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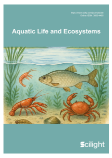

Review

Review and Outlook for Aquaculture of Scalloped Spiny Lobster (*Panulirus homarus*)

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Abstract: The scalloped spiny lobster (*Panulirus homarus*) is a commercially significant species widely distributed in the Indo-Pacific region. With wild populations experiencing decline, there is growing interest in its aquaculture potential. This review consolidates global research conducted between 2000 and 2025, addressing four critical areas: *Germplasm Resources*, *Aquaculture Technologies*, *Artificial Seed Production*, and *Feed, Toxicology, and Diseases*. Progress has been made in germplasm resources exploration and captive breeding, significant challenges remain. One of the major constraints is the continued dependence on wild-caught seeds, largely due to the inability to achieve consistent artificial culture from the phyllosoma to puerulus stages. In addition, the absence of specialized formulated diets tailored to the species' complex nutritional requirements constrains larval growth, survival, and overall production efficiency. Efforts to close the life cycle under culture conditions will require innovations in larval rearing protocols, improved water quality and environmental control, targeted research on larval nutrition, and the application of functional genomics to accelerate selective breeding. Strong interdisciplinary collaboration among genetics, nutrition, physiology, and engineering is essential to overcome these technical bottlenecks and establish an environmentally responsible, economically viable aquaculture framework for *P. Homarus*.

Keywords: *Panulirus homarus*; aquaculture; germplasm resource; captive breeding; aquaculture techniques

1. Introduction

The scalloped spiny lobster (*Panulirus homarus*) is a decapod crustacean belonging to the family Palinuridae. It is widely distributed throughout the Indo-Pacific region, ranging from East Africa to Japan, Indonesia, Vietnam, the Philippines, Australia, and French Polynesia. Based primarily on abdominal sculpturing, coloration patterns and habitat diversion, three subspecies have been recognized: (1) *P. h. homarus*. This subspecies is predominantly green and occurs across a broad range from South Africa to the Pacific, with its type locality in Indonesia; (2) *P. h. megasculpta*. This subspecies is characterized by yellowish abdominal spots, restricted to the Arabian Sea region; (3) *P. h. rubellus*. This subspecies is distinguished by large squamae and a brick-red coloration, is confined to the south-eastern African coast and Madagascar [1]. Recent molecular studies analysing mitochondrial and combined nuclear–mitochondrial datasets suggest that *P. h. rubellus* has likely evolved reproductive barriers, whereas *P. h. homarus* shows no significant divergence from the described *P. h. megasculpta* [1,2].

Consistent with the general pattern observed in other decapod crustaceans, *P. homarus* periodically undergoes ecdysis to facilitate growth, and its early life cycle is characterized by a complex metamorphosis through multiple larval stages. First stage of puerulus is free-swimming, non-feeding, transparent and lobster-like. Within 2–3 weeks, it becomes pigmented, settles to the bottom, and moults into an adult. Maximum recorded total length is 31 cm with carapace length of 12 cm [3]. Dietary requirements vary across life stages, but juveniles and adults are omnivorous, feeding on small crustaceans, molluscs, worms and algae. Compared to other members of its genus, *P. homarus* exhibits broader adaptability to temperature and salinity and may possess a faster growth rate among tropical lobsters.

P. homarus has long been exploited in Indo-Pacific fisheries, but by the mid-1970s, overfishing caused marked declines in wild stocks, prompting concerns over resource depletion. In response, several countries initiated research into aquaculture techniques to cultivate *P. homarus* under controlled conditions. Aquaculture of *P. homarus* remains heavily reliant on the capture of wild juveniles. Indonesia and Vietnam, with abundant wild seed resources in their coastal waters, are the leading producers of *P. homarus*, primarily using net cage aquaculture. In China, research efforts have focused primarily on artificial breeding environments, followed by studies on individual development and seed resources. However, the *P. homarus* aquaculture industry in China remains small and relies largely on imported seed stock. Due to the limited scale of the *P. homarus* aquaculture industry, species-specific production volumes and economic values are not available, as global databases and trade records generally classify *P. homarus* under the broader categories of the Panulirus genus or spiny lobsters.

Despite recent progress and the gradual expansion of farming practices, aquaculture of *P. homarus* continues to face several fundamental constraints. A major concern is the absence of artificially bred seed, resulting in a persistent reliance on wild-caught juveniles; the lack of nutritionally balanced formulated feeds; and the limited development of intensive farming technologies. This review systematically examines literature published between 2000 and August 2025, focusing on germplasm resources, artificial seed production, and aquaculture technology. As a high-value crustacean species with considerable development potential, *P. homarus* requires targeted research to overcome these challenges. This study aims to consolidate existing research, evaluate industrial prospects, and highlight priority scientific and technical issues that must be addressed to achieve full-lifecycle aquaculture and ensure the sustainable utilization of *P. homarus*.

2. Materials and Methods

Publications in Chinese were retrieved from the China National Knowledge Infrastructure (CNKI) database. English publications were sourced from the ScienceDirect database and the Web of Science Core Collection (SCIE). The search strategy included querying the article title, abstract, and author keywords for the term "*Panulirus homarus*".

The search for publications spanned from 1 January 2000 to 24 August 2025. Microsoft Excel was used to organize information such as paper titles, author keywords, abstracts, publication dates, authors, and journal sources. The country of origin for each publication was determined by the institutional affiliation of the first author. In cases where the first author was affiliated with multiple institutions, the address of the first-listed institution was used. The relevance of each publication to the target species was evaluated by reviewing the titles and abstracts. Articles confirmed to be relevant were categorized into four thematic areas: *Germplasm Resource*, *Aquaculture Technology*, *Artificial Seed Production*, and *Feed, Toxicology and Disease*.

3. Results

A total of 181 Chinese and English publications were identified 52 publications were retrieved from CNKI, 30 from ScienceDirect, and 99 from the SCIE database. After removing non-research publications, duplicate records, and studies unrelated to *Panulirus homarus*, 150 relevant publications were retained for analysis. No publications were identified in 2001 or 2002. 2022 had the highest number of publications, with 14 recorded (Figure 1).

Among the 150 publications spanning from 1 January 2000 to 24 August 2025 (Figure 1), studies focusing on *Germplasm Resources* accounted for 30%, addressing topics such as genetic resources and fisheries management. Publications on *Aquaculture Technology* represented 28.67%, primarily examining controlled rearing environments. Research related to *Artificial Seed Production* constituted 22%, encompassing investigations into individual development and reproduction, whereas *Feed and Toxicology* comprised 19.33%, focusing on feed formulation and heavy metal pollution.

In terms of geographic distribution (Figure 2), China contributed the largest number of publications, totalling 52, with *Aquaculture Technology* being the most intensively studied area, represented by 19 publications. India ranked second with 28 publications, showing the strongest emphasis on *Feed, Toxicology and Diseases* with 11 publications. Indonesia followed with 17 publications, the most concentrated on *Aquaculture Technology* with 9 publications.

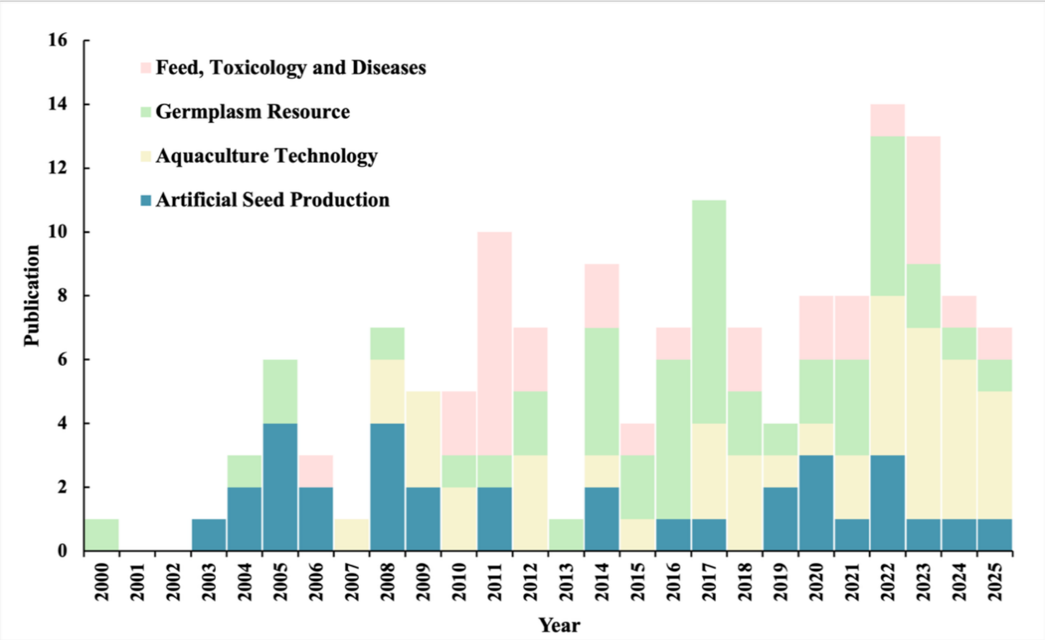

Figure 1. Annual number of publications on *Panulirus homarus* (1 January 2000 to 24 August 2025). Over this period, publications are categorized as follows: *Feed, Toxicology, and Diseases* (29 publications, 19%), *Germplasm Resources* (45 publications, 30%), *Artificial Seed Production* (33 publications, 22%), and *Aquaculture Technology* (43 publications, 29%).

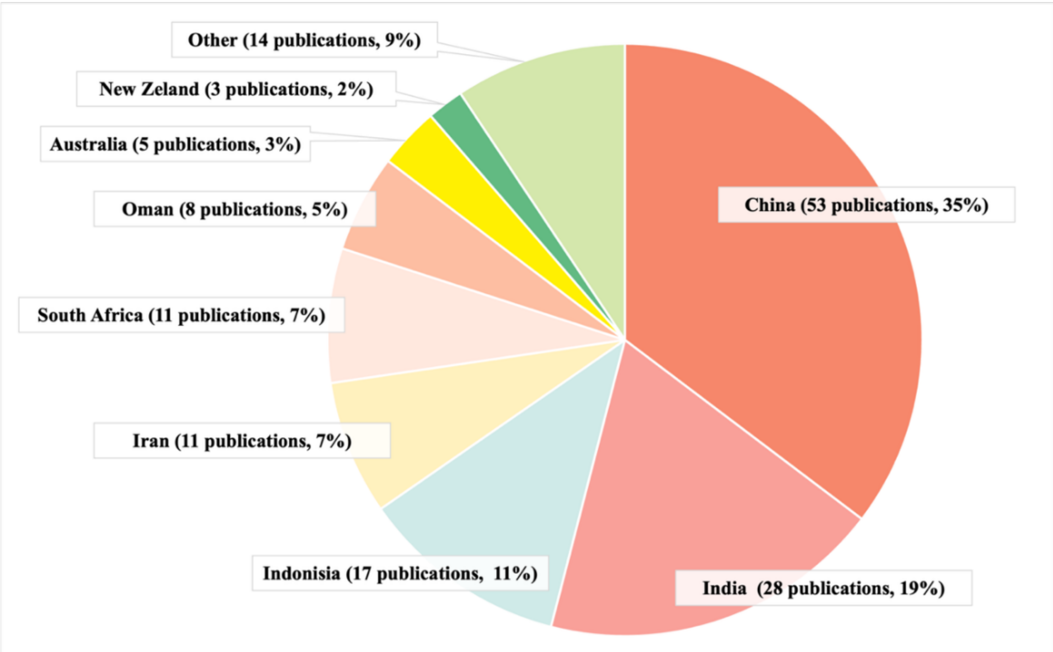

Figure 2. Proportion of *Panulirus homarus*' publications by country.

3.1. Germplasm Resource

3.1.1. Species Identification

In species identification, early classifications that relied solely on comparative morphology were impeded by strong phenotypic similarities among *Panulirus* congeners. The taxonomic resolution of *P. homarus* has been significantly enhanced through molecular systematics. DNA barcoding, especially the analysis of the mitochondrial cytochrome c oxidase I (COI) gene, has provided a reliable framework for species identification, clearly differentiating *Panulirus homarus* from related species by revealing interspecific genetic divergences that far exceed intraspecific variation [4,5]. Phylogenetic studies have further revealed complex phylogeographic structuring across the Indo-Pacific, indicating historical biogeographic barriers that have driven allopatric divergence [1,6]. Recent genomic analyses using genome-wide SNPs and mitochondrial DNA have further examined population divergence in the *P. homarus* species complex across the Indo-Pacific, revealing a complex evolutionary history involving multiple divergence events, a hybrid origin of the NW Indian Ocean population, and asymmetric gene flow [6]. These insights into species boundaries and intraspecific diversity form a critical basis for targeted conservation and management efforts.

3.1.2. Germplasm Resource Management

Due to germplasm resource management, the sustainable utilization of *P. homarus* germplasm depends on a detailed understanding of its population genetic architecture and the environmental factors shaping connectivity. High-resolution markers, including microsatellites and single nucleotide polymorphisms (SNPs), have uncovered significant genetic structuring among major geographic regions separated by well-defined biogeographic barriers such as the Mozambique Channel and key ocean currents, which restrict larval dispersal and limit gene flow [6–8]. In contrast, populations along uninterrupted coastlines, such as those in Oman, often exhibit genetic homogeneity, supporting their treatment as single management units [9,10]. Wild stocks are under increasing pressure from overexploitation, as indicated by declining landings in major fisheries [9,11]. A critical concern is the large-scale, frequently unregulated harvest of wild pueruli for aquaculture seed, which threatens natural recruitment and may undermine stock resilience. Therefore, integrating genetic data into fisheries policy is essential to safeguard long-term population viability.

3.1.3. Molecular Markers, Genome, and Functional Genes

In the field of molecular markers, genome, and functional genes, research on *P. homarus* has evolved from developing neutral genetic markers for population studies to utilizing genomic resources for functional analysis and trait improvement. This transition marks a shift from purely descriptive population studies to applied genomic research. The recent release of a high-quality, chromosome-level genome assembly signifies a major milestone, offering a robust platform for evolutionary research, trait mapping, and genomics-assisted breeding [11]. This genomic resource has expedited the discovery of genes associated with commercially important traits. At the functional level, several key gene families have been characterized. In terms of immune defence, key pattern-recognition receptors and effector molecules, such as C-type lectins (PhLec) and antimicrobial peptides including β-defensin (Ph-Def), have been cloned and demonstrated to be strongly upregulated following bacterial and viral challenges [12,13]. Similarly, genes regulating reproduction and growth have been identified. In reproductive physiology, neurohormones like crustacean hyperglycaemic hormone (PhCHH) and gonad-inhibiting hormone (PhGIH) have been identified as regulators of ovarian maturation in response to environmental cues such as photoperiod [14,15]. Furthermore, growth-related genes, particularly the ecdysone receptor (PhEcR), have been implicated in moulting and regeneration [16]. Collectively, these findings highlight the potential for molecular tools to inform germplasm management. The ongoing functional validation of these genes provides critical targets for marker-assisted selection and supports the development of improved aquaculture strains with enhanced disease resistance, reproductive control, and growth performance.

3.2. Artificial Seed Production

3.2.1. Sexual Maturity and Reproductive Output

Sexual maturity in *Panulirus homarus* is strongly correlated with body length, with larger individuals generally exhibiting more advanced ovarian development. Based on ovarian development and the presence of ovigerous setae, approximately 50 percent of females reach maturity at a carapace length (CL) of 50–63 mm [17], while individuals measuring 66–80 mm CL contribute about 62 percent of total egg production [18]. Fecundity increases significantly with female size, with the number of eggs per spawning event ranging from 1.6×10^4 to 5.3×10^5 [19]. Under artificial conditions, enhanced nutrition and improved management practices promote female growth and allow repeated reproduction [19]. In captivity, optimization of rearing conditions can increase the annual spawning frequency from fewer than two events to four per year, with some females spawning as many as five to seven times annually; the interval between successive spawning averages 15–20 days [20].

3.2.2. Hormonal Regulation and Reproductive Manipulation

Ovarian development in *P. homarus* is regulated by multiple hormones. Transcript levels of crustacean hyperglycaemic hormones (PhCHH-A and PhCHH-B) in the female eyestalk rise in parallel with ovarian maturation [14]. Steroid hormones such as estradiol-17β and progesterone gradually increase through oocyte stages II–IV, peaking at stages III and IV, respectively, while serotonin (5-HT) exhibits stage-specific changes synchronized with ovarian development [17]. These findings indicate that the eyestalk X-organ-sinus gland complex and its secreted hormones coordinate oogenesis, and that both steroid hormones and neurotransmitters play central roles in gonadal maturation [17,21]. Eyestalk ablation, which entails the physical removal of the eyestalks, is widely used to manipulate hormonal control of growth and reproduction in *P. homarus*. Bilateral eyestalk ablation (BESA) accelerates both somatic growth and reproductive processes. In the early moult stage, eyestalk ablation stimulates oogenesis, whereas ablation in late moult stages promotes earlier entry into premoult but yields relatively lower reproductive activity [22]. In addition, eyestalk ablation enhances larval survival, stimulates feeding, and increases body weight and length without markedly affecting the moulting cycle [23]. In sexually mature females, it alters fatty acid composition, producing a predominance of stearic and oleic acids [21].

3.2.3. Embryonic and Larval Development under Culture Conditions

Embryonic development in *P. homarus* is strongly influenced by environmental factors. Development occurs within tolerance ranges of 7–36 °C for temperature, 15–45 ppt for salinity, and pH 5.8–9.4, with optimal conditions at 15–30 °C, salinity 30–35 ppt, and pH 7.0–8.5. Toxicity of ammonia and nitrite nitrogen increases with concentration and exposure duration; safe concentrations for embryos are 2.66 mg L^{-1} and 13.54 mg L^{-1}, respectively. Fertilized eggs hatch into phyllosoma larvae within 20–25 days at 27–30 °C, yielding up to 3×10^5 larvae per brood [24]. Under normal feeding regimes, early phyllosoma undergo eight moults and attain a body length of about 4.69 mm within 69 days [21]. Newly hatched phyllosoma exhibit high starvation tolerance, surviving up to 192 h without food; delayed initial feeding for 24–36 h does not impede moulting to the next stage, starvation beyond 120 h lowers metamorphic success. Feeding on *Artemia* for 60 h enables limited moulting even without subsequent feeding [25]. Feeding trials demonstrate that a mixed diet of *Platymonas* plus *Artemia* provides the highest survival rate (25 percent after 48 days) and metamorphic success, with some larvae completing six to nine moults, whereas diets of *Artemia* alone or *Chaetoceros* plus *Artemia* yield lower survival and fewer moults [26]. Later-stage phyllosoma can consume more structurally complex prey [27]. High-density culture increases fouling and disease transmission, while larval interactions appendage damage swimming ability and survival. Individual rearing with fish-oil-enriched *Artemia* maximizes survival and metamorphic rates, allowing phyllosoma to reach 4.68 mm and complete eight moults within 69 days [21].

3.3. Feed, Toxicology and Diseases

3.3.1. Nutritional Requirements and Feeding Strategies

The nutritional requirements of *Panulirus homarus* at various developmental stages are not well understood, and stage-specific formulated feeds have not been fully developed. Live feeds and inert feeds remain the primary options for larval rearing (Table 1). During the phyllosoma stage, Artemia is commonly used. Feeding phyllosoma with Artemia enriched with 0.4% mannan oligosaccharides (MOS) has been shown to significantly improve survival rates [28], while supplementation with the microalga *Nannochloropsis salina* effectively enhances the essential fatty acid content in lobster larvae [29]. As larvae grow, their requirement for MOS gradually decreases [30], and feeding practices tend to shift toward inert feeds. Mixed diets consisting of fish, shrimp, and bivalves produce the highest survival and growth performance, outperforming single-ingredient inert feeds [31]. Among single fresh feeds, bivalves such as clams and green mussels significantly improve juvenile growth [31,32] and feed utilization efficiency [32]. Semi-cooked bivalve meat supports similar growth to fresh bivalve meat increases survival while significantly reducing feed costs [33]. Formulated diets are not yet optimized more effective when combined with fresh feeds. A 75:25 formulated-to-fresh feed ratio promotes subadult growth more effectively than a 100% formulated diet (weight gain 0.73 g), without compromising survival [34]. Notably, high-carbohydrate diets induce elevated amylase activity and histopathological abnormalities in the hepatopancreas of lobster larvae [35]. A dry compound feed containing 54.5% crude protein and stabilized with sodium alginate (3%), commercial plant gum (1%), and agar (3%) produces pellets of 103–114 mm with good stability and palatability [36].

Table 1. Summary of experimental design and culture conditions for *Panulirus homarus*.

Weight (g)	Stocking Number	Life Phase	Feed	Culture System/Facility	Environmental Parameters					Publications
					Temperature (℃)	Salinity (ppt)	pH	Dissolved Oxygen (mg L^{-1})	Additional	
\	30	Egg	\	Plastic Tank	15–30	30–35	7.0–8.5	\	\	Luo et al. [24]
\	20	Phyllosoma	Artemia + 0.4% MOS (live)	Cement Pond	28–29	30 ± 0	8.0–8.2	\	\	He et al. [28]
~0.16	10	Puerulus	Formulated feed + 0.4–0.6% MOS	Marine Net Cage	27–28.5	\	8.0–8.3	5.0–6.2	DO: 6.5 ± 0.2 mg L^{-1}	Hoang et al. [30]
60	2	Puerulus	Clam (inert)	Fiberglass Reinforced Plastic (FRP) Tank	\	\	\	\	\	Arumugam et al. [32]
50.30–62.25	300	Puerulus	Semi-cooked shellfish (inert)	Cement Pond	22–31	28–32	7.8–8.4	5	Light intensity: <400lx	Huang et al. [33]
191.10 ± 18.10	10	Adult	Formulated + inert	FRP Tank	27.3–29.4	32–33	\	5.0–6.2	DO: 5.0–6.2 mg L^{-1}	Giri et al. [34]
171.28 ± 23.12	6	Adult	Crab (inert)	Recirculating Aquaculture System (RAS)	28–32	27–34	7.5–8.5	7	Ammonia-N concentration (NH_3-N): 0.2 mg L^{-1}; Nitrite-N concentration (NO_2^--N): 0.02 mg L^{-1}; Light intensity: 500lx; Photoperiod: 12L:12D	Wang [37]
20.30–43.60	5	Puerulus	Shrimp + crab (inert)	Cement Pond	23–31	28–32	\	5	Light intensity: <400lx	Shen et al. [38]
88 ± 5	12	Puerulus	Formulated feed (protein 460 gkg^{-1})	FRP Tank	\	35 ± 8	8.2 ± 0.02	5 ± 0.5	NH_3-N: <1 mg L^{-1}; NO_2^--N: <0.1 mg L^{-1}; H2S: <0.1 mg L^{-1}	Rathinam et al. [39]
58.05 ± 1.69	20	Puerulus	Fish (inert)	FRP Tank (RAS)	27.1–27.9	27.0–31.5	\	4.53–6.08	DO: 4.53–6.08 mg L^{-1}; $CaCO_3$: 200 mg L^{-1}	Supriyono et al. [40]

3.3.2. Toxicology of Pharmaceuticals and Heavy Metals

In lobster aquaculture, the toxic effects of pharmaceuticals and heavy metal pollution on the *P. homarus* show significant differences. Pharmaceuticals commonly used in recirculating aquaculture systems (RAS) to control bacteria and parasites, such as potassium permanganate, formaldehyde, and trifluralin, have been reported to have safe concentrations for phyllosoma larvae of 0.31 mg L^{-1}, 5.34 mLm^{-3}, and 0.16 mL m^{-3}, respectively [27]. Their primary function is pathogen management without inducing broad structural damage to the organism [27]. In contrast, heavy metal contamination, more frequently encountered in open-water cage culture, exhibits substantially higher toxicity and can trigger pathological alterations across multiple tissues and organs. For instance, the 96-h LC_{50} values for cadmium (Cd^{2+}) and mercury (Hg^{2+}) in *P. homarus* are 0.9500 mg L^{-1} and 0.0227 mg L^{-1}, respectively, with very low safe concentrations (Cd^{2+}: 0.0095 mg L^{-1}; Hg^{2+}: 0.000227 mg L^{-1}) [41]. Exposure to sublethal concentrations of copper (9.55–19.1 μg L^{-1}) for 28 days induced widespread histopathological damage in the hepatopancreas, muscle, gills, midgut, thoracic ganglia, and heart, manifested as tubule necrosis, muscle fibre disruption, gill lamellae structural impairment, haemocyte infiltration, and chromosomal aberrations. These changes impair physiological functions such as nutrient absorption, osmoregulation, and neural transmission, accompanied by changes in wet weight proportions and abnormal body coloration, ultimately affecting survival and growth [42].

3.3.3. Embryonic and Larval Development under Culture Conditions

The risk of disease in *P. homarus* varies with aquaculture systems, as open-water cages are generally more susceptible than land-based farms. High stocking densities and poor water quality can increase stress and aggression, leading to injuries that facilitate bacterial infection, while the accumulation of food and carcass residues further promotes pathogen spread. In land-based systems, ciliates, bacterial gill rot, *Mucor* infections, and unsuccessful moulting are typically managed through water exchange, chemical treatments, or feed interventions [43]. The identification of the β-defensin Ph-Def in *P. homarus* indicates a role in innate immunity [13]. Bacterial pathogens, including *Aeromonas hydrophila* and *Vibrio spp.*, are present in wild populations, with some isolates exhibiting high antibiotic resistance [44]. White spot syndrome virus exhibits viral susceptibility that depends on the route of exposure, causing complete mortality after intramuscular injection but minimal effects when given orally [45].

3.4. Aquaculture Technology

3.4.1. Thermal Tolerance and Temperature-Dependent Physiology

Panulirus homarus exhibits distinct thermal tolerances across its life stages. Embryos develop within a broad range of 7–36 °C, with optimal development occurring between 15–30 °C [24]. Adults can survive temperatures ranging from 13–36 °C, but they achieve maximum performance at 20–30 °C [31,46]. Short-term exposure to extreme high (e.g., 36 °C) or low (below 13 °C) temperatures triggers stress responses, similar to those observed in yellowfin tuna (*Thunnus albacares*) [47]. However, *P. homarus* can acclimate through physiological adjustments such as dormancy and a markedly reduced metabolism at 12 °C [48]. Growth and moulting are highly temperature dependent. The highest specific growth rate (SGR), moult increment (64.24%), and feed efficiency occur at 28 °C. Although higher temperatures (e.g., 31 °C) shorten the moulting cycle, they increase the feed conversion ratio (6.43) and metabolic cost, indicating suboptimal energy utilization [31,46]. The metabolic rate, reflected by oxygen consumption, rises significantly with temperature, from 0.0645 mgg^{-1} h^{-1} at 25 °C to 0.1879 mg g^{-1} h^{-1} at 33 °C, elevating the risk of hypoxia under high temperatures [49]. Digestive enzyme activities (pepsin, amylase, and lipase) also show temperature dependence, with optima at 25–30 °C [50].

3.4.2. Effects of Salinity and pH on Growth and Physiology

Salinity and pH are two crucial abiotic factors shaping the physiology and aquaculture performance of *P. homarus*. The species demonstrates euryhaline adaptability, tolerating salinities from 15 to 45 ppt, with optimal growth and survival achieved at 28–35 ppt [31,51]. Low salinity (15–20 ppt) induces gill damage, oxidative stress (elevated SOD, GPx, and MDA [51]), increased energy expenditure on osmoregulation (via heightened GDH/GPT activity [51]), and detrimental shifts in gut microbiota toward opportunists like *Photobacterium* and *Vibrio*, accompanied by suppression of antibiotic biosynthesis pathways [52]. High salinity (38–45 ppt) disrupts calcium homeostasis [51,53] and compromises immune function, reducing total hemocyte count and nitroblue tetrazolium reduction activity [53]. Oxygen consumption and ammonia excretion are minimized at 26–30 ppt, indicating peak metabolic efficiency within this range [49]. Similarly, pH significantly affects embryonic development and metabolic activity. Embryos tolerate pH 5.8–9.4 but develop optimally at pH 7.0–8.5 [24]. Oxygen consumption rate decreases as pH increases from 7.4 to 8.6; however, the tolerance to hypoxic conditions may be compromised under alkaline conditions (e.g., suffocation point 0.2341 mg L^{-1} at pH 8.0) [49].

3.4.3. Influence of Light Regimes on Behaviour and Reproduction

Light conditions, including intensity and photoperiod, profoundly influence behaviour, growth, reproduction, and metabolic rhythms. *P. homarus* displays strong negative phototaxis, preferring dim light environments, with red light eliciting the highest habitat preference (58.61%) [54]. An intensity of 500 LX supports optimal growth, physiological performance, and expression of circadian clock genes [37]. Regarding photoperiod, a 12L:12D cycle yields the highest weight gain rate (WGR), specific growth rate (SGR), and promotes favourable activity levels of digestive enzymes (e.g., lipase), immune enzymes (AKP, LZM), and antioxidant enzymes (T-AOC, CAT, SOD), along with maintaining intact hepatopancreatic structure [55]. An extended photoperiod (14L:10D) enhances ovarian development in females, significantly increasing the gonadosomatic index (GSI) and reducing expression of gonad-inhibiting hormone (GIH) in the eyestalk, while upregulating crustacean hyperglycaemic hormone (CHH) isoforms PhCHH-A and PhCHH-B [9,56]. Consistent with its nocturnal nature, oxygen consumption at night is 67% higher than during daytime, aligning with its nighttime foraging behaviour [57].

4. Challenges and Further Goals

4.1. Current Limitations

Despite significant advances in scientific research and aquaculture technology, several critical challenges impede the sustainable aquaculture of *Panulirus homarus*. One major issue is germplasm resource management. Wild seed collection still dominates aquaculture practices, leading to inconsistent seed quality. Excessive focus on populations of known origin has created a high risk of overexploitation of natural stocks. Moreover, standardized protocols for the optimal spatiotemporal collection of healthy seedlings remain undeveloped, which not only increases seedling mortality during collection but also results in failure to recruit new seedlings while simultaneously damaging wild populations.

While genomic tools have revealed high genetic diversity and population structure, the practical application of functional genomic findings remains limited. Because full life-cycle aquaculture has not yet been achieved, the establishment of stable broodstock populations and the implementation of selective breeding programs are severely constrained.

Significant progress has been made in the rearing of post-puerulus juveniles, and preliminary insights have been gained into aspects of the species' biology, including stress tolerance, metabolism, and development. However, knowledge of how these processes vary across different culture systems remains insufficient. This gap is particularly evident in disease research, where understanding of common pathogens affecting *P. homarus* is limited, and effective prevention and treatment strategies are lacking.

Most critically, artificial seed production has not been achieved at a commercial scale due to the many unknowns of larval development, particularly during the phyllosoma-to-puerulus transition. Detailed data on maximum rearing age achieved in experimental settings, stage-specific mortality rates, and the precise environmental parameters required for each stage remain largely absent, leaving major gaps in knowledge. Furthermore, the lack of information on nutritional requirements and feed palatability across successive moulting stages has slowed the development of effective, stage-specific diets.

These factors collectively result in extremely high mortality during the phyllosoma-to-puerulus stages, severely hindering the establishment of closed life-cycle aquaculture. As a result, the industry remains heavily dependent on wild-caught juveniles, constraining production capacity and limiting the scalability of *P. homarus* aquaculture.

4.2. Research Priorities and Strategic Directions

Future research should prioritize integrated efforts to achieve a fully closed aquaculture cycle for *P. homarus* through advances in seed technology, artificial breeding, dedicated feed development, and complete farming system construction.

In terms of seed technology, systematic surveys and evaluations of germplasm resources, including genetic diversity assessments, growth phenotyping, and physiological and biochemical analyses, are essential for a comprehensive understanding of this species' genetic characteristics. Genetic diversity studies can provide a basis for selecting superior broodstock and preventing germplasm degradation. Growth phenotyping allows the screening of fast-growing, high-quality individuals, while physiological and biochemical profiling clarifies environmental adaptability, guiding environmental control strategies and improvements in stress resistance.

Molecular and genomic tools can further support these efforts by enabling the identification of key genetic markers for traits such as growth, disease resistance, and reproductive performance.

For artificial breeding, research should focus on overcoming challenges in phyllosoma larval survival and development while establishing stable breeding populations. Detailed documentation of growth trajectories and mating behaviours is also crucial, as it provides a reference for optimizing husbandry protocols and maintaining broodstock quality across generations. Studies on molecular mechanisms, particularly those regulating embryonic and larval development, will provide theoretical support for controlled breeding.

Feed development should address the lack of stage-specific formulated diets by creating nutritional profiles tailored to each developmental stage. Such diets can improve feed conversion efficiency, lower production costs, maintain balanced nutrition, and enhance product quality and market value.

Finally, aquaculture technology should be optimized to develop management protocols for water temperature, salinity, oxygen levels, and disease control. Exploration of both land-based and offshore cage culture systems will enable higher farming density and greater production capacity. Cross-disciplinary collaboration will be essential to translate scientific advances into practical solutions for the sustainable aquaculture of *P. homarus*.

Author Contributions

Q.M.: conceptualization, investigation, writing—original draft, visualization; F.Z.: visualization, writing—review & editing; G.Y.: supervision, project administration; Y.L.: writing—original draft, writing—review & editing, funding acquisition. All authors have read and agreed to the published version of the manuscript.

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The authors declare no conflict of interest.

Use of AI and AI-Assisted Technologies

No AI tools were utilized for this paper.

References

1. Lavery, S.D.; Farhadi, A.; Farahmand, H.; et al. Evolutionary Divergence of Geographic Subspecies within the Scalloped Spiny Lobster *Panulirus homarus* (Linnaeus, 1758). *PLoS ONE* **2014**, *9*, e97247.
2. Singh, S.P.; Groeneveld, J.C.; Al-Marzouqi, A.; et al. A Molecular Phylogeny of the Spiny Lobster *Panulirus homarus* Highlights a Separately Evolving Lineage from the Southwest Indian Ocean. *PeerJ* **2017**, *5*, e3356.
3. Kizhakudan, J.K. *Panulirus homarus homarus* (Linnaeus, 1758). In *Prioritized Species for Mariculture in India*; Food and Agriculture Organization of the United Nations: Rome, Italy, 2017; pp. 216–220.

4. Liang, H.; Xu, X.; Huang, Z.; et al. The Molecular Phylogeny on Eight Species of *Panulirus* Genus from the Chinese Coast Based on COI Gene Sequence. *Acta Sci. Nat. Univ. Sunyatseni* **2011**, *50*, 94–98.
5. Ahmed, M.S.; Barua, A.; Datta, S.K.; et al. Characterization of Spiny Lobsters from Bangladesh Waters Using Morphology, COI and 16S rRNA sequences. *Heliyon* **2022**, *8*, e08846.
6. Farhadi, A.; Jeffs, A.G.; Lavery, S.D. Genome-Wide SNPs in the Spiny Lobster *Panulirus homarus* Reveal a Hybrid Origin for Its Subspecies. *BMC Genom.* **2022**, *23*, 750.
7. Pancoro, A.; Indriatmoko, D.; Wijaya, D.; et al. Sea Surface Temperature and Current-Related Parameters Affecting Local Adaptation of Scalloped Spiny Lobster Population in Indonesia's Archipelagic System. *Sci. Rep.* **2024**, *14*, 18403.
8. Singh, S.P.; Groeneveld, J.C.; Willows-Munro, S. Between the Current and the Coast: Genetic Connectivity in the Spiny Lobster *Panulirus homarus rubellus*, Despite Potential Barriers to Gene Flow. *Mar. Biol.* **2019**, *166*, 36.
9. Al-Breiki, R.D.; Kjeldsen, S.R.; Afzal, H.; et al. Genome-Wide SNP Analyses Reveal High Gene Flow and Signatures of Local Adaptation Among the Scalloped Spiny Lobster (*Panulirus homarus*) Along the Omani Coastline. *BMC Genom.* **2018**, *19*, 690.
10. Al-Barashdi, H.K. The Potential of Microsatellite Markers for Genetic Assessment of Scalloped Spiny Lobster (*Panulirus homarus*) Populations in Al Sharqiyah Governorate and Their Application in Species Fishery Management. Master's Thesis, Sultan Qaboos University, Muscat, Oman, 2017.
11. Sun, D.; Lv, J.; Gao, B.; et al. Chromosome-Level Genome Assembly of Scalloped Spiny Lobster *Panulirus homarus homarus*. *Sci. Data* **2025**, *12*, 900.
12. Li, B.; Liang, H.; Chen, Z.; et al. Gene Cloning and Analysis of a Novel C-Type Lectin PhLecA from *Panulirus homarus*. *J. Trop. Oceanogr.* **2016**, *35*, 29–37.
13. Thomas, A.M.; Lenin, K.L.D.; Antony, S.P. Bioinformatic Characterization and Functional Evaluation of Ph-Def: A Novel Marine Antimicrobial Peptide from *Panulirus homarus*. *Ecol. Genet. Genom.* **2024**, *32*, 100285.
14. Luo, J.; Zhuo, H.; Chen, J.; et al. Cloning, Expression and Photoperiodic Response of Gonad-Inhibiting Hormone (GIH) Gene in Scalloped Spiny Lobster *Panulirus homarus*. *J. Dalian Ocean. Univ.* **2021**, *36*, 727–735.
15. Luo, J. Cloning and Expression of Crustacean Hyperglycemic Hormone (CHH) and Gonad-Inhibiting Hormone (GIH) from the Spiny Lobster *Panulirus homarus*. Master's Thesis, Guangdong Ocean University, Zhanjiang, China, 2021.
16. Zhuo, H.B.; Liang, H.F.; Cai, C.X.; et al. Molecular Cloning, Characterization and Expression Analysis of the Ecdysone Receptor from the Spiny Lobster *Panulirus homarus* (Linnaeus, 1758) (Decapoda, Palinuridae). *Crustaceana* **2020**, *93*, 769–783.
17. Kulmiye, A.; Mavuti, K.; Groeneveld, J. Size at Onset of Maturity of Spiny Lobsters *Panulirus homarus homarus* at Mambrui, Kenya. *Afr. J. Mar. Sci.* **2006**, *28*, 51–55.
18. Kulmiye, A.J. Reproductive Seasonality and Fecundity of the Spiny Lobster *Panulirus homarus homarus* (Linnaeus, 1758) (Decapoda: Achelata: Palinuridae) in Kenya: Implications for Sustainable Management. *J. Crustacean Biol.* **2022**, *42*, ruac028.
19. Kirubagaran, R.; Peter, D.; Dharani, G.; et al. Changes in Vertebrate-Type Steroids and 5-Hydroxytryptamine During Ovarian Recrudescence in the Indian Spiny Lobster, *Panulirus homarus*. *N. Z. J. Mar. Freshw. Res.* **2005**, *39*, 527–537.
20. Chen, C.; Ji, D.; Wu, K.; et al. The Preliminary Research on the Artificial Reproduction and Culture of the Phyllosomas of *Panulirus homarus*. *J. Jimei Univ.* **2003**, *8*, 197–202.
21. Adiputra, Y.T.; Zairin, M., Jr.; Suprayudi, M.A.; et al. Identification of Steroid Hormones and Fatty Acids During Gonadal Maturation of Spiny Lobster *Panulirus homarus*. *Invertebr. Reprod. Dev.* **2019**, *63*, 77–87.
22. Fernandez, R.; Radhakrishnan, E.V. Effect of Bilateral Eyestalk Ablation on Ovarian Development and Moulting in Early and Late Intermoult Stages of Female Spiny Lobster *Panulirus homarus* (Linnaeus, 1758). *Invert. Reprod. Dev.* **2016**, *60*, 238–242.
23. Zhuo, H.; Wu, J.; Liang, H.; et al. Effects of Eyestalk and Antenna Ablation on Survival, Molt, Feeding and Growth of Scalloped Spiny Lobster *Panulirus homarus*. *J. Dalian Ocean Univ.* **2020**, *35*, 814–821.
24. Luo, J.; Cheng, J.; Wang, C.; et al. Adaptation of Five Ecological Factors in Embryo of *Panulirus homarus*. *J. Guangdong Ocean Univ.* **2021**, *41*, 94–102.
25. Ji, D.; Chen, C.; Zhou, H.; et al. Study of Starvation and Ingestion on the Growth of Phyllosoma of *Panulirus homarus*. *J. Jimei Univ.* **2004**, *1*, 11–16.
26. Liu, H.; Li, C.; Huang, X.; et al. Culturing and Observation on Morphological Character of the Early Phyllosoma of Scalloped Spiny Lobster *Panulirus homarus*. *Fish. Mod.* **2008**, *4*, 36–40.
27. Li, J.; Liang, H.; Chen, Z. Acute Toxicity Tests of Three Commonly Used Drugs on *Panulirus homarus* phyllosoma. *Curr. Fish.* **2023**, *48*, 68–69+72.
28. He, Y.; Huang, B.; Lin, J. Effects of Manno-Oligosaccharides on Growth of *Panulirus homarus* phyllosoma. *Jiangxi Fish. Sci. Technol.* **2023**, *2*, 3–5.

29. Mashaii, N.; Rajabipour, F.; Shakouri, A. Feeding Habits of the Scalloped Spiny Lobster, *Panulirus homarus* (Linnaeus, 1758) (Decapoda: Palinuridae) from the Southeast Coast of Iran. *Turk. J. Fish. Aquat. Sci.* **2011**, *11*, 45–52.
30. Hoang, D.H.; Jones, C.M. Effects of Dietary Mannan Oligosaccharide Supplementation on Juvenile Spiny Lobster *Panulirus homarus* (Palinuridae). *Aquaculture* **2014**, *432*, 258–264.
31. Huang, D. Effect of Temperature, Salinity, Density and Feed on the Survival, Feeding Behavior and Growth of *Panulirus homarus*. Master's Thesis, Guangdong Ocean University, Zhanjiang, China, 2014.
32. Arumugam, A.; Dineshkumar, R.; Rasheeq, A.A.; et al. Growth Performance of Spiny Lobster, *Panulirus homarus* (Linnaeus, 1758). *Indian J. Geo Mar. Sci.* **2020**, *49*, 812–819.
33. Huang, B.; You, J.; Feng, C.; et al. The Effects of Semi-Cooked Shellfish Meat and Fresh Shellfish on the Growth of *Panulirus homarus*. *J. Fish. Res.* **2021**, *43*, 419–425.
34. dan Segar, D.M.S.; GIRI, N.A.; IRVIN; S; et al. Growth Response of Lobster *Panulirus homarus* Reared in Tanks and in Floating Net Cages Fed with Compound and Fresh Feed. *Sains Malays.* **2023**, *52*, 2747–2759.
35. Gora, A.; Jayasankar, V.; Rehman, S.; et al. Biochemical Responses of Juvenile Rock Spiny Lobster *Panulirus homarus* Under Different Feeding Regimes. *J. Appl. Anim. Res.* **2018**, *46*, 1462–1468.
36. Saleela, K.N.; Somanath, B.; Palavesam, A. Effects of Binders on Stability and Palatability of Formulated Dry Compounded Diets for Spiny Lobster *Panulirus homarus* (Linnaeus, 1758). *Indian J. Fish.* **2015**, *62*, 95–100.
37. Wang, Y. The Effects of Light Intensity and Photoperiod on the Growth, Physiological Indices, and Biological Clock Genes of Spiny Lobster (*Panulirus homarus*) in a Recirculating Water System. Master's Thesis, Dalian Ocean University, Dalian, China, 2024.
38. Shen, M.; Fu, F.; Fan, W. Effect of Different Food Resources on the Growth Rate of Lobster. *Trop. Agric.* **2011**, *31*, 55–59.
39. Rathinam, M.M.; Kizhakudan, J.K.; Vijayagopal, P.; et al. Effect of Dietary Protein Levels in the Formulated Diets on Growth and Survival of Juvenile Spiny Lobster *Panulirus homarus* (Linnaeus). *Indian J. Fish.* **2014**, *61*, 67–72.
40. Supriyono, E.; Soelistyowati, D.T.; Adiyana, K.; et al. The Effects of Alkalinity on Production Performance and Biochemical Responses of Spiny Lobster *Panulirus homarus* Reared in a Recirculating Aquaculture System. *Isr. J. Aquac. Bamidgeh* **2022**, *74*, 14. https://doi.org/10.46989/001c.38426.
41. Liang, H.; Zhuo, H.; Liao, Y.; et al. Acute Toxicity of Cd^{2+} and Hg^{2+} to Scalloped Spiny Lobster *Panulirus homarus*. *Fish. Sci.* **2020**, *39*, 420–424.
42. Maharajan, A.; Rajalakshmi, S.; Vijayakumaran, M.; et al. Sublethal Effect of Copper Toxicity Against Histopathological Changes in the Spiny Lobster, *Panulirus homarus* (Linnaeus, 1758). *Biol. Trace Elem. Res.* **2012**, *145*, 201–210.
43. Huang, B.; Lin, X.; Feng, C. Aquaculture and Disease Prevention Techniques of *Panulirus homarus*. *J. Aquac.* **2021**, *42*, 60–61.
44. Ansari, M.; Raissy, M. *In vitro* Susceptibility of Commonly Used Antibiotics Against *Vibrio* spp. Isolated from Lobster (*Panulirus homarus*). *Afr. J. Microbiol. Res.* **2010**, *4*, 2629–2631.
45. Musthaq, S.S.; Sudhakaran, R.; Balasubramanian, G.; et al. Experimental Transmission and Tissue Tropism of White Spot Syndrome Virus (WSSV) in Two Species of Lobsters, *Panulirus homarus* and *Panulirus ornatus*. *J. Invertebr. Pathol.* **2006**, *93*, 75–80.
46. Huang, D.; Liang, H.; Zhang, Z.; et al. The Effect of Temperature on the Survival, Food Intake, Molting, and Growth of *Panulirus homarus*. *Acta Ecol. Sin.* **2017**, *37*, 5973–5980.
47. Fu, Z.; Bai, J.; Ma, Z. Physiological Adaptations and Stress Responses of Juvenile Yellowfin Tuna (*Thunnus albacares*) in Aquaculture: An Integrative Review. *Aquat. Life Ecosyst.* **2025**, *1*, 3.
48. Chen, S.; Chu, X.; Ban, T.; et al. On Dormancy Temperature and Low Temperature Dormancy Technique of Three Kinds of Lobster. *Mar. Fish.* **2018**, *40*, 489–494.
49. Liang, H.; Zhao, Y.; Huang, D. Study on the Oxygen Consumption Rate and the Asphyxiated Point of *Panulirus homarus*. *J. Aquac.* **2012**, *33*, 1–4.
50. Huang, D.; Liang, H.; Wen, C.; Liao, Y. Effects of Different Temperatures on the Digestive Enzyme Activities in *Panulirus homarus*. *Fish. Mod.* **2017**, *44*, 32–36+42.
51. Ran, H.; Li, Z.; Yang, F.; et al. Molecular Pathways of Osmoregulation in Response to Salinity Stress in the Gills of the Scalloped Spiny Lobster (*Panulirus homarus*) within survival salinity. *Comp. Biochem. Physiol. Part D Genom. Proteom.* **2024**, *52*, 101308.
52. Chen, H.; Pan, J.; Wang, Y.; et al. Growth, Health Status and Gut Microbiota of the Scalloped Spiny Lobster (*Panulirus homarus*) at Different Salinities. *Aquaculture* **2023**, *562*, 738779.
53. Verghese, B.; Radhakrishnan, E.V.; Padhi, A. Effect of Environmental Parameters on Immune Response of the Indian Spiny Lobster, *Panulirus homarus* (Linnaeus, 1758). *Fish Shellfish Immunol.* **2007**, *23*, 928–936.
54. Tong, Y.; Liang, H.; Wen, C.; et al. The Influence of Light Intensity and Shelter on Habitat and Feeding Behavior of the Spiny Lobster (*Panulirus homarus*). *J. Dalian Ocean Univ.* **2025**, *40*, 382–389.

55. Wang, Y.; Yang, R.; Fu, Z.; et al. The Photoperiod Significantly Influences the Growth Rate, Digestive Efficiency, Immune Response, and Antioxidant Activities in the Juvenile Scalloped Spiny Lobster (*Panulirus homarus*). *J. Mar. Sci. Eng.* **2024**, *12*, 389.
56. Ju, Z.; Luo, J.; Ndandala, C.B.; et al. Cloning, Expression Analysis, and the Photoperiodic Response of CHH Gene in *Panulirus homarus*. *Aquac. Rep.* **2025**, *40*, 102552.
57. Kemp, J.O.G.; Britz, P.J.; Cockcroft, A.C. Effect of Body Size, Photophase, Feeding and Emersion on the Oxygen Consumption of the East Coast Rock Lobster *Panulirus homarus rubellus*. *Aquac. Res.* **2009**, *40*, 833–844.