matter most when inland saline water is used for shrimp culture.

Ion or property	Why it matters	Typical concern at inland sites
Sodium and chloride	Main osmotic and ionic components of the medium [6, 7]	Seldom limiting once salinity is set
Potassium	Ion transport and cell function in the gill and other tissues [1, 8]	Often low relative to sodium [2, 3]
Magnesium	Linked to survival and growth in low-salinity trials [1, 16]	Varies by site; sometimes short, sometimes ample
Calcium	Moulting and shell hardening; regulation at the gill [9]	Often adequate; ratio to magnesium may matter
Alkalinity and hardness	Buffering of pH in the pond [41]	May be high or low; ties to ionic make-up
Ionic ratios	Proportions relative to sodium or to seawater [2, 14]	Site-specific; need analysis, not assumption

Note: Qualitative summary of the cited literature. Concentrations differ widely between sites, so no values are given; the point is which ions to measure and why.

2.3 Magnesium, Calcium and Mixed-Salt Environments

Potassium is not the whole story. Work on low-salinity and mixed-salt environments examined how postlarvae fared in waters assembled from different combinations of salts, and found that survival and growth were sensitive to what the medium contained, not only to its strength [16]. Reviews of inland culture list magnesium and calcium alongside potassium as ions whose supply or proportion may limit performance in some waters and not in others [1].

Calcium has a distinct role because shrimp must harden a new shell after every moult, and the gill handles calcium as part of its general ion work [9]. A water that is rich in calcium but poor in magnesium, or the reverse, is not a simple case of surplus or shortage: the ratio between them may matter as much as either amount. We found no

study that settles the question across sites, and this is a gap the evidence has not closed.

2.4 Nitrogenous Wastes, Alkalinity and Pond Dynamics

Feed that is not eaten and waste that is excreted release ammonia into the water, and ammonia is oxidised to nitrite and then nitrate by bacteria. Both ammonia and nitrite are toxic to shrimp, and their effect varies with salinity: acute-toxicity work with juveniles at different salinity levels reported that sensitivity to each compound changed with the salinity of the test water [17, 18], and tests at low salinities confirmed that the margin of safety can be narrow [19]. Because the interaction depends on the ions present, as well as on salinity, a reading from one water cannot safely be applied to another.

Management of nitrogen has therefore been a major topic in intensive and zero-exchange systems. The ratio of carbon to nitrogen in the water can be adjusted so that heterotrophic bacteria take up inorganic nitrogen and turn it into biomass [20], and the broader literature on biofloc systems describes both the benefits and the challenges of this strategy [21]. Engineering analyses set out how photoautotrophic, autotrophic and heterotrophic routes remove ammonia, and what each demands in oxygen and alkalinity [22].

Field studies of high-intensity ponds with little water exchange describe how nutrients and microbial communities develop as a crop proceeds [23], and work on intensive raceways with limited discharge records how water quality shifts under that regime [24]. Reviews of no-exchange, biofloc-dominated systems point to a set of limiting factors that become important at high density, including the handling of solids, nitrogen and alkalinity [25]. Each of these studies concerns systems with their own water, so their findings apply to inland saline ponds by analogy rather than by direct evidence. This is one reason the same species can look hardy in one report and fragile in the next.

2.5 Disease and Biosecurity

Disease is the largest single cause of loss in shrimp farming, and it interacts with water quality in ways that are hard to untangle. The histories of shrimp pathogens in the Americas and in Asia describe viral and bacterial diseases that have repeatedly swept through farmed populations [26, 27], and reviews of virus diseases and emerging threats outline the agents that matter most [28, 29]. An illness of the hepatopancreas that spread

across several countries was shown to have an infectious cause, and its identification changed how farms thought about early mortality [30]. Reviews of threats to cultivated penaeid shrimp in Asia continue to emphasise how quickly new problems appear [31].

Inland farms have a partial advantage here, because distance from the coast and from neighbouring farms can reduce exposure to pathogens carried in water, and the source water is often free of the organisms that cause disease in coastal systems. The advantage is not guaranteed, since postlarvae, feed, equipment and people move between farms. The literature on disease and global food supply argues that disease will limit the sector unless it is managed deliberately [32], and a review of selective breeding and biosecurity describes how stock choice and routine hygiene prevent outbreaks [33]. Wider surveys of disease management in Asian aquaculture reach the same conclusion in a different setting [34].

Disease and salinity can also interact. Early work on *Penaeus vannamei* noted observations on how a viral infection and salinity behaved together [10], and the point has not lost its force: stress from poor water quality can make animals more vulnerable, and an outbreak can be mistaken for an ionic or nitrogen problem, or the other way round. This is why a report of poor survival that does not describe disease status is hard to interpret.

3. Materials and Methods

3.1 Scope and Question

The review asks one question in two parts. First, what is known about the dynamics of water quality in inland saline shrimp ponds, in particular its ionic composition, nitrogen, alkalinity and related variables? Second, how do these factors, together with acclimation and disease, bear on the survival of *L. vannamei*? The question was broken into sub-questions that any survival study would need to answer: what the water contained, how the animals were acclimated, how the pond was managed, what the disease status was, and how survival was measured. None of these steps is hard, but each is easy to skip when a stocking date is close.

3.2 Literature Assembly

The review draws on peer-reviewed work in five areas: the ionic composition of inland waters; crustacean osmoregulation; acclimation and low-salinity culture of the species; pond water chemistry and nitrogen management; and shrimp

disease and biosecurity. Sources were chosen for relevance, citation in the field and the clarity of their methods. Studies of other species, and of intensive systems that are not inland, are used for what they teach about mechanism and limits, not as proof of effects in inland ponds.

We did not run a formal systematic search and we do not claim one. This is a narrative synthesis, and the choice of sources reflects the authors' judgement. The practical consequence is that the review is a better guide to what a good study should report than to the size of any effect, and it avoids quoting survival percentages from individual trials that could not be checked against the primary papers for this article.

3.3 Appraisal Framework

To judge how far a report can be trusted, we used four questions. Does the report give the full ionic composition of the water, or only salinity [2]? Is the study large enough, and is the unit of replication the unit that received the treatment [35]? Does it describe acclimation and disease status? And does it run long enough, and under conditions close enough to a working pond, to say anything about a crop [36]? Table 2 lists the steps in acclimation and stocking that we looked for in descriptions of method.

4. Results

4.1 What the Inland Water Is Likely to Lack

The surveys and trials examined agree on a broad pattern. Many inland saline waters have a lower proportion of potassium than diluted seawater, and potassium is the ion most often named as limiting [2, 3]. Magnesium is the second most frequently discussed, with reports that animals reared in some low-salinity waters performed better when the supply of both ions was raised [1, 16]. The pattern is not universal: some waters are adequate, and some farms are reported to operate without any correction at all.

Sodium and chloride, by contrast, are seldom the problem once salinity has been set, since they dominate any saline water [6, 7]. Calcium is often abundant, sometimes strikingly so, and the worry in that case is the ratio to magnesium rather than a shortage. Figure 2 sketches how we read the evidence for each ion; the grid summarises judgement, not measurements. Small differences of this kind rarely look dramatic in a single day, but they add up over a crop.

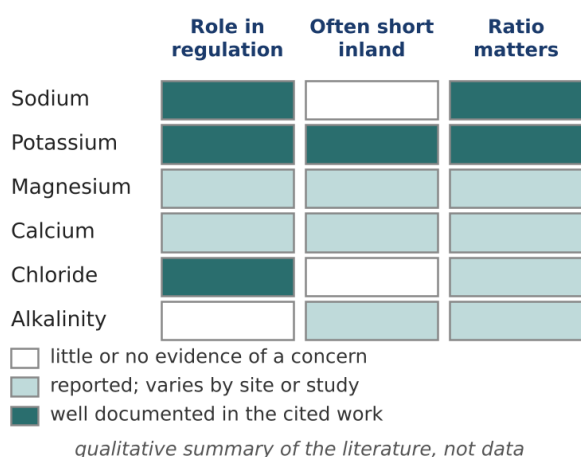


Figure 2. Evidence grid for major ions in inland saline water (qualitative summary, not data).

Correction by adding salts has been tried. The usual approach is to add the missing ions, most often potassium and magnesium, to the pond water, and the reports we reviewed describe it as workable but dependent on the cost and availability of the salt, as well as on the water [1, 15]. A different approach changes the animal rather than the water: work in an inland desert setting examined whether altering the diet could improve the osmoregulatory capacity of the shrimp, an idea with obvious appeal to farms that cannot easily alter their water [37]. The evidence for either strategy comes from a few sites.

4.2 Acclimation as a Source of Variation

Even where the water is adequate, the way animals are moved into it matters. Postlarvae shipped from a hatchery at one salinity and stocked in water at another must adapt, and the literature shows that the age of the postlarvae, the final salinity and the rate of change all influence survival [38]. Younger animals have been reported to tolerate abrupt change less well than older ones, which makes the timing of transfer as important as its speed.

Acclimation reports are often brief. A trial that says animals were acclimated to the test salinity, without saying over what period, by what steps and with what ions, leaves the reader unable to tell whether survival reflects the water or the transition. Some farms bridge the gap with a nursery phase in tanks or raceways before pond stocking, and intensive work with low-salinity groundwater suggests this can be a productive route, though the cited work concerns raceways and not earthen ponds [39]. Table 2 summarises the steps and the question each is meant to answer.

Table 2. Acclimation and stocking steps and the questions each should answer.

Step	Question to ask	Why it matters
Test the water	Which ions are short relative to seawater at this salinity? [2, 3]	Salinity alone hides deficits
Match batch to water	Is the postlarval batch old enough for this water? [38]	Age and tolerance are linked
Step down salinity	Was the change gradual, with ions checked on the way? [16, 38]	Abrupt change harms survival
Hold and observe	Did a nursery stage show the batch coping before pond stocking? [39]	Cheap early warning
Stock the pond	Are loading and feeding matched to what the pond can process? [23]	Wastes build faster than expected
Monitor	Are nitrogen, pH and oxygen recorded often enough? [40]	Problems begin before animals look unwell

Note: Steps summarise practices described in the cited literature; they are not a protocol and do not specify rates, which depend on the farm and the water.

4.3 Water Quality Through the Crop

Pond chemistry changes through a crop as feed is added, biomass grows and plankton populations rise and fall. Descriptions of semi-intensive and intensive ponds show nitrogen accumulating as the crop proceeds, with the risk of ammonia and nitrite peaks that tend to follow phases of rapid feeding [23, 40]. In systems that rely on bacterial communities to process waste, oxygen demand and alkalinity consumption both rise, so a pond that starts with low alkalinity can run into pH trouble sooner than one that starts with ample buffering [22, 41].

Here the ionic composition and the nitrogen cycle meet. If the toxicity of ammonia and nitrite to the animal depends on salinity, as the acute tests indicate [17, 18, 19], a pond with an unusual ionic make-up has an unusual margin of safety, and the margin may be smaller exactly when the animals are largest and the waste load is highest. No study we reviewed followed ions, nitrogen and survival together through a full crop in inland saline ponds, and so the interaction remains plausible but unmeasured.

4.4 Quality of the Evidence

Reports on inland saline culture commonly share a set of design limits (Table 3). Many trials run in small tanks for short periods, whereas the questions of interest concern whole crops in ponds, where natural productivity and the pond bottom contribute to nutrition and water quality in ways tanks cannot reproduce [36]. Animals are

often few, the number of replicate units is small, and animals sharing a tank are sometimes treated as independent replicates, which overstates the precision of the result [35].

Table 3. Common limits of the experimental evidence and what follows from them.

Limit	Consequence	What would help
Short tank trials	Poor guide to a full pond cycle [36]	Follow animals to harvest
Few replicate units	Unstable effects [42, 43]	More units; report intervals
Animals as replicates in shared tanks	Overstated precision [35]	Analyse at the unit treated
Ionic make-up not reported	Result cannot be transferred [2]	Report full water analysis
Disease status unrecorded	Mortality cause unclear [26, 31]	Screen stock; record diagnoses
Single water source	Site-specific answer [1]	Test several sources

Note: Limits are those discussed in the cited methodological literature or noted by the authors; they are not attributed to any single study.

Small studies in any field give unstable estimates, and those that reach statistical significance tend to overstate effects [42, 43]. Aquaculture is not special in this, but the case for particular ion corrections, acclimation protocols and nitrogen strategies rests largely on such studies. The sensible reading is that they identify what is worth testing and that they cannot, by themselves, say how much to expect from it. The point is not that a trial is poor, only that its result travels less far than its abstract suggests.

Reporting is a second problem. Many papers give salinity and perhaps potassium but not the full ion profile; few give disease screening of the stock; and survival is often reported as a bare figure at the end of a trial with no indication of when deaths occurred [2, 31]. A mortality that clusters in the first days points to acclimation, one that appears in the later weeks may point to nitrogen or disease, and a flat loss suggests something else again. Without timing, the cause is guesswork.

Publication practice adds a quiet bias. Trials in which a correction raised survival are more likely to be written up than those in which nothing changed, and site-specific successes are more likely to be reported than failures at sites that were abandoned. We cannot measure this bias, but any reader should assume it exists. Put plainly, the literature supports only a cautious statement: ion proportions matter, potassium and magnesium are the usual suspects, acclimation and disease modify the outcome, and the strength of each effect at a given site is not established by evidence we can

cite with confidence. That is a modest claim, and it is the one the evidence will currently bear.

4.5 Reading a Report of Survival

A reader meeting a claim that inland saline ponds support good survival can put a short series of questions to it. What was in the water, ion by ion? How and over what period were the animals acclimated, and from what starting point? What was the disease status of the stock, and how was it checked [26, 31]? When did mortality occur, and what were nitrogen, pH and oxygen doing at the time? A report that answers all four is uncommon, and one that answers none should be read as an observation, not as evidence of what the water can do.

Sites differ in water source, soil, climate and management, and an effect found at one is not automatically expected at another. Because trials are few and small, the variation between sites cannot yet be separated from chance, and the honest summary is a range of plausible outcomes rather than a single expectation [1, 42].

Environmental claims need the same scrutiny. A farm that avoids coastal habitat and uses salt-affected land may have a real environmental advantage, but its net effect depends on what happens to the water, the salt and the nutrients, and the disposal of saline water is a design question to settle before stocking [44, 45]. Shrimp aquaculture as a whole has documented environmental costs, and inland farms are not exempt from them [44, 45]. Statements that inland culture is sustainable are best replaced by measurements of inputs and outputs for the system in question.

5. Discussion

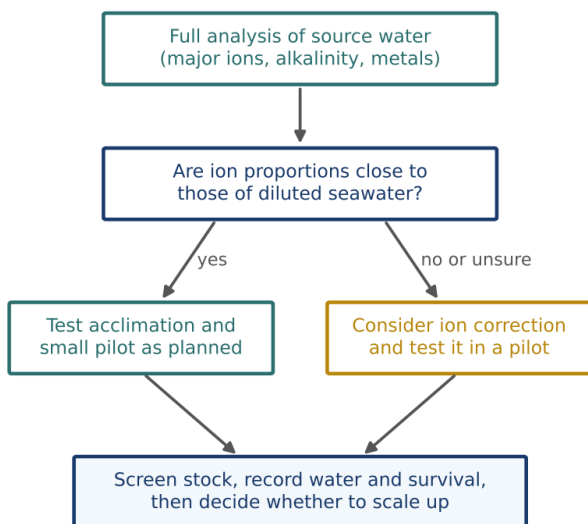
5.1 Interpretation and Practical Reading

The main finding of this review is a conditional one. Inland saline water can support the Pacific white shrimp, and many farms have shown it, but success depends on what the water contains, on how animals enter it and on how nitrogen and disease are handled. That fits what is known of crustacean physiology, in which the gill must work with the ions on offer [7, 8], and it implies that the useful question for a farmer is not whether inland saline water works but what this water lacks and what this farm will do about it. Nothing here argues against inland culture; it argues for knowing the water before stocking it.

The second conditional concerns scale and money. A correction that makes sense in a small pilot may not pay at the scale of a large pond, since salts are

bought by the tonne and the amounts needed rise with volume. A farm with cheap access to the missing ions, a good hatchery relationship and trained staff may gain; one that lacks them may not. The same arithmetic can come out differently on neighbouring farms, and a single successful site is weak evidence for another.

A third point concerns uncertainty about mechanism. Several variables move together: salinity, ion ratios, alkalinity, ammonia and nitrite, and disease pressure. In practice, a farm that sees poor survival cannot say which is responsible without measuring them, and a trial that changes one variable while others drift cannot say either. A sketch of a sensible order of work is given in Figure 3. It begins with an analysis of the water and ends with a recorded pilot, and nothing in it is costly compared with the loss of a failed crop. Read this way, a failure in one pond is a prompt for measurement, not a verdict on the site.



schematic of a decision sequence, not a protocol

Figure 3. Decision sequence for assessing a site before stocking (schematic, not a protocol).

Three findings would change this reading. A well-designed multi-site study in which corrected and uncorrected ponds were followed to harvest, with ions, nitrogen and disease all recorded, would show how much of the variation in survival is attributable to ionic make-up. Clear evidence that a particular ion ratio is harmful or protective across waters would replace the current site-by-site picture with a rule. And long-term data on the fate of saline discharge would settle whether inland culture is as benign as its advocates suggest [1, 44].

5.2 Limitations

This is a narrative review and shares the limits of that form. The selection of sources reflects

judgement, no formal search or quality scoring was done, and the review does not quote survival percentages from individual studies, because these could not be checked against the primary reports for this article. A reader who needs an effect size should consult the original studies directly and apply the appraisal questions above, or wait for a formal systematic review.

The review also draws on evidence from other species, from intensive tank and raceway systems and from coastal ponds, all of which are imperfect proxies for earthen inland ponds. Studies of related species in potassium-fortified saline water, and of toxicity in juveniles in laboratory tanks, describe mechanisms that may or may not operate in the same way in a pond [15, 18]. We have used them to frame hypotheses, and the conclusions should be read in that light. Reviews of this kind are more useful when they say where the evidence stops than when they smooth it over.

5.3 Implications for Study Design

A study that could settle the question would report the full ionic profile of the source and pond water at intervals, state the age and source of the postlarvae, describe acclimation step by step and screen the stock for the main pathogens [31, 33]. It would use enough ponds, or enough tanks if tanks are all that is available, to estimate variability, and would treat the pond or tank as the unit of analysis [35]. It would record the timing of mortality and the nitrogen, pH and oxygen record that goes with it.

It would also run to harvest. A short trial can show whether animals survive the transfer, but it cannot show whether they will survive a crop, grow at an acceptable rate and reach a size the market wants. Multi-site designs, in which the same protocol is run on waters of different composition, would be especially valuable since they separate the effect of a protocol from the effect of a site. These requirements are demanding, but they are those that distinguish a result a farmer can use from one that only supports a hunch.

5.4 Directions for Future Work

Three needs stand out. First, a formal systematic review with a transparent search and quality appraisal of the inland low-salinity literature. Second, multi-site trials in waters of different composition that follow ions, nitrogen and disease together through a crop. Third, work on the economics of ion correction and on the treatment or reuse of saline effluent, both of which determine whether a technically feasible practice is also viable [1, 37].

5.5 Practical Reading for Advisers and Producers

For an adviser, the sensible position is neither to discourage inland culture nor to promise results. A producer who wishes to try it can begin with a complete water analysis from a laboratory, compare the ion proportions with those of diluted seawater, and decide whether a correction is likely to be needed [1, 2]. A small pilot pond or nursery stage, stocked with a batch of known origin and screened for disease, can then show whether animals acclimate and survive before any large commitment is made [38, 39].

6. Conclusion

Inland saline ponds can grow Pacific white shrimp, and the biology explains why: the species is a strong osmoregulator that tolerates a wide salinity range. What the literature also shows is that salinity is only the beginning. The proportions of potassium, magnesium and calcium relative to sodium differ from site to site, acclimation practice affects survival, nitrogen wastes behave differently as salinity and ionic make-up change, and disease can mimic or amplify each of these. The evidence is weaker than the confidence with which it is sometimes quoted, because most of it comes from small trials at a few sites.

For the practitioner the message is practical rather than discouraging. Analyse the water before stocking, acclimate carefully, screen the stock, keep records of nitrogen, pH, oxygen and mortality, and pilot before scaling. For the researcher, the opportunity is a set of multi-site studies, followed to harvest and fully reported, that turn a plausible set of cautions into measured guidance that inland farmers can rely on.

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9. Conflict of Interest

The authors declare no conflict of interest.

10. Author Contributions

D.C. conceived the review and wrote the sections on water quality and pond management. C.R. wrote the sections on disease, biosecurity and study design. G.F. wrote the sections on

osmoregulation, acclimation and environmental aspects. All authors revised the manuscript and approved the final version.

11. Ethics Statement

This is a review of published literature. No animals were used and no ethical approval was required.

12. Data Availability

No new data were generated. All sources are cited in the reference list.

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