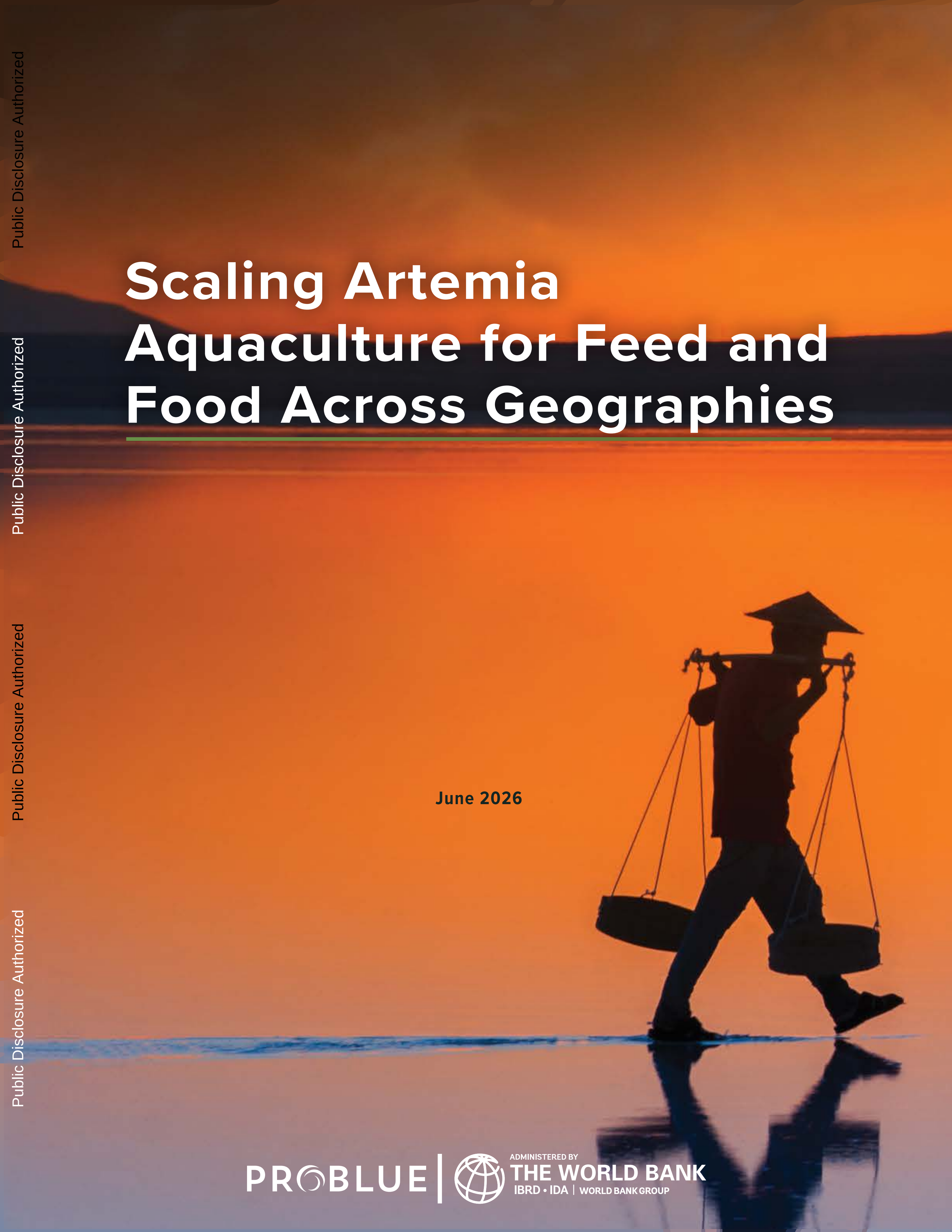

Scaling Artemia Aquaculture for Feed and Food Across Geographies

June 2026

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SCALING ARTEMIA AQUACULTURE FOR FEED AND FOOD ACROSS GEOGRAPHIES

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GLOSSARY

Artemia biomass: Live, mainly adult Artemia, which may be bulk harvested for use as an animal feed or human food.

Artemia4 Bangladesh: A project aimed at promoting the sustainable cultivation of Artemia (brine shrimp) to support Bangladesh's aquaculture sector. The overall objective of the Artemia4Bangladesh project is to enhance food and nutrition security in Bangladesh through climate-smart innovative technologies.

Compound feeds: Formulated animal feeds made by combining animal proteins, fats, grains, proteins, vitamins, and minerals, into balanced diets for livestock, often in pellet or granule form.

Cyst: A dormant Artemia embryo encased in a protective shell, capable of surviving harsh conditions for decades. Produced when habitats dry up, cysts can be stored long term and hatch into nauplii within 24 hours under suitable conditions. They are a key aquaculture feed and the primary traded Artemia product.

Cyst separation: The process of removing empty cyst shells from newly hatched Artemia nauplii, typically using methods like sieving or magnetic separation systems.

Decapsulation: Removal of the hard outer shell of Artemia cysts, typically using a chemical process. This allows cysts to be used as a direct feed without the need for hatching.

Enrichment: The process of enhancing the nutritional profile of live feeds, such as Artemia nauplii, by feeding them with nutrient-rich substances before they are provided to aquaculture species.

Gene (cyst) bank: A repository for storing genetically diverse Artemia cysts of different species and strains under controlled conditions to preserve genetic resources for future breeding, research, and aquaculture use.

Integrated livelihoods: A holistic approach to improving rural livelihoods by combining aquaculture, agriculture, and other income-generating activities to enhance food security, economic resilience, and sustainable resource use.

PROBLUE: An umbrella multi-donor trust fund administered by the World Bank that supports sustainable and integrated development of marine and coastal resources in healthy oceans.

Solar saltworks: Facilities where salt is produced through the evaporation of seawater or brine in shallow ponds using solar energy, often providing a habitat for Artemia populations.

ACRONYMS

AAC	Artemia Association of China
AHPND	Acute Hepatopancreatic Necrosis Disease
ARARC	Asian Regional Artemia Reference Center
ASA	Advisory Services and Analytics
ASEAN	Association of Southeast Asian Nations
BFAR	Bureau of Fisheries and Aquatic Resources
CIBA	Central Institute of Brackishwater Aquaculture
DAP	Diammonium Phosphate
DOF	Department of Fisheries
ECUASAL	*Ecuatoriana de Sal y Productos Químicos*
EU	European Union
FAO	Food and Agriculture Organization of the United Nations
GAFRD	General Authority for Fish Resources Development
GDP	Gross Domestic Product
GSL	Great Salt Lake (USA)
HUFA	Highly Unsaturated Fatty Acids
IOT	Internet of Things
KAUST	King Abdullah University of Science and Technology
KBP	Kenya-Belgium Project
KMFRI	Kenya Marine and Fisheries Research Institute
MAE	Ministry of Agriculture and Environment (Viet Nam)
MOET	Ministry of Education and Training (Viet Nam)
MOST	Ministry of Science and Technology (Viet Nam)
NACA	Network of Aquaculture Centres in Asia-Pacific
NaFIRRI	National Fisheries Resources Research Institute
NAMARET	National Mariculture Research and Training
NFDB	National Fisheries Development Board
NGO	Nongovernmental Organization
NTT	East Nusa Tenggara

PMSSY	Pradhan Mantri Matsya Sampada Yojana
PPP	Public-Private Partnership
PUFA	Polyunsaturated Fatty Acids
PVC	Polyvinyl Chloride
QA	Quality Assurance
R&D	Research and Development
RN	Rio Grande do Norte
ROI	Return on Investment
SFB	San Francisco Bay
SHG	Self-Help Group
TTL	Task Team Leader
UAE	United Arab Emirates
UNDP	United Nations Development Programme
WSSV	White Spot Syndrome Virus

EXECUTIVE SUMMARY

Artemia, commonly known as brine shrimp, is a critical live feed ingredient in aquaculture, particularly for shrimp and marine finfish hatcheries. The global Artemia industry is experiencing increasing demand driven by expanding aquaculture production. This report provides an in-depth analysis of Artemia in five key countries where Artemia aquaculture is established or in early stages of development —Viet Nam, China, Thailand, Bangladesh, and Kenya. The studies highlight Artemia value chains and associated production systems, market potential, and investment needs.

The findings confirm that Artemia can be successfully, profitably, and sustainably produced through aquaculture as cyst or biomass products in hypersaline environments, across diverse systems, providing important and critical products for aquaculture, with potential for wider application and product development as aquafeed and human food.

The productivity and profitability of Artemia compares positively with traditional salt production, providing new income and livelihood opportunities for people living in hypersaline and salt-affected coastal and inland regions. A key factor for success is access to markets. Case studies identify important opportunities for investment that include working capital and infrastructure for farm and storage improvements, training and extension activities, product diversification, and post-harvest and market product development, including investing in Artemia and novel aquafeed ingredients and human food applications.

The case studies also provide examples of four systems or business cases with potential for wider application and scaling, including (a) Integrated Artemia-Shrimp Farming (Viet Nam Model); (b) Solar Saltworks-Artemia Integration (China Model); (c) Artemia Biomass for Aquafeed & Livestock Feed (Thailand Model); and (d) Smallholder Artemia Pond Culture (Bangladesh Model). The potential scalability of these models is assessed by countries in Africa, Latin America, Asia, and the Middle East. The assessment shows significant opportunities for scaling the models in Africa and more globally in hypersaline ecosystems, provided the market, regulatory, and research environment is in place.

In Africa, the assessments reveal widespread opportunity, with country-by-country assessments provided for Madagascar, Mozambique, Federal Republic of Somalia, Namibia, Botswana, Zambia, Tanzania, Kenya Uganda, Rwanda, Ghana, Nigeria, Tunisia, the Arab Republic of Egypt, Senegal and Ethiopia. The studies provide guidance on potential; the follow up actions would involve more detailed country level assessments and the development of country-specific investments strategies for the public and private sector. A coordinated approach for public investment (in research, policy, and investment environment) and private investment (in Artemia production businesses, processing, and product marketing) is required.

The next steps will involve feedback on this draft case study report and the preparation of a comprehensive investment synthesis and strategy to progress the priorities and opportunities for Artemia.

INTRODUCTION AND METHODS

The report presents the results of in-depth studies of Artemia value chains. The purpose of the studies was to conduct detailed studies on the selected Artemia value chain in selected countries to identify critical investment opportunities, policy recommendations, and investment interventions. The goal is to enhance specific points of the value chain for improved efficiency, sustainability, and profitability, making Artemia a more viable and impactful sector for aquafeed and human food, with the potential as a novel ingredient in terrestrial animal feeds (poultry and livestock).

Key Focus Countries and Areas

The studies were conducted by research teams in each of the selected countries that include Bangladesh, China, Kenya, Thailand, and Viet Nam, supplemented by regional assessments of Africa. The key topics included

- **Integration of Artemia with Other Systems:** integration with solar salt production, desalination plants, aquaculture systems, and other farming models to assess co-production benefits and opportunities for scaling;
- **Socioeconomic Impacts:** analyzing how Artemia production contributes to socioeconomic development, such as income generation, job creation, and seasonal labor transitions to year-round activities, especially involving women and youth;
- **Value Chain Development Needs:** assessing specific needs within the value chain for infrastructure, market development, processing, and policy improvements; and
- **Investment and Market Insights:** identifying critical factors and investment points necessary for growth, such as technology upgrades, value adding processes, and financial support options.

Methods

Each country study was implemented by an in-country team that conducted a value chain analysis, focusing on identifying investment gaps, policy needs, and market opportunities within each country's Artemia production and use systems, considering aquafeed, animal feeds, and human food markets.

- **Gap Analysis:** This was used to pinpoint areas where the current value chain is underperforming or lacking (for example, infrastructure gaps, regulatory bottlenecks, and technical skill gaps).
- **Field Visits and Stakeholder Interviews:** Field visits and in-depth interviews were conducted with key stakeholders, including hatchery operators, farmers, traders, policy makers, and consumers, to understand where targeted investments or reforms would have the highest impact.
- **Market Assessment:** Local and export markets were assessed to identify growth opportunities or demand-side interventions, such as marketing, to increase Artemia consumption.

Key data points collected in each country case study included

- **Policy and Regulatory Data:** information on import/export tariffs, subsidies, and local production incentives;
- **Cost Structure and Pricing:** data on costs at each stage of the value chain, from inputs to processing and distribution, to identify where cost reductions could improve competitiveness;
- **Market Insights:** information on local and international market demand, consumer preferences, and competition with imported Artemia products;
- **Stakeholder Roles:** profiles of key stakeholders, including their contributions to the value chain, and identification of influential entities (for example, policy bodies and industry associations);
- **Community Impact:** economic benefits for local communities, focusing on how Artemia production creates income, jobs, and new market channels; and
- **Infrastructure and Capacity Building:** infrastructure upgrades (for example, cold storage and processing facilities) and capacity-building needs (for example, training on improved farming methods).

Scalable Country Analysis and Business Model Mapping

To complement the targeted value chain analysis conducted for the five in-depth country case studies, a secondary analysis was undertaken to identify additional countries where Artemia production and commercialization could be feasibly scaled. This involved a structured approach to mapping scalable business models in selected countries based on key economic, environmental, and sectoral indicators.

1. Business Model Alignment and Country Selection

- **Comparative matching:** Potential Artemia-producing countries were categorized based on their alignment with four main business models identified in the case studies (for example, Bangladesh, Thailand, Viet Nam, and China model).
- **Preliminary screening:** Countries were assessed using secondary data sources, including aquaculture reports, salt industry datasets, policy documents, and trade statistics, to short-list those with existing Artemia-compatible environments (for example, saltworks, saline lakes, and coastal aquaculture zones).
- **Scalability potential:** Considerations included climate, production feasibility, regulatory environment, and potential market links.

2. Key Data Sources and Analytical Approach

- **Saline geography and ecology:** identification of salt lakes, salt pans, coastal evaporation ponds, and aquaculture zones suitable for Artemia farming
- **Salt industry and production:** analysis of salt production levels, industry structure (smallholder versus industrial), and Artemia integration potential
- **Aquaculture and feed demand:** evaluation of aquaculture production scale, species farmed, and Artemia demand in hatcheries and fish/shrimp farming
- **Aquafeeds and terrestrial feeds:** review of Artemia's potential as a protein ingredient in aquafeeds and terrestrial livestock feeds, particularly poultry and small-scale farming applications

- **Consumption and market (human nutrition):** assessment of per capita seafood consumption, local dietary habits, and potential human food applications of Artemia (for example, dried shrimp alternatives and protein supplements)
- **Regulatory and research support:** review of national aquaculture policies, biosecurity measures, past Artemia research, and institutional capacity for Artemia-related development
- **Gender, youth, and social inclusion:** assessment of the role of women and youth in the value chain and points of entry to improve social inclusion
- **Opportunities and constraints:** identification of country-specific advantages and limitations for Artemia farming, including environmental, economic, and policy-related factors.

3. Country-Specific Investment and Development Considerations

For each selected country, a structured analysis was conducted to

- Determine the most suitable Artemia business model for scaling;
- Identify potential Artemia production zones (natural or artificial);
- Evaluate regulatory and research support for Artemia farming;
- Assess investment opportunities in Artemia production and utilization; and
- Provide feasibility insights for Artemia's role in aquafeeds, terrestrial feeds, and human nutrition.

By applying this structured approach, a preliminary strategy was prepared for investing in Artemia farming in new regions, aligning business models with country-specific industry needs and development goals.

1

BANGLADESH

1.1. Introduction and Overview of Artemia in Bangladesh

1.1.1. Establishment of Artemia culture in Bangladesh

Artemia pond culture in Bangladesh began in 2021 in Cox's Bazar through a European Union (EU)-funded and WorldFish-implemented Artemia4Bangladesh project. In 2021, the project began local Artemia cyst and biomass production, inoculating in a 1 ha pond area with the San Francisco Bay *Artemia franciscana* Vinh Chau (Viet Nam) strain. The first successful harvest yielded 3 kg of wet weight cysts and 111 kg biomass after 60 days of culture in 2021. During the four-year (2021–2024) project period, 120 kg wet weight cysts and 11.4 metric tons of Artemia biomass were harvested in a 7 ha area.

FIGURE 1. **Artemia pond culture in Bangladesh**

Source: Van Hoa, FutureFish

1.1.2. Status of the Artemia sector and value chains

Artemia farmers in Bangladesh presently produce biomass rather than cysts, prioritizing ease of production, quick cash flow, and higher production compared to cysts and easy access to markets in the country's shrimp hatcheries, nurseries, and grow-out farms. In 2024, 54 farmers were successful in producing 6.7 MT Artemia biomass in 5 ha, with a total farm gate value of approximately US$40,000. The average cost-benefit ratio was 1.96. Returns on investment (ROIs) are influenced by factors such as market price, productivity, and demand—especially for live Artemia biomass. All Artemia farms lie adjacent to solar salt fields, where high evaporation rates ensure high-salinity culture systems can be maintained.

The Artemia value chain in Bangladesh involves import of Artemia and the production of biomass through aquaculture to a limited extent. Processing is limited to date, though there are emerging uses in human food, as well as traditional uses in shrimp hatchery production. Bangladesh annually imports approximately 50 MT cysts with 90 percent sourced from Great Salt Lake (GSL), USA (Muhammad Meezanur Rahman, personal communication), with Artemia widely used in shrimp and prawn hatchery production.

1.2. Production Systems, Input Supply, and Technology

1.2.1. Current production practices

Artemia farming in Bangladesh is focused on production of *Artemia franciscana* biomass in ponds. Farming systems can be classified as 'semi-intensive', with regular partial harvests, either weekly or fortnightly.

Artemia aquaculture ponds are characterized by small, shallow ponds including canals of around 0.03–0.12 ha with a depth of 0.3–0.5 m. Artemia production is seasonal (January–May) due to shallow ponds and heavy monsoon. There is little management of the pond other than fertilization. Harvesting is through a fine mesh net (push net, hand net) that congregates Artemia around the edges of the pond for easy capture.

Salinity for Artemia biomass culture is normally maintained around 70–90 ppt to exclude predatory copepods, insects, or fish and competitors such as rotifers that may proliferate and compete for food with the Artemia. New ponds are inoculated with Artemia nauplii and/or biomass from the same farms.

Artemia pond culture inputs are mostly available locally. The major cost items are pond construction, brine preparation, land lease, and casual labor. Brine cost can be minimized through the adoption and utilization of pond surface and surrounding areas for seawater evaporation.

Crude salt production in Bangladesh is a seasonal activity (December–May). Artemia ponds were constructed within the crude salt production area and operated during the salt production season. The canals and ponds/ditches near the crude salt production area can be used for shrimp/crab nursing and grow-out farms. In 2024, all Artemia ponds including algae ponds were used for Tilapia culture during the wet season (July–October). Approximately, 75 percent of the crude salt production area of Bangladesh is used for traditional aquaculture of fish and crustaceans during the rainy season.

1.2.2. Input supply chain

Farms can construct much of their own harvesting nets using bamboo and clothes. Farms can generally use cheap, locally available inorganic and organic fertilizers for farm operation. The main inputs required for Artemia biomass production are lime and inorganic and organic fertilizers, which are used to stimulate a bloom of halophilic algae and bacteria on which Artemia can feed. Ponds are fertilized 2–3 times a week, according to need as assessed by the appearance of the plankton bloom. At present, ponds are mainly fertilized with inorganic fertilizer (urea and triple super phosphate) and organic fertilizer (cow dung and chicken manure). There are fuel and power costs to hatching Artemia cysts and pumping sea water to algae and Artemia ponds.

Instar I Artemia nauplii is managed through stocking and hatching Artemia cysts in the beginning of the culture. Thereafter, the Artemia population can be maintained through self-recruitment and transfer from one pond to other neighboring ponds. This management approach is useful to reduce cost and to ensure faster production and successful inoculation.

TABLE 1. **Proportion of cost items of Artemia pond culture in Bangladesh**

Cost Item	Unit	Unit Cost (BDT)	Proportion of Total Cost (%)
Fixed Cost			
Land lease	per m^2 / 6 months	6.18	11%
Earth excavation	per m^2 (10-year depreciation)	146.09	26%
Cyst inoculation	per kg	20,000.00	7%
Brine water	per liter	0.85	19% (50% fixed / 50% operational)
Operational Cost			
Fertilization • Cow dung • Chicken manure • TSP	per kg	5.00 5.00 26.00	2%
Chemical: • Lime • Urea	per kg	26.00 33.00	1%
Fuel: • Diesel • Lubricant	per liter	86.00 300.00	4%
Casual labor	per person-day	600.00	30%

Source: Artemia4Bangladesh project reports.

1.2.3. Technology adoption

Technology adoption from the Artemia4Bangladesh project is slow, considering Artemia farming is a new technology in Bangladesh, the market for biomass is small, and market and consumer acceptance needs to be increased. Fertilization depends on visual observation and harvesting conducted via hand-drawn nets. Cysts are stored in saturated brine and sold on a wet weight basis. Artemia biomass is sold mainly in oxygenated bags.

Artemia farmers adopted technologies for brine preparation, selling live Artemia biomass to neighboring shrimp hatcheries, nurseries, and grow-out farms. Cyst processing, drying, and freezing facilities are yet to be developed.

Technological improvements can be made to increase the rate of cyst production; marketing to the domestic shrimp/ fish hatcheries, nurseries, and grow-out farms; processing and product development using Artemia biomass; and services that can help Artemia value chain actors.

Artemia cyst and biomass productivity can be enhanced in various ways. Artemia culture in deeper and more compact ponds creates a more stable salinity to avoid erratic rainfall and ensure a longer culture duration. Organic fertilization (cow dung, chicken manure) and fermentation of kitchen waste are cheap and can be used as fertilizers to enhance Artemia productivity. Improvements in fertilization and algae management can help farmers optimize productivity.

1.3. Policy and Regulatory Environment

1.3.1. Existing framework

At present, there are no policies, regulations, and/or legal frameworks specific to Artemia farming in Bangladesh. Artemia aquaculture is subject to general regulations on aquaculture, environment, biodiversity, biosecurity, and food safety within the country.

A general legislative framework is in place for competent authorities to issue regulations necessary to govern the aquaculture sector, or to place restrictions and requirements on specific aquaculture industries, should the need arise, but such regulations are not specific to Artemia farming, processing, or product development.

TABLE 2. Legislation framework related to Artemia farming in Bangladesh

Instrument	Relevance
Fish Feed Act 2024 Link	Fish feed production, marketing, and quality
Fish Hatchery Act 2010 Link	Fish breeding, feeding, and quality
National Shrimp Policy 2014 Link	Shrimp culture, diversification, quality, processing, and marketing
National Fisheries Policy 1998 Link	Fish culture and coastal aquaculture

1.3.2. Barriers and opportunities

The Bangladesh Government has a legislative framework for the regulation of aquaculture, considering its contribution to gross domestic product (GDP), food and nutrition security, employment, and export earnings. There are no barriers to the development of Artemia farming and the trend of integrating Artemia production into existing salt production and aquaculture systems.

Bangladesh sets a 5 percent tariff on the importation of Artemia cysts. Importation of Artemia cysts is regulated, with controls on pathogen-free certification and sourcing from recognized facilities. Approval by the Department of Fisheries (DOF) is required to export Artemia products to Bangladesh.

1.4. Infrastructure and Capacity

1.4.1. Infrastructure

Bangladesh needs to improve infrastructure in the crude salt production areas in the southeast and shrimp culture areas in the southwest of Bangladesh to support the expansion of Artemia culture. Artemia can readily be cultured within Bangladesh's existing aquaculture pond infrastructure and coastal saltworks, with minimal modifications. There is no need to construct dedicated Artemia culture facilities, but modifications can be made to existing salt-producing infrastructure.

Well-developed cold chain, cold storage, and seafood processing facilities as well as road and transportation links are available to support aquaculture and fisheries. Biomass cultivation in proximity to aquaculture markets—hatcheries and nurseries—will have synergistic effects.

1.4.2. Gaps and needs

Training and extension are required to support the expansion of the industry, considering the awareness in the integrated Artemia-solar salt and aquaculture is low. Only 50 small farms offer limited visibility of Artemia production as a profitable opportunity for potential new entrants to the industry. Training and extension programs, access to finance, business models, and marketing facilities can benefit a large number of people considering the technology to be relatively simple, reliable, and affordable.

Artemia cyst processing facilities are yet to be developed. Transport logistics and cold storage facilities similar to shrimp processing industries can be utilized for Artemia.

1.5. Market Assessment and Demand

1.5.1. Local and export markets

Local markets

Bangladesh's Artemia aquaculture is focused on biomass. Around 7 MT tons of artemia biomass (wet weight) was produced in 2024, valued at US$40,000. Of the total biomass produced, around 17 percent was used in shrimp hatcheries and 75 percent in nurseries and grow-out farms (postlarvae and juveniles) and fish and crab hatcheries (nursery feed). The potential as ornamental fish feed, animal feed, human food, and export as frozen Artemia biomass is significant but yet to be explored.

The nutritional profile of Artemia biomass clearly demonstrates its potential as an alternative protein for terrestrial animal feeds and human consumption. Depending on the attractive recipe and cost-effectiveness, Artemia biomass has significant market potential as a substitute for fishmeal in both terrestrial and aquatic feeds.

1.5.2. Pricing and competition

Artemia biomass availability and demand are seasonal relative to shrimp hatchery and grow-out farms and crude salt production. A small portion of Artemia biomass is supplied in frozen form due to long travel distance and monsoon (off-season); however, the price remains the same due to limited customer demand. The farm gate price varies depending on the neighboring farms or shrimp/crab hatcheries. The typical price of live or frozen Artemia varied between US$4 and US$5 per kg in 2024.

Production cost is largely affected by the cost of brine (relative to crude salt price), productivity, and casual labor cost.

Competition for Artemia comes from other products used to condition shrimp broodstock, including polychaetes, squid, and mollusks. However, polychaetes and mollusks carry a significant risk of introducing shrimp pathogens. The hypersaline culture environment required by Artemia culture minimizes risks of most known shrimp pathogens. Fish, crustaceans, copepods, and other animals cannot survive high saline conditions (>70 g/L). So, no pathogen carrier is available. Thus, it minimizes the risk of pathogens.

1.5.3. End-user behavior

Live Artemia biomass is a highly regarded and favored food for shrimp broodstock maturation in hatcheries and for the growth of postlarvae and juveniles in nurseries and grow-out farms. The preliminary results suggest better broodstock performance of carps and catfishes with the inclusion of Artemia biomass in supplementary diets. Research findings showed the potential of the partial replacement of fish meal with Artemia biomass in a crablet nursing diet.

Artemia biomass recipes as human food have been accepted by Bangladesh consumers (see accompanying report, *Opening Potential for Use in Human Food*).

1.6. Socioeconomic Impacts and Inclusion

In 2024, 54 farmers operated Artemia pond culture across 7 ha of land in Bangladesh, catalyzed by the EU-funded Artemia4Bangladesh grant project, with significant improvement in incomes resulting from the project activities. Integrated salt-Artemia-aquaculture systems offer a year-round income opportunity, reducing reliance on a single crop and mitigating risks associated with crop failure. However, additional research and investment are needed to develop technologies that enable year-round Artemia cyst and biomass production.

Salt farming in Bangladesh is predominantly male dominated, with almost all salt farmers in Bangladesh being men. In 2020, 81 percent of salt farmers operated on leased land, highlighting the precarious nature of land access. The average household size among salt farmers was 6.15, which is higher than the national average. Education levels among salt farmers remain low, with 30 percent having no formal education and 56 percent receiving only primary education. The average homestead land size was 600 m^2 per household. Living conditions were modest, with 82 percent of farmers residing in mud-built houses, 96 percent using shared toilets, and 86 percent relying on pit latrines. Financial insecurity is widespread, with 48 percent of farmers having no savings and 74 percent relying on borrowed money to sustain their livelihoods.

The average annual household income for salt farmers was BDT 412,533 (~US$4,860), with crude salt production contributing 70 percent of total household earnings. Dietary patterns indicated a low level of dietary diversity, with 89 percent of households classified by the Artemia4Bangladesh project as having low dietary diversity.

Salt production in Bangladesh faces significant cost pressures, with land lease expenses accounting for 38 percent of total production costs, followed by labor at 33 percent, polyethylene at 15 percent, and water supply at 8 percent. The average salt production cost per hectare per season was BDT 191,497 (~US$2,250). Despite the potential for integration with aquaculture, only 2 percent of salt farmers engaged in integrated salt-aquaculture. There are roughly half a million people involved in salt production in Bangladesh, in harvesting and processing activities; hence, the potential for impact of Artemia production and aquaculture is significant. Gender and youth participation can also be enhanced in areas such as cyst hatching, biomass and cyst processing, preservation, and the utilization of Artemia biomass for human and animal feed. Expanding Artemia farming and integrated aquaculture systems combined with market development could provide economic improvements and enhance nutrition for salt farmers and their families in Bangladesh.

Bangladesh presents a strong opportunity for scaling Artemia production through its vast network of approximately 50,000 salt farmers operating across 27,000 ha, many of whom already rotate salt and aquaculture seasonally. The demand for Artemia is driven by a rapidly growing aquaculture sector, which includes over 300,000 shrimp farmers covering 200,000 ha; 40 commercial shrimp hatcheries requiring an estimated 50 metric tons of Artemia cysts annually; and a broader ecosystem comprising 100 shrimp nurseries, thousands of freshwater fish nurseries, broodstock maturation centers, grow-out farms, and ornamental fish businesses. Artemia biomass, used for feeding shrimp postlarvae, is especially relevant given that these hatcheries produce around 10 billion postlarvae each year. This presents a significant market pull for both Artemia cysts and biomass. By integrating Artemia pond culture into the existing salt-farming cycle, farmers can diversify income, reduce dependence on costly imports, and support the development of a more resilient, locally anchored aquafeed supply chain.

1.7. Climate Resilience and Environmental Considerations

1.7.1. Environmental risks

Artemia pond culture is environmentally friendly, with no risk reported so far. Artemia culture in hypersaline conditions naturally excludes predators and competitors including fish, crustaceans, and insects. Bangladesh has no native Artemia species. Artemia, as a filter feeder, grazes algae and bacteria which helps convert nutrients into biomass. Integration of Artemia in the crude salt production can potentially remove contaminants and algae and thereby improve salt quality. Leftover Artemia biomass can be food for wildlife, such as birds.

1.7.2. Climate resilience

Bangladesh is one of the most climate vulnerable countries in the world, affected by sea level rise, intrusion of seawater, and soil salinization. Artemia culture provides scope for adaptation to increased salinity and temperature associated with climate change. Crude salt production can be suddenly hampered by erratic rainfall; Artemia culture remains stable with such erratic rainfall as it can withstand salinity fluctuations to some extent. Integrated salt-Artemia-aquaculture has the potential to enhance resilience to climatic vulnerability.

1.8. Investment Opportunities and Case Studies

Investment opportunities in Artemia farming in Bangladesh are substantial, particularly in integrated salt-Artemia-aquaculture, biomass processing and value addition, and feed product development for both domestic and international markets. The coastal districts of Cox's Bazar, Khulna, and Satkhira provide a strong, suitable environment for expansion, given the existing base of salt and shrimp farmers who could adopt Artemia farming as an additional income source.

Integrated salt-Artemia-aquaculture systems have the potential to increase year-round income, reduce the risks associated with single-crop farming, and enhance climate resilience. Scaling up these systems would provide economic and environmental benefits, as Artemia cultivation helps filter organic matter from aquaculture effluents, improving water quality for salt production and adjacent aquaculture operations. Artemia4Bangladesh projected that at least 3,000 farmers could adopt integrated salt-Artemia-aquaculture technologies, leveraging existing knowledge and farming infrastructure to transition to a more profitable and sustainable production model.

Another major investment opportunity lies in businesses associated with processing, preservation, and value addition of Artemia biomass for the aquafeed industry. Developing new feed products using Artemia biomass could serve hatcheries, nurseries, and grow-out farms, reducing reliance on fishmeal-based feeds and creating a more sustainable protein source for aquaculture. Artemia biomass has already shown potential as a substitute for fishmeal, particularly in the early-stage diets of shrimp, crab, and marine fish species. Investing in biomass drying, flaking, and powdering technologies would allow for better product stability and increased market reach, both within Bangladesh and for export.

Beyond cyst and biomass production, brine sales represent an additional economic opportunity. In Khulna/Satkhira, up to 1,000 MT of brine could be marketed annually to inland hatcheries, with Cox's Bazar contributing 200 MT and other coastal areas 100 MT. The increasing demand for bio-secure, high-quality seawater in marine hatcheries makes brine transport a viable and growing revenue stream.

Integrated salt-Artemia-aquaculture technologies have already demonstrated their profitability, climate-smart potential, social acceptance, and environmental benefits. Targeted investments in finance, training, infrastructure, and market access could accelerate adoption, helping Bangladesh strengthen its position in Artemia production while improving livelihoods, enhancing food security, and promoting sustainable coastal aquaculture.

1.8.1. Promising Business Models

Table 3 synthesizes case study data into the Bangladesh Integrated Salt-Artemia Farming Model that integrates salt, artemia (biomass and cysts) as well as tilapia and/or shrimp farming, leveraging the synergies between multiple system components. This model presents opportunities for diversified income generation, increased resource efficiency, and sustainable farming practices. The integration of Artemia farming into saltworks enhances productivity and contributes to the long-term sustainability of both salt and Artemia production systems, with positive community resilience and impacts. Table 3 provides key elements and metrics for the model.

TABLE 3. **Bangladesh Integrated Salt-Artemia-Aquaculture Farming Model**

Name of Business Model	Bangladesh Integrated Salt-Artemia-Aquaculture Farming
Category	**Details**
Diversified Income Opportunities	Artemia cysts, biomass, salt production, brine sales, and shrimp and crab hatchery integration. 'Off-season' culture of other aquatic species such as fish and shrimp provides additional income.
Description	Seasonal Artemia biomass and cyst farming integrated with salt production and aquaculture, providing Artemia and other aquatic products for market into shrimp and crab hatcheries and for human consumption
Total Production per Cycle	Artemia Cysts: ~17 kg/ha per cycle (120 kg total over 7 ha in 4 years) Artemia Biomass: 1.3–1.4 tons/ha per cycle Multiple aquaculture products - tilapia, shrimp
Cycle Time	January–May (dry season) Aquaculture products in rainy season
Tons per ha per Cycle	Cysts: ~17 kg/ha Biomass: 1.3–1.4 tons/ha
Cost per kg	Around US$36/kg for cysts and US$1.4/kg for live biomass
Cost per ha per Cycle	Pond construction, land lease, fertilization, brine preparation, casual labor (US$2,500/ha/season for both)
Selling Price (US$/kg)	Wet weight cysts: US$50–$100/kg Dry weight cysts: US$200/kg Live biomass: US$4–5/kg
Revenue per ha	Estimated US$8,000 per ha per season (artemia grown for 6 months and tilapia or shrimp grown for the remainder)
Profit Margin	60–70%
Investment Cost and ROI	1.96 cost-benefit ratio
Employment per ha	54 farmers in 2024 producing 6.7 MT of biomass in 5 ha, 1–2 workers per farm (total 108 laborers)
Average Farmer Income	US$740 per farmer per season (from total US$40,000 revenue split among 54 farmers)
Women in Workforce	Involved in post-harvest processing and sorting (20%)
Technology Needed	Nets, fertilization systems, seawater pumps, brine evaporation ponds
Environmental Conditions	Salinity: 70–90 g/L, seasonal production limited by monsoon rains
Main Markets	Shrimp, crab, and finfish hatcheries Tilapia and other aquaculture products into domestic food markets
Domestic vs. Export Market	100% sold domestically to hatcheries and nurseries
Untapped Potential	Potential for expanding Artemia biomass processing for frozen feed, integration with shrimp and crab aquaculture and human food applications

1.9. Recommendations

The following investment recommendations are from the Bangladesh case study.

	Recommendations for Investment
Production Improvement Strategies	• Round-the-year Artemia production systems • Improved Artemia cyst production efficiency • Expanded Artemia farming areas to other saline coastal districts with high potential • Diversified production systems, with salt, Artemia, and other aquatic species
Policy and Regulatory	• Policy and guidelines to promote locally produced Artemia cyst and biomass developed by government • Public and private sectors, including policy makers, sensitized for the policy reforms to promote integrated Artemia-aquaculture • Government organizations such as DOF, Bangladesh Fisheries and Research Institute, and Ministry of Fisheries and Livestock involved in setting up an Artemia Reference Center and on station and field trial
Infrastructure and Technology	• Establishing an Artemia Reference Center for Artemia cyst processing, quality assurance (QA), and certification
Market Development Strategies	• Diversify the market (geographical area, product diversification, aquatic and terrestrial animal and human food) • Increase the engagement of the private sector for Artemia as a business investment, including animal feed and human food uses
Socioeconomic	• Catalyze community collaboration among smallholder salt and crustacean farmers • Stimulate entrepreneurship and business in the Artemia value chain • Support gender equality and youth participation
Impact Potential	• High potential for positive impacts on coastal livelihoods, incomes, and nutritional status, particularly as a low-cost biomass product with significant nutritional value for humans and animals.

2

CHINA

2.1. Introduction and Overview of Artemia in China

2.1.1 Establishment of Artemia culture in China

Artemia populations naturally exist in many salt lakes and coastal solar saltworks in China. The controlled Artemia production (improvement of Artemia biomass and cysts yield) started from the early 1990s, along with increasing demand of Artemia live food worldwide (FAO 2024; Bureau of Fisheries and Fishery Administration et al. 2024). Artemia culture is mostly operated in Bohai Bay coastal solar saltworks where thousands of hectares of land are used for sea-salt production over 1,000 years.

Bohai Bay is located in the northeast part of China, covering large coastal areas (Figure 2). The brine water in Bohai Bay salt works is considered highly productive as the result of extreme eutrophication in the Bohai Bay. Artemia cysts and biomass are seasonally produced in salt ponds (from April to November) when water temperature allows cyst hatching and microalgae blooming. The size of individual Artemia production ponds is usually large, ranging from tens to hundreds of hectares.

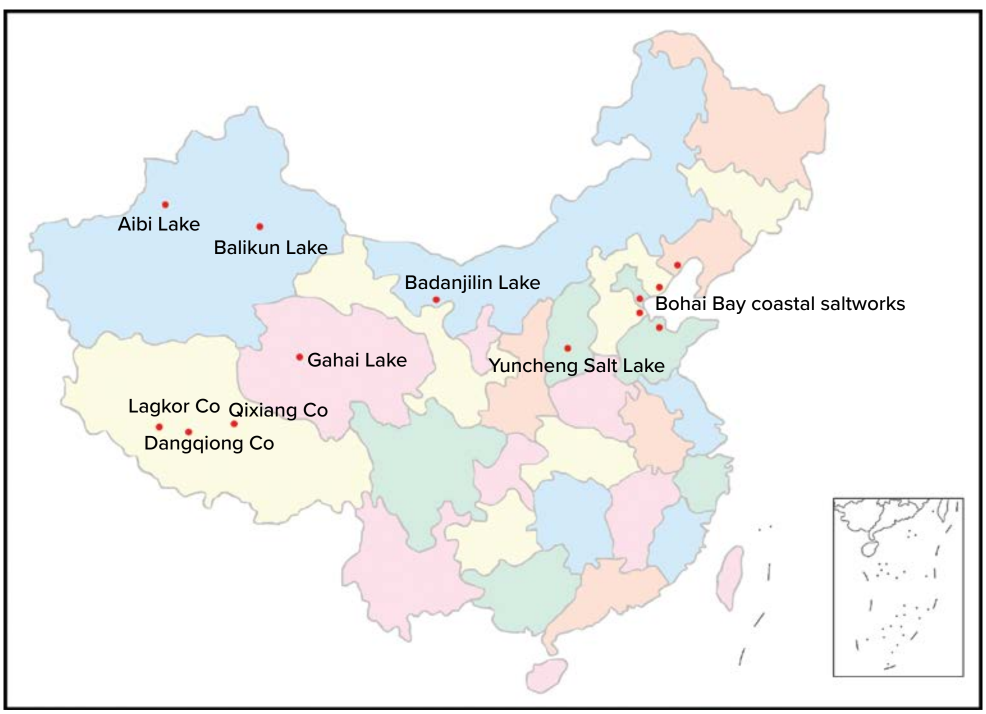
FIGURE 2. **Location and overview of Bohai Bay saltworks**

Source: Sorgeloos, FutureFish

2.1.2 Status of the Artemia sector and value chains

Unlike the decline of cyst harvest in inland salt lakes in China (Figure 4), the cysts and biomass production in Bobai Bay saltworks remains relatively stable, with annual cyst harvest of 500–600 tons wet weight and annual Artemia biomass harvest of 200,000–300,000 tons wet weight. Only a very small portion (3,000–4,000 tons of weight per year) is harvested from Yuncheng salt lake.

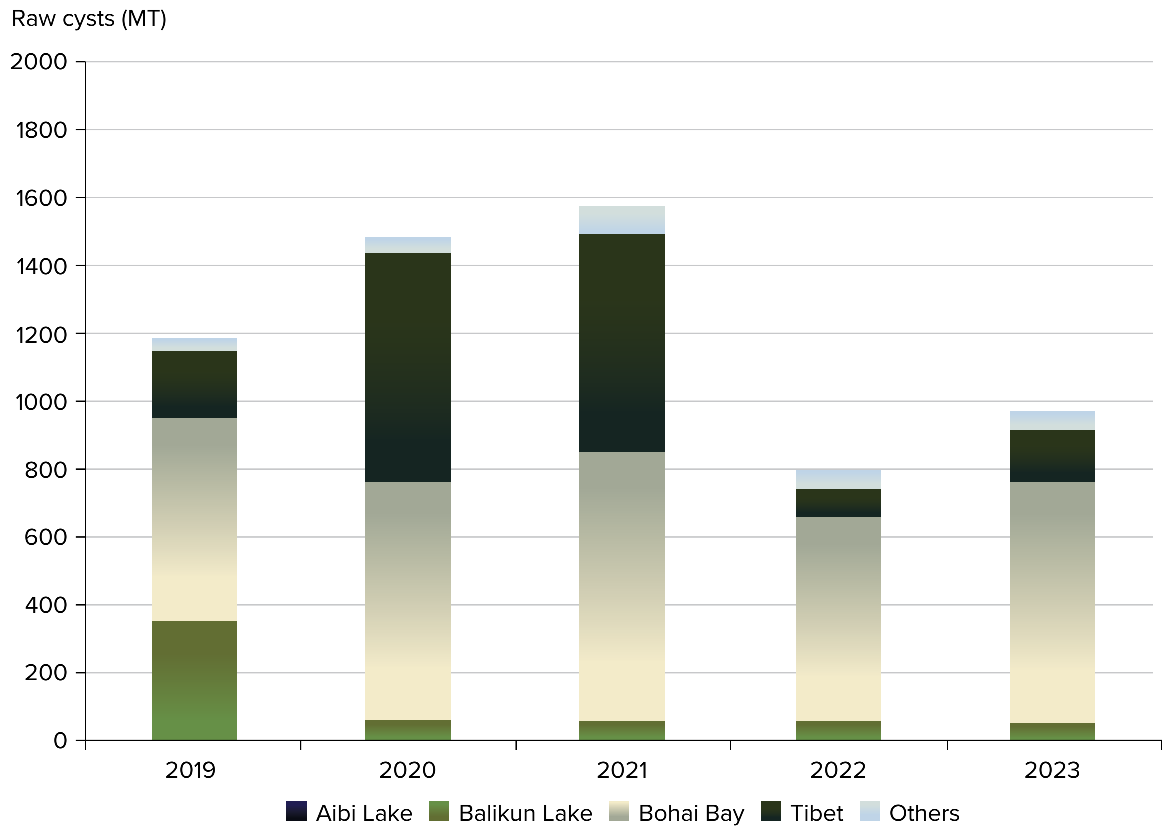
FIGURE 3. **Main Artemia fishery sites in China[1]**



Source: Sui, FutureFIsh

1 This map is for illustrative purposes and does not imply the expression of any opinion on the part of the World Bank concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

FIGURE 4. Annual harvest of Artemia cysts (in wet weight) in 2019–2023



Source: Data from Artemia Association of China [AAC].

Bohai Bay Artemia cysts are characterized by small size (240–250 µm), higher hatchability, and highly unsaturated fatty acids (HUFA) contents and thus have better market price. Most of them are sold to *Macrobrachium* hatcheries in Yangtze river delta (for example, Zhejiang Province and Jiangsu Province), Zhujiang river delta (for example, Guangdong Province and Guangxin Province), and Hainan Province, supporting 30–35 billion postlarvae production and final yield of 180,000–190,000 metric tons. A small percentage (5 to 25 percent) is exported to southeast Asian countries (mainly Viet Nam, Indonesia, Malaysia, and Thailand), Republic of Korea, and Japan. However, the market of Bohai Bay cysts has been challenged due to the replacement by the cysts from central Asia countries and the Russian Federation. The large amount of fresh Artemia biomass is sold directly to shrimp farms (nursery and grow-out farms) and fed directly to the shrimp. Only a small percentage of biomass is frozen (60,000–80,000 tons of wet weight), to be used during winter and early spring, when fresh biomass is not available in the field. The frozen biomass is also used as ornamental fish feed.

China is the biggest consumer of Artemia globally, accounting for more than half of the global production, with complex value chains involving import, processing, distribution, and consumption. There is a wide range of domestic and imported Artemia cyst products with different prices and quality. Salt-producing companies in the Bohai Sea area are a major source of farmed Artemia cyst and biomass production.

In the late 1980s and 1990s, the fast development of shrimp and crab farming facilitated the increase of local cysts demand, and since then, China became the second Artemia cysts processing country after the USA. The raw cysts are not only from domestic salt lakes and saltworks but also imported from Russia, Uzbekistan, and Kazakhstan.

The Chinese cysts processing companies master the techniques for different Artemia strains, and the quality of products is generally stable. Most cysts are consumed domestically. The annual cyst processing in China is around 1,500 tons in dry weight, which is more than the US (around 1,000 tons). In recent years, Russia also has been processing a small amount of cysts (no exact data), and Viet Nam produces around 100 tons small-size cysts. For biomass production, China is far more advanced than other countries in terms of quantity.

2.2. Production Systems, Input Supply, and Technology

2.2.1 Current production practices

Artemia pond production is mostly integrated with the production of salt (NaCl) and other salt chemicals (for example, bromine, $MgSO_4$, $MgCl_2$, and so on), as well as shrimp farming. All these production sectors interact and sometimes constrain each other, which may cause inefficiencies in the production system. For example, bromine is extracted from seawater and the effluent of shrimp farms. The acidification of bromine factory effluent (pH 2–3) kills nearly all brine organisms in brine, leading to less microalgae and microorganisms and reduced or unstable Artemia production. Salt businesses seek to manage these different elements across the production system.

Fertilization is used to improve the food supply for Artemia, though overfertilization in Artemia ponds usually results in inferior water quality and blooms of blue-green algae (unwanted algae) in summer, which negatively affects Artemia production and downstream salt production.

Artemia biomass harvesting is conducted manually by netting and recently by using suction pumps carried by boat. Due to the large quantity (the peak harvest may reach 60–100 tons per day in one salt farm), Artemia biomass is usually not treated in a proper way. There is no conditioning treatment (for example, emptying the gut content in clean water) before they are fed directly to the shrimp. Most of the frozen Artemia biomass is processed after cleaning.

In China, many innovations have been developed for Artemia. For example, a unique system that automatically rolls out a plastic cover over the crystallizer ponds when rain is expected. This system prevents the dilution of brine from heavy rain.

2.2.2 Input supply chain

The main input required for Artemia farming is food for Artemia in big quantities and good quality, with organic fertilizers (chicken manure) and inorganic fertilizers (for example, urea and diammonium phosphate [DAP]) widely used. Ponds are fertilized once a week according to the water color and density of the algae. Agriculture by-products (molasses, rice bran, and fermentation waste) are also added to the ponds to facilitate the biofloc formation. As the ponds are commonly large (30–60 ha per unit pond) and deep (80–150 cm), boats are needed for bottom raking and feeding when necessary. The biomass harvester (boat + suction pump) is used for a large amount of biomass collection daily. There are some minor fuel and power costs to the operation (Figure 5). Polyvinyl chloride (PVC) pipes, digging machines, and pumps are needed to construct the algae ponds (the newly applied strategy) and to pump water.

FIGURE 5. Pond bottom racking

Source: Sui, FutureFish

Seed stock is only required at the beginning of the production season (April) for quick establishment of the Artemia population (Figure 6). Considering the management of genetic diversity and conservation, it is recommended to inoculate the cysts collected from the Bohai Bay saltworks in the previous year.

FIGURE 6. Artemia inoculation in early spring

Source: Sui, FutureFish

Stainless steel cleaning tanks, refrigeration equipment, and cold storage facilities are needed for frozen biomass processing. Apart from these, simple plastic or concrete tanks (to clean the cysts and to remove the impurities), cold storage, and fluid dryers are needed for dry cyst production (Figure 7).

FIGURE 7. **Artemia biomass processing infrastructures**

Source: Sui, FutureFish

2.2.3 Technology adoption

The supplementation of chicken manure has been applied as a major means to stimulate algal blooms in Artemia ponds for many years. However, increasing environmental protection concerns and market demand have facilitated technology adoption and introduction of new technology. Recently, the adopted Vietnamese pond management strategy has been applied, which significantly improved Artemia production in some saltworks. Management strategies include setting up algae ponds to provide microalgae with high nutritional value, bottom raking to facilitate pond nutrient circulation and increase the water turbidity, and supplementary feeding when the algae are not enough.

Nowadays, there is a high biosecurity requirement from Artemia products from downstream customers, challenging the producers, in particular biomass producers. In some companies, the Artemia gut cleaning process is applied during processing to produce better bio-secured frozen biomass. Overall, the technology for bio-secure Artemia biomass products needs to be improved.

2.2.4. Productivity enhancement

Technology adoption and introduction of new technology have resulted in significant improvement of Artemia cysts and biomass production. For example, by using the new technology (for example, constructing algae ponds, bottom raking, and supplementary feeding), the annual cyst harvest in the Bohai Aqua (see the business case study) has increased from 10 tons to 33 tons wet weight (40 kg wet weight per ha), and biomass harvest increased from 2,000 tons to 4,300 tons wet weight (5,000 kg wet weight per ha), from a total Artemia pond surface of 860 ha.

2.3. Policy and Regulatory Environment

2.3.1. Existing framework

Although China's aquaculture industry is the world's largest consumer of Artemia cysts and biomass, development of the Artemia sector has not featured prominently in policy and sectoral development initiatives. There is limited governmental support in technology innovation. In China, Artemia production is mostly operated by salt-producing companies, mainly larger businesses. Although there are several large state-owned saltworks in the Bohai Bay coastal region (each has several square kilometers, with Artemia ponds of 2,500–7,000 ha), Artemia is usually considered a by-product of brine chemical production and shrimp farming.

The sustainable development of the Artemia industry needs the support of the government and efforts of industry and academia. In recent years, with increasing demand of Artemia and unstable supply of good quality Artemia cysts, the Ministry of Agriculture and Rural Affairs has realized the importance of improved Artemia production and efficient use of Artemia in aquaculture. Moreover, the establishment of Artemia organizations, for example, AAC (in 2017, with over 40 members), Asian Regional Artemia Reference Center (ARARC, in 2016, collaborated with Food and Agriculture Organization of the United Nations [FAO]), and Professional Committee of Live Feed of China Fisheries Society (in 2022) have promoted Artemia business and research in the country. In particular, ARARC promotes and coordinates interdisciplinary and interregional Artemia research, provides a platform for information exchange on Artemia, and provides technical consultation and services for the production of Artemia cysts and their use.

Two aquaculture industrial standards: Artemia Cysts (SCT2001-2023) and Frozen Artemia (SCT2123-2023) were recently formulated; both of them are standards for Artemia products. However, there are no regulations/guidelines on how to conserve the genetic diversity of Artemia, efficiently and safely use Artemia nauplii and biomass in hatcheries and improve Artemia pond production using ecological-friendly approaches. Relevant guidelines should be formulated by joint efforts of government, industry, and academia, particularly for sustainable Artemia farming practices, including water management, biosecurity, and disease control.

In developing improved practices, the farming practices in Viet Nam and Thailand can be a good reference, though there are differences in climate and salt pond systems to be considered.

2.3.2. Barriers and opportunities

Barriers: Artemia price closely depends on the annual harvest and market demand. The unstable price for the raw cysts material purchase and dry cysts sale challenges the benefit of the business.

The high demand of Artemia cysts in the Chinese market means that the import of large amounts of high-quality raw cysts is needed. There are tariffs on the imported raw Artemia cysts from Russia, Uzbekistan, and Kazakhstan (6 percent tariff), and the dry GSL cysts imported from the USA (6 percent tariff + 18.5 percent) (Trade and Industry Department 2025).

Opportunities: The high tariffs and more importantly the increasing price of raw cysts encourage the local production of Artemia cysts, especially in the Bohai Bay coastal region where high-quality cysts can be produced.

2.4. Infrastructure and Capacity

2.4.1. Infrastructure

Artemia production infrastructure is relatively simple and low cost. The cyst processing infrastructures required include plastic/concrete tanks, freezing and cold storage equipment, and fluid dryers. In general, the cost of freezing and cold storage equipment is the major expenses for post-harvest processing. Such infrastructure is easily obtained or already exists in China.

There are plenty of salt ponds with suitable salinity for Artemia culture in the Bohai region. Roads and transportation links are good for quick transportation. Reliable electricity supplies are available, including large-scale solar panels and wind power generation, which are usually set up on top of the salt ponds or nearby.

2.4.2. Gaps and needs

Improvements in awareness, knowledge, and technology can ensure the overall development of Artemia and the aquaculture industry. Given the successful training course organized by ARARC in 2023 and 2024 (more than 160 participants from 10 provinces in China) and positive feedback from the trainees, it appears that technical training to the managers, farmers, distributors, end users as well as researchers and university students are necessary (Figure 8). Training courses are needed on all aspects, including basic knowledge of Artemia biology and resources, production and processing technology, marketing, and efficient utilization of Artemia in the hatchery.

Training in China is organized by government, industrial associations, and companies, with the involvement of Artemia experts from industry and academia. Moreover, technical demonstrations and extension are required to support expansion of the industry.

FIGURE 8. **Training on sustainable exploitation and utilization organized by ARARC and AAC in China**

Source: Sui, FutureFish

2.5. Market Assessment and Demand

2.5.1 Local and Export Markets

The fast development of aquaculture in China over the past decade has led to a demand for dry Artemia cysts of 1,000–1,500 tons per year, which corresponds to roughly 50 percent of the entire world demand. According to the estimation of AAC, an average 800–1,000 tons of dry cysts are imported annually from Russia, Kazakhstan, and USA. The Bohai Bay Artemia cysts are mostly sold to Zhejiang Province where Bohai Bay cysts are preferred by *Macrobrachium* hatcheries. The company also processes cysts that are purchased from other Bohai Bay saltworks as well as inland salt lakes in China and in other countries. The cysts are usually sold to direct consumers (the hatcheries), and only a small quantity is sold to wholesalers. A small quantity of the cysts is exported.

The fresh and frozen Artemia biomass are mostly consumed by the local shrimp nursery and grow-out farms, as well as aquarium fish markets. Very small quantities of frozen Artemia biomass are exported to Southeast Asia.

2.5.2 Pricing and competition

The price of Artemia cysts in the Chinese market fluctuates with cyst yields and with the demand of the market, both at the international and domestic levels (Table 4). Artemia cysts from the Bohai Bay salt ponds on the other hand are known for higher hatchability and better nutritional value and are thus sold in China at a price roughly 150 percent higher than inland cysts. Meanwhile, the price of Artemia biomass remains very low, about US$0.3 per kg, largely as it is regarded almost like a by-product of the solar salt industry.

TABLE 4. Price of Artemia cysts in the Chinese market (US$ per kg)

Product origins (hatching rate/water content)	2020	2021	2022	2023	2024
Russian + Central Asian countries (85 percent/15 percent)	20–25	25–27	25–32	32–38	40–44
Russian + Central Asian countries (80 percent/15 percent)	18–22	22–27	22–27	27–32	36–38
Russian + Central Asian countries (<75 percent/15 percent)	11–16	14–16	14–16	19–21	27
Bohai Bay (85 percent/15 percent)	37–41	38–41	44–66	77–83	80–83
Bohai Bay (<85 percent/15 percent)	36	38	41	73	77

Note: US$1 = RMB 7.28

2.5.3 End-user behavior

China consumes the largest quantity of Artemia cysts and biomass in the world, with annual consumption of 1,000–1,500 ton dry weight cysts (data from AAC). Price is the main concern of the customers, no matter whether the cysts are locally produced or imported.

In China, Artemia is currently not used as human food (neither as food ingredient nor direct food item). There is an intention to develop Artemia as a functional food or food ingredient for human consumption, but the procedure is considered very complex and time/money consuming.

2.6. Socioeconomic Impacts and Inclusion

2.6.1. Community Involvement

Artemia production needs manual labor. Most of the field workers are men of age 40–60. Very few women and young people are involved in the Artemia business in China. For example, in Bohai Aqua, no woman is in a leading position, and about 10 percent women (5 out of 50) work in canteens. In other Artemia cysts companies (family businesses), 3–4 ladies are in leading positions out of 40 companies (10 percent).

2.6.2. Economic Impact

The positive economic impact of Artemia farming includes jobs and businesses, including diversification of income opportunities in salt works and stabilization of market prices for cysts and biomass. Further work is needed on the development of sustainable culture technologies adapted to the local climate and production system. The development of new Artemia-based products, such as food ingredients and human food items, will increase the economic opportunities from the Artemia business.

2.7. Climate Resilience and Environmental Considerations

2.7.1. Environmental risks

Rapid salinity reduction due to heavy rainfall in summer or increased salinity due to high evaporation rate in spring may influence Artemia pond production. Fortunately, in the solar salt production system, management can reduce these impacts by regulating the inlet or outlet water flow to maintain the suitable salinity range in the ponds.

Improper fertilization or overfertilization can result in a high organic load in brine and consequently cause impurity problems for salt. The solution is to build up a kitchen (algae pond) to prepare high-density microalgae for Artemia instead of fertilizing water in Artemia ponds. The former is much more efficient in nutrient utilization and therefore has less ecological impact on downstream salt production.

2.7.2. Climate resilience

Compared to the Artemia harvest from the salt lakes, to some extent, Artemia pond production integrated with salt production can be better controlled and managed through regulating salinity. Moreover, the nutritional quality can be manipulated, and the traits can be selected according to market and quality demands.

2.8. Investment Opportunities and Case Studies

2.8.1. Key Investment Gaps and Value Chain Development Needs

Apart from being crucial live food for aquaculture, as an extremophile aquatic organism, Artemia possesses some special metabolites or molecules (for example, GP4G) to cope with the hypersaline and hypoxia environments. Artemia is rich in proteins, lipids, HUFA, and minerals and thus has potential application in food industry, human health care, and nutraceuticals, as well as aquafeed industry. Some relevant products are being developed, such as Artemia biomass peptide, Artemia PUFA (polyunsaturated fatty acids), GP4G, and hydrolyzed Artemia biomass pulp (used as feed additive). The exploration of new markets can definitely improve the business and economic benefits of Artemia.

2.8.2. Financing and market access

Capital requirements for Artemia biomass and/or cyst production are low since existing shrimp ponds or salt pan infrastructure can be used. Operating costs are also low due to the use of agricultural wastes. On the other hand, investments are needed for exploring new Artemia products that have wider applications.

A stable market price (both biomass and cysts) is critical for the Artemia business. There is increasing market potential for Artemia biomass provided the products can be maintained with high quality and biosecurity.

2.8.3. Promising Business Models

Bohai Bay Artemia has been in the leading position in China for Artemia pond production. Although the scale and yield of Artemia pond production far exceed those of other countries, there is still room for scaling up the production with technological improvements and using more salty land to meet the increasing demand of the aquaculture industry in China. With the increasing demand for Artemia, especially for high-quality Artemia biomass, the business can also be expanded to other coastal regions (for example, Fujian Province, Guangdong Province, and Hainan Province where the climate conditions are similar to Southeast Asia and the aquaculture industry is more developed) as well as inland salty land (for example, in Gansu Province and Ningxia Province in northwest China where more income can be created to the local people).

Artemia production can also be integrated with intensive shrimp or fish culture. Also, the indoor tank culture is expected to develop in China to produce high nutrition and bio-secured Artemia biomass for broodstock maturation of shrimp and fish.

Table 5 outlines the China Solar Salt Work Business Model, which integrates large-scale Artemia production into solar saltworks. This model leverages the seasonal production of Artemia cysts and biomass alongside salt, maximizing the use of salt ponds for multiple income-generating activities. The model highlights its potential for large-scale production, emphasizing the revenue generation, market potential, and environmental conditions that contribute to its success. It also provides insights into the operational costs, profit margins, and the workforce involved.

TABLE 5. China Solar Salt Works Business Model

Name of Business Model	China Artemia Solar Saltworks Model
Category	**Details**
Diversified Income Opportunities	Artemia cysts, biomass, salt production, brine sales, and shrimp aquaculture integration
Summary	Large-scale Artemia production integrated into massive solar saltworks, where cysts and biomass are produced seasonally alongside salt.
Total Production per Cycle	Cysts: 500–600 tons annually (wet weight) Biomass: 200,000–300,000 tons annually
Cycle Time	April–November (seasonal production)
Tons per ha per Cycle	Cysts: Produced in large salt ponds (30–60 ha per pond) Biomass: High-yield, large-scale collection
Production Cost per kg	US$0.30 per kg for biomass
Cost per ha per Cycle	US$5,000 per ha per year (for salt and cysts) - Fertilization (organic: chicken manure, inorganic: urea and DAP), labor, boats, pumps, and power costs
Selling Price (US$ per kg)	Cysts: Premium quality at over US$100 per kg, 150% higher price than inland cysts Biomass: US$1.5 per kg
Revenue per ha	US$6,000–30,000, but artemia biomass treated like by-product of salt production and much also used within vertically integrated hatchery
Profit Margin	30–50%, stable due to high demand; cysts sold at a premium due to better hatchability and nutrition
Investment Cost and ROI	Large-scale investment with infrastructure needs (boats, pumps, PVC pipes), but high return due to scale
Employment per ha	Manual labor-intensive due to pond size; most workers are men ages 40–60
Total Jobs Created	Bohai Bay saltworks employ hundreds in seasonal Artemia harvesting
Women in Workforce	Low participation of women (10% in labor, very few in leadership positions)
Technology Needed	Boats, pumps, PVC pipes, biomass harvesters, and seed stock (once per season)
Environmental Conditions	Salinity: 80–150 g per L Ponds: 30–60 ha per unit, 80–150 cm deep High eutrophication supports Artemia and algae growth
Main Markets and Consumers	*Macrobrachium* and shrimp hatcheries, domestic aquaculture, and export markets
Domestic vs. Export Market	90% of cysts sold domestically (Zhejiang Province); 10% exported (Southeast Asia, Korea, Rep.)
Untapped Potential	China still imports 800–1,000 tons of Artemia cysts per year, mostly from Russia, Kazakhstan, and USA; there is significant potential for expanding domestic cyst production to reduce imports.

2.9. Recommendations

The following investment recommendations are from the China case study.

	Recommendations for Investment
Production Improvement Strategies	• Improve the traits of Artemia strain through proper genetic management and breeding programs. • Promote the application of sustainable culture technology, such as the ‘algae kitchen’, bottom raking, and optimal fertilization.
Policy and Regulatory	• Formulate guidelines for sustainable Artemia farming practices, including water management, biosecurity, and disease control. • Enhance the role of industrial association (such as AAC) in stabilizing price and standardizing the processing operation and quality of products. • Support Artemia research, education, and technical service platforms (such as ARARC). • Invest in new technology and innovations for production efficiency and market development (for example, indoor mass Artemia culture and human food).
Infrastructure and Technology	• Demonstrate and extend sustainable technology to achieve improved and stable Artemia production. • Conduct research and development (R&D) of novel technology to produce Artemia cysts and biomass with high nutrition and biosecurity. • Develop Artemia-based food ingredients, food items, and bioactive compounds (for example, peptides and functional proteins).
Market Development Strategies	• Emphasize the crucial role of Artemia for larviculture. • Demonstrate the benefits (for example, enhanced immunity and stress resistance of aquatic animals) resulting from increasing Artemia feeding (nauplii and biomass).
Socioeconomic	• Training and technical demonstration are required to support expansion of the industry. • Improve the benefit of the Artemia business to attract young people involved in the business. • Increase investments in Artemia product development for human food applications.
Potential Investment Impacts	• Employment in Artemia businesses, including in more remote salt-affected regions • New business investment opportunities and economic activity in new aquafeed and human food applications

3

KENYA

3.1. Introduction and Overview of Artemia in Kenya

3.1.1. Establishment of Artemia culture in Kenya

Artemia production in Kenya has grown in recent years, primarily through its integration with solar salt farming, which is common in Kenya's coastal regions. The country's progress in Artemia farming has been catalyzed by research institutions, aquaculture businesses, and international collaboration.

The introduction of Artemia into Kenyan saltworks dates back to the early 1980s under the Kenya-Belgium Project (KBP). This initiative aimed to position Kenya in the global Artemia cyst market and was spearheaded by researchers from the Kenya Marine and Fisheries Research Institute (KMFRI) and Ghent University.

Kurawa and Fundisha salt farms were the first sites to be inoculated with Artemia under the KBP. Over time, Artemia spread naturally across existing salt farms through wind and bird activity (Nyonje 2011). However, no deliberate reinoculation efforts were undertaken until the 1990s, when a massive algal bloom severely affected Kensalt, Kenya's largest salt producer. The algal bloom disrupted salt production to the extent that the farm faced potential closure. Seeking a solution, Kensalt's management turned to KMFRI, having learned of their work on Artemia that had successfully mitigated similar issues in neighboring salt farms. The KMFRI Artemia research team subsequently introduced Artemia into Kensalt's ponds, and within a month, the algae had cleared, enabling the farm to resume operations.

Building on such experience, Kenya's Artemia researchers have developed best practices for Artemia pond culture, and markets have been slowly developed. Locally produced Artemia are now successfully used as a live feed in aquaculture hatcheries, supporting the growth of the country's aquaculture industry.

3.1.2. Status of the Artemia sector and value chains

The Artemia value chain in Kenya involves the production, processing, and application of Artemia biomass, mainly in the coastal regions. Artemia production occurs in artisanal and commercial salt pans, the latter often managed and owned by salt-producing companies.

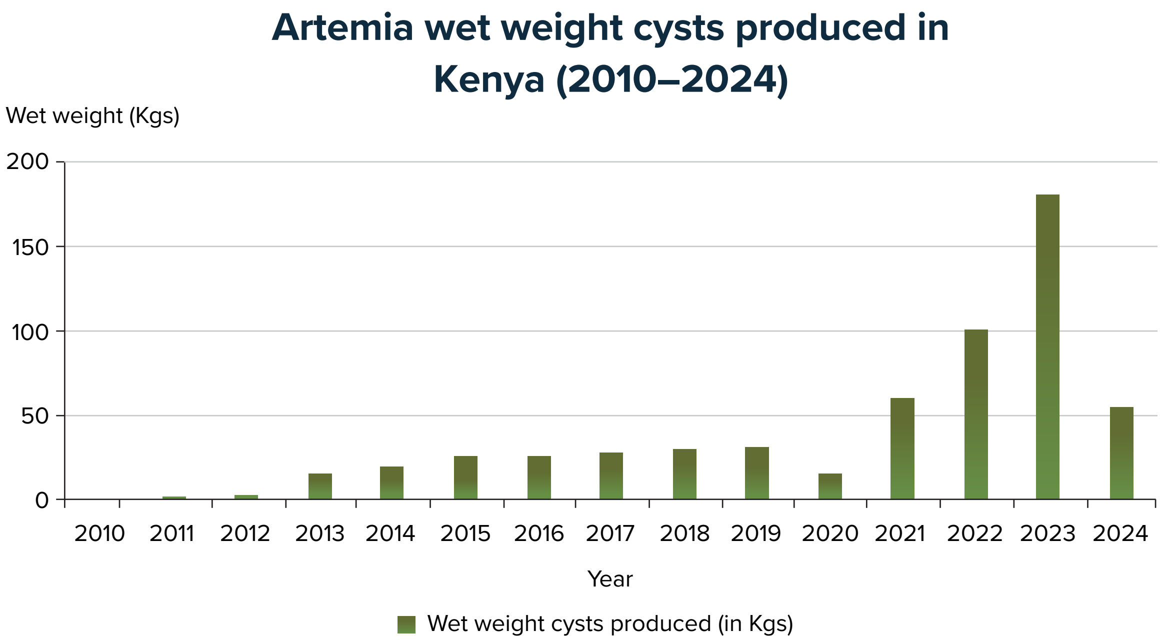
Artemia production in Kenya has been growing, driven largely by increasing demand from aquaculture hatcheries. The country remains heavily dependent on imported Artemia cysts for its expanding aquaculture industry. The imported cysts are sold to finfish (catfish, marine fish, ornamental fish) and shellfish (crabs, prawns.) hatcheries. However, significant progress has been made in domestic Artemia in artisanal and commercial production.

Historically, Artemia farmers in Kenya have focused on cyst production for reinoculation in salt farms. However, there is a noticeable shift toward Artemia biomass production, driven by the need to reduce reliance on fishmeal and improve reproductive attributes of fish broodstock in hatcheries. Aquaculture nutritionists are advocating against the use of fishmeal in aquafeeds, emphasizing the importance of minimizing competition between fish and human consumption. Artemia biomass, with its high protein content, presents a sustainable alternative with potential as human food and in livestock and poultry feeds.

Despite over four decades of efforts in Artemia cyst and biomass production, Kenya's output remains relatively low (Figure 9) compared to global standards. This has been caused by a lack of resources for effective inoculation and collection of Artemia cysts especially in large commercial saltworks, as well as market limitations. Kenya has significant potential for Artemia farming, supported by the availability of suitable farming space (about 7, 300 ha of saline ponds within the Ngomeni-Kurawa area) (Yap and Landoy, 1986), saline water, and solar energy for operations. Yet Kenya continues to rely largely on imported Artemia cysts from global markets, including the United States and Asian countries.

Artemia farming in Kenya remains institutionally dependent on KMFRI, which has played a central role in the sector's development and operational continuity. Initially, the industry was heavily reliant on KMFRI for technical guidance on inoculation, cultivation, and utilization of Artemia, particularly during the foundational years up to around 2010. While this dependency has somewhat declined due to KMFRI's targeted training programs for both artisanal and commercial farmers, the institute remains a vital technical backbone. KMFRI not only provides access to critical processing equipment—which is otherwise unavailable locally due to the specialized nature of the sector—but also fills persistent knowledge gaps. When KMFRI equipment fails, farms often revert to inefficient manual methods, highlighting the lack of decentralized processing capacity. Moreover, within commercial salt farms, the transfer of KMFRI-trained expertise is vulnerable to staff turnover, as the departure or retirement of trained personnel often leaves companies without the operational know-how to manage Artemia production independently. This underscores the sector's ongoing dependence on KMFRI for both equipment and sustained technical capacity.

FIGURE 9. A trend in artemia cysts production in Kenya between 2010 and 2024



Source: Mukami, FutureFish
Note: The final year, 2024, does not cover the whole year.

3.2. Production Systems, Input Supply, and Technology

3.2.1. Current production practices

Kenya's Artemia production is closely integrated with salt farming due to the species' ability to thrive in hypersaline environments. The introduction of *Artemia franciscana* from San Francisco Bay, United States, in the 1980s marked the beginning of Artemia farming in the country. However, subsequent reintroductions of other strains, such as those from the GSL, by salt-producing companies may have led to genetic dilution of the original *A. franciscana* strain.

Artemia farming in Kenya is predominantly extensive, relying on naturally occurring algae as the primary source of nutrition. Unlike intensive production systems there is minimal human intervention in terms of feeding, pond fertilization, or environmental control within Kenya's culture ponds.

Artemia is cultured in both commercial and artisanal salt farms, with significant differences in scale and management:

Commercial Salt Farms

There are 7 commercial farms in Kenya with pond sizes of at least 2 ha, with an average depth of 0.5 m. The farms are operated by privately owned companies.

Artemia is inoculated in salt ponds with salinity levels between 100 and 120 ppt, after which they naturally colonize higher salinity ponds of up to 220 ppt, where they eventually die. During the rainy season, commercial farmers manage pond salinity by allowing excess rainwater on the salt pond to drain, ensuring optimal conditions for Artemia survival. Inoculation of Artemia is carried at the onset of each salt production season.

FIGURE 10. KMFRI officers inoculate Artemia in one of the salt ponds belonging to Tana Salt Ltd.

Source: Mukami, FutureFish

Artisanal Salt Farms

These smaller-scale farms range between 0.03 and 0.5 ha with depths of 0.8 m and a 0.3 m trench around the pond edges. Unlike commercial farms, artisanal ponds are more susceptible to dilution during the rainy season, requiring farmers to rebuild brine water concentrations after heavy rains to restore suitable salinity levels. There are nine artisanal farms, with eight owned by individuals/families and one owned by a group.

FIGURE 11. **Ponds for artisanal Artemia farmers**

Source: Mukami, FutureFish

In Kenya, Artemia cyst production peaks at the onset of the rainy season, differing from other Artemia-producing regions. Harvesting techniques are similar across both commercial and artisanal farms. Cysts accumulate along the muddy edges of salt ponds and are typically collected early in the morning or late in the evening when wind activity is minimal.

The harvesting process involves

1. Collecting cysts mixed with mud and transferring them into basins or buckets partially filled with saturated brine water;
2. Allowing the cysts to separate naturally, where they float while the mud settles at the bottom;
3. Filtering the floating cysts through a series of mesh screens (1,000 µm, 500 µm, and finally 100 µm) to remove debris;
4. Collecting the purified cysts retained in the 100 µm mesh and storing in saturated brine for sale or further processing;
5. Carrying out the final processing at the KMFRI Artemia laboratory, which hosts the only cysts processing equipment in Kenya; and
6. Sieving the processed cysts and storing in a fridge before selling to customers.

FIGURE 12. **Cyst collection from Kurawa Salt Ltd**

Source: Mukami, FutureFish

For harvesting artemia biomass, a mesh net of 250 µm is used. The biomass is then dried in a custom-made drier for further formulating fish feeds.

Kenya's Artemia production, though largely extensive and low input, has the potential for further expansion through improved management practices, genetic conservation efforts, and investment in cyst processing facilities.

3.2.2. Input supply chain

Kenya's Artemia supply chain relies heavily on imported cysts, as local production remains insufficient (45–50 kg per year) to meet the growing demand. Despite the country's potential to expand Artemia farming, production is still largely dependent on natural conditions, requiring minimal external inputs. The key inputs for Artemia farming include seed stock, saline water, and solar energy.

Seed stock

The quality of Artemia seed stock in Kenya has been affected by genetic erosion due to repeated introductions of different strains over time. This dilution of the originally introduced Artemia strain has negatively affected its productivity. Additionally, high taxation rates on imported Artemia cysts have increased production costs, making them less accessible to farmers. Enhancing local production capacity could reduce dependency on imports, improve affordability, and ensure long-term sustainability of the Artemia sector.

Saline water

Water supply for Artemia culture is drawn from the ocean using pumps and then directed through gravity-fed trenches into the production ponds. Commercial salt farms, equipped with high-capacity pumps, can efficiently draw large volumes of water. However, artisanal Artemia farmers often rely on smaller, less durable pumps that are prone to wear and tear due to rust. These farmers also face additional costs for purchasing pipes and fuel to operate their pumps, which increases operational expenses. Salt-Artemia farmers who are a few kilometers from the ocean have drilled boreholes to ensure that they have a year-round water supply in case the creek water supply dries up.

Solar energy

Kenya's coastal region receives abundant solar radiation, which plays a critical role in Artemia farming by naturally evaporating water to increase salinity levels in production ponds. In the future, solar energy could be harnessed to power aerators, facilitating the transition to more intensive Artemia farming systems and improving overall productivity.

3.2.3. Technology adoption

Technology adoption in Artemia farming in Kenya remains limited due to the relatively low production levels. However, there is great potential to increase Artemia production and efficiency by incorporating advanced technologies. The key improvements targeted include the following:

- Improved Artemia production techniques through the adoption of improved farming methods that are being undertaken in other parts of the world. This will optimize yields and ensure sustainable Artemia production.

- Automated harvesting and drying systems to enhance efficiency. In Kenya, there is only one Artemia cyst processing equipment that was sourced from Viet Nam. Since Artemia farming is not so popular in Kenya, there are very few equipment that are available in the country, the cyst processing equipment being one of them. If the only available cyst processing machine in the country breaks down, it becomes very difficult to get a person to repair it in the country. This also makes it very expensive to repair. It is imperative to come up with technologies that enable mechanized harvesting and drying processes. This will improve efficiency and reduce post-harvest losses.
- Need to research on production of small-size Artemia cysts. Based on the preferences of marine hatcheries for small-size Artemia, it is important to investigate methodologies that will enable production of such cysts.
- Genetic improvement for higher productivity. It is necessary to conduct research on strain enhancement and selective breeding to improve Artemia quality and overall yield.
- Engaging the younger generation in Artemia research is essential for fostering innovation in and the sustainability of the sector. A good number of interns and attachments hosted at KMFRI have demonstrated significant interest in Artemia studies, with some selecting it as the focus of their final-year research projects.

FIGURE 13. KMFRI interns running their experiments in the Artemia laboratory

Source: Mukami, FutureFish

3.2.4. Productivity enhancement

Improving Artemia production in Kenya requires the adoption of advanced farming techniques, technological innovations, genetic improvements, strain selection, selection of cheap organic and inorganic food sources for Artemia, and optimized management practices.

A key strategy involves transitioning farmers from extensive to semi-intensive or intensive production systems. By the extensive system, the farmers just inoculate Artemia in their farms without adding any other inputs, while in the semi-intensive and intensive systems, additional inputs are applied in the farms such as fertilizers, supplementary food to the Artemia, aeration systems, and so on The extensive system has low degree of control, low-level technology, and low production efficiency and is less costly compared to semi-intensive and intensive systems. This shift can be facilitated through government incentives, input subsidies, and capacity-building initiatives. Encouraging farmers to form cooperative clusters will enable them to benefit from economies of scale, improving resource utilization and market access.

The integration of automated and mechanized systems will enhance operational efficiency, reduce labor intensity, and increase overall productivity. Additionally, the adoption of solar-powered pumps will lower energy costs, ensure a sustainable water supply, and support the natural proliferation of microalgae, which serves as the primary food source for Artemia. Further, the development of a skilled human resource in Artemia farming through capacity-building campaigns is key in improving efficiency in the Artemia farming sector. Therefore, there is a need to intensify training campaigns to improve local skills and knowledge which in turn will improve productivity in the sector.

3.3. Policy and Regulatory Environment

3.3.1. Existing framework

Kenya's existing regulatory frameworks have not explicitly recognized Artemia as a distinct aquaculture product. This omission is largely due to Artemia's relatively low profile in the aquaculture sector and its minimal social, economic, and environmental impact. As a result, existing policies primarily address Artemia indirectly through broader regulations on fish feed production and importation. The absence of specific guidelines for Artemia culture, trade, and utilization creates a regulatory gap that may limit sectoral growth, discourage investment, and hinder efforts to optimize local production. Integrating Artemia into Kenya's aquaculture policies would provide a structured framework for its development, enhance market confidence, and support sustainable expansion of the industry.

3.3.2. Barriers and opportunities

Several policy-level challenges hinder the growth of Artemia production in Kenya:

1. **High tariffs on imported Artemia cysts:** The taxation of imported Artemia cysts significantly raises production costs for hatcheries and farmers, making local aquaculture operations less competitive.
2. **Lack of specific regulations for Artemia farming:** The absence of a dedicated legal framework governing Artemia production, trade, and utilization limits sectoral growth and discourages investment.
3. **Limited access to financial support:** Due to the lack of formal recognition of Artemia farming within national policies, farmers face difficulties in accessing credit facilities, grants, and government funding.
4. **Inconsistent quality standards:** The absence of standardized quality control mechanisms for locally produced Artemia affects market confidence and limits its adoption as a reliable aquaculture feed input.

Despite these challenges, several opportunities exist to support the development of the Artemia sector:

1. **Policy integration and recognition:** Embedding Artemia production within national aquaculture policies can create a supportive regulatory environment, attract investment, and drive industry growth.
2. **Incentives for local production:** Government interventions such as subsidies, tax exemptions on Artemia farming equipment, and financial incentives for local producers can enhance production capacity and reduce reliance on imports.
3. **Development of industry standards:** Establishing and enforcing quality standards for locally produced Artemia can improve product consistency, facilitate market access, and enhance competitiveness in regional and international markets.
4. **Public-private partnerships (PPPs):** Strengthening collaboration between the government, research institutions, and private sector stakeholders can foster innovation, capacity building, and the adoption of sustainable Artemia farming practices. Market development is also required.

3.4. Infrastructure and Capacity

3.4.1. Infrastructure

Kenya's Artemia farming sector operates within existing solar salt farms, both artisanal and commercial, with minimal modifications while leveraging their infrastructure for water intake, pond management, and salinity control. However, dedicated facilities for Artemia harvesting and processing are limited. The sole Artemia laboratory in the country, and probably in Africa, at KMFRI's Mombasa Centre, relies on specialized equipment imported from the United States, Belgium, and Asia. This equipment includes the Artemia hatching jars, mesh nets, Artemia cyst processing machine, salinometers, and so on. The limited awareness of Artemia farming, coupled with its concentrated cultivation in the Kenyan salt belt, has contributed to the scarcity of locally manufactured infrastructure in this sector. However, the importation of specialized equipment faces delays due to stringent government procurement processes, while high transportation costs further increase the overall expense. These challenges hinder the development and scaling of the Artemia sector. Though the electricity and road infrastructure within the Artemia-producing region are generally in good condition, the quality of feeder roads leading to specific salt-Artemia farms which are managed by individual salt farms vary in quality with some salt farms experiencing poor access by cars but can be accessed by cyclists.

Kenya's vibrant Jua Kali sector, renowned for its innovative craftsmanship and adaptability, offers a promising avenue to locally manufacture some specialized Artemia equipment. By tapping into this established network of skilled artisans, the Artemia sector can reduce its heavy reliance on imported tools and overcome challenges associated with long procurement processes, high transportation costs, and breakdown of imported equipment. This will also foster local skill development and create job opportunities for the youth. This initiative can further stimulate innovation within the Artemia sector supporting long-term growth and competitiveness in both domestic and international markets.

FIGURE 14. From left to right: Centrifuge and a cyst sieve - the Artemia cyst fluidizer and packaging machine, imported by KMFRI from Viet Nam

Source: Mukami, FutureFish

3.4.2. Gaps and needs

a. Limited specialized equipment locally
b. Reliance on imported equipment
c. Transport and distribution networks
d. Limited Artemia farming skills - training and capacity building
e. Limited knowledge on the availability of Artemia markets - both supply and demand
f. Low technology adoption.

3.5. Market Assessment and Demand

3.5.1. Local and Export Markets

The demand for both Artemia cysts and biomass in Kenya is expected to rise with the ongoing expansion of hatchery infrastructure, representing a market opportunity.

Currently, four government marine hatcheries are under construction at the National Mariculture Research and Training (NAMARET) Centre at KMFRI Shimoni. According to Preston (2025a), the new prawn broodstock and hatchery module, which is designed to produce domesticated broodstock and hatchery-reared postlarvae of the Indian white prawn (*Fenneropenaeus indicus*) and the Black Tiger prawn (*Penaeus monodon*), can produce 3 million postlarvae per year to supply the seedlings to the current 15 ha of community mariculture ponds around the Kenyan coast assuming two stocking cycles per year, at 10 postlarvae/m^2. The hatchery can produce up to a maximum of six million postlarvae per year. The NAMARET prawn hatchery requires approximately 15 kg of Artemia cysts per year to produce 3 million postlarvae at a 40 percent survival rate, with demand expected to double to 30 kg per year by 2030 if production increases to 6 million postlarvae and potentially reaching 75 kg per year if survival improves to 100 percent.

TABLE 6. Artemia demand projections for the NAMARET prawn hatchery in Kenya

Postlarvae Target (in millions)	Total Artemia Nauplii Needed	Artemia Cysts Required (kg/year)
3 postlarvae (40% survival)	3,000,000,000	15.0
7.5 postlarvae (100% survival)	7,500,000,000	37.5
6 postlarvae (40% survival, 2030)	6,000,000,000	30.0
15 postlarvae (100% survival, 2030)	15,000,000,000	75.0

According to Preston (2025b), the NAMARET fish hatchery has been designed to produce domesticated broodstock and hatchery-reared seedstock (fry) from the White Spotted Rabbitfish (*Siganus sutor*) and marine-adapted Nile tilapia (*Oreochromis niloticus*). It can produce 1.5 million fry (Preston 2025b) at a 70 percent survival rate in 2025 based on the acreage of fish farms around the Kenyan coast. It therefore requires approximately 33.2 kg of Artemia cysts per year, with demand expected to double to 66.4 kg per year by 2030 if production increases to 3 million fry. If survival improves to 100 percent, Artemia demand could reach 47.4 kg per year for 2.14 million fry in 2025 and 94.9 kg per year for 4.28 million fry by 2030.

TABLE 7. **Artemia demand projections for fish production at the NAMARET hatchery in Kenya**

Target (in millions)	Survival Rate (%)	Total Artemia Nauplii Needed	Artemia Cysts Required (kg/year)
3 fry	70	6,642,859,800	33.2
4.3 fry (100% survival)	100	9,485,083,286	47.4
6 fry (2030)	70	13,285,719,600	66.4
8.6 fry (100% survival, 2030)	100	18,970,166,571	94.9

Additionally, Nintai Aquaculture, a privately owned shrimp farm, is developing a marine hatchery, while Crab Alive Limited operates a crab hatchery. These facilities, along with existing hatcheries, require a consistent supply of Artemia cysts for larval rearing and Artemia biomass for broodstock conditioning.

The local demand for Artemia in Kenya is driven by the growth of the aquaculture industry, which has been slowly but steadily increasing with the growing recognition of the critical role it plays in the aquaculture sector as a high-quality larval feed for shellfish and finfish hatcheries. The level of demand varies based on the species cultured. In Central Kenya, where catfish farming is predominant, Artemia is highly sought after since catfish larvae require it during their early developmental stages. Conversely, in the Nyanza region, where farmers primarily culture Nile tilapia due to consumer preference, Artemia demand is lower. Along the Kenyan coast, the demand is significantly higher, as many aquaculture farmers rear marine fish that require Artemia at their early stages. Additionally, ornamental fish farmers across the country rely heavily on Artemia as a key live feed for their fish. Currently, the country does not export Artemia due to low production levels. However, there is potential to increase production through specialized equipment, improved skills, and knowledge through training and exchange programs, and possibly automated systems

The establishment of an Artemia Reference Centre in Africa to act as a demonstration site may also help the local Artemia producers meet international standards and contribute to greater competitiveness on export markets.

3.5.2 Pricing and competition

The prices for the locally produced Artemia are primarily determined by the production costs, while the pricing of imported Artemia reflects the purchase price as well as additional factors such as taxation and transportation costs. The relatively low production of locally produced cysts makes it less competitive to imported cysts which are readily available but scarcely used—only for the pet industry totaling a few kilograms of cysts. However, if production efficiency and consistency are improved, the locally produced cysts have the potential to become more competitive as their cost is generally lower than the imported Artemia cysts.

3.5.3 End-user behavior

End-user behavior plays a critical role in shaping the market growth of Artemia, which is influenced by factors such as costs, reliability, and product quality. Feed, being the most expensive component of any aquaculture enterprise, directly affects the production capacities of hatcheries and other aquaculture ventures. Limited awareness of locally produced Artemia and a preference for imported Artemia can affect the market growth for locally produced Artemia. Improving consumer confidence through positive and prompt response to consumer feedback, quality control certification, and capacity-building initiatives will improve the end-user behavior. Shorter supply chains, improved cyst quality, traceability, and potential cost savings will shift consumer preference from the imported to the locally produced Artemia cysts.

3.6. Socioeconomic Impacts and Inclusion

Efforts to enhance the inclusion of women and youth in Artemia value chain initiatives from production to the marketing phase have been actively promoted, leading to increased female participation in community groups. For instance, the Kadzuhoni Self-Help Group (SHG) comprises 34 members, with 21 women (62 percent) and 13 men (38 percent), reflecting significant female representation. Similarly, the Kadzuhoni Artemia Conservation SHG consists of 15 members, of whom 10 are women (67 percent) and 5 are men (33 percent). These figures highlight the growing involvement of women in community-led aquaculture enterprises. Despite high female participation in Artemia production, women remain underrepresented in leadership roles. In the Kadzuhoni SHG, only one woman out of five leaders (20 percent) holds a leadership position—serving as the treasurer. In the newly formed Kadzuhoni Artemia Conservation SHG, all the men in the group are leaders, along with two women who hold the positions of secretary and treasurer, bringing women's leadership representation to 29 percent (two out of seven leaders). Women have been entrusted with the role of managing finances, showing the trust the community has on them.

FIGURE 15. Women engaged in pond construction

Source: Mukami, FutureFish

3.7. Climate Resilience and Environmental Considerations

3.7.1. Environmental risks

Key aspects of environmental risks related to Artemia in Kenya include the following:

- Brine needs to be properly managed as the industry grows, to avoid risks to nearshore marine ecosystems.
- Highly saline water used in Artemia farming can contaminate soils, surface water, and groundwater thus having an effect on terrestrial plants (Kaushal et al. 2023). Suitable site selection is essential.
- Oil spills from pumps may contaminate soil and water.
- Poor disposal of rusted machinery and metal and plastic fragments can contaminate the environment and pose health risks.
- Groundwater abstraction through borehole drilling also needs to be carefully managed.

FIGURE 16. Rusty water pump

FIGURE 17. Deforested mangrove forest for the establishment of a salt pond in Magarini Sub-county, Kilifi

Source: Ocholla et al. 2013.

Coastal deforestation has also arisen as a result from clearing areas for salt farming (Figure 17), emphasizing the importance of coastal planning for future salt production and potential for development of Artemia-salt-forestry integrated systems that better preserve biodiversity while providing livelihood opportunities for coastal communities.

3.7.2. Climate resilience

The region where Artemia is cultivated experiences harsh climatic conditions, including very high temperatures, prolonged droughts, and periodic flooding, which contribute to crop failures and livestock mortality. As a result, Artemia farming emerges as a viable alternative livelihood, providing a sustainable means of supporting the local economy. Artemia farming has particular potential to stimulate economic growth of the underdeveloped Magarini Area.

3.8. Investment Opportunities and Case Studies

3.8.1. Key investment gaps and value chain development needs

The following investment gaps are identified:

- Limited processing infrastructure is hindering Artemia quality.
- Lack of mechanized harvesting equipment leads to inefficiencies and high labor costs.
- The sector lags in adopting modern technology. Digital tools could be explored to enhance traceability and market transparency.
- Marketing strategies for locally produced Artemia are ineffective. Further investment is needed in market promotion, including branding the locally produced Artemia to enhance consumer awareness and market penetration.
- Fish hatchery managers and fish farmers lack expertise in Artemia utilization.

3.8.2. Financing and market access

Farmers have limited ability to access finances from banks and other financiers since there are no finance products that target the aquaculture industry, let alone the Artemia sector. There is poor awareness among investors of the business opportunity.

3.8.3. Promising business models

Apart from farming, Kenya has retailer and manufacturer enterprise models. In the retailer models, there are local aquapet shops which mostly import processed Artemia cysts from different countries in the world and repackage them into smaller quantities (from less than 10 g to 1 kg) to suit the needs of different local customers. A few such shops exist in Kenya and they include Samaki Express in Nairobi and Coast Ornamental Fish & Pets in Mombasa. Generally, the prices vary from KES 10,200 to KES 12,000 (US$85–100 exclusive of shipment costs) but rise to KES 15,600 inclusive of shipment costs. The supply is largely from abroad, increasing the costs of cysts from the local price of KES 7,000. This model could be explored with increased domestic production since these outlets can be located closer to customers and effectively serve them.

The manufacturer model is only practiced by KMFRI. The institute procured and installed a full Artemia processing plant. The system consists of a fluidized bed cyst drier, centrifuge, sieve, and a canning machine. At the moment, KMFRI has been buying raw cysts from local artisanal salt producers which are processed and sold to local hatcheries and retail outlets. The plan going forward is to operationalize the canning process of the dried cysts and distribute them directly to customers which are local retailers and hatcheries and where possible target regional markets. The institute also lined up training and advertising campaigns to improve knowledge of Artemia locally, influence favorable policy, and attract investment in the Artemia value chain.

Table 8 synthesizes the key characteristics of Artemia farming in Kenya, incorporating both cyst and biomass production. The system is largely based on Asian experiences, modified as appropriate to the Kenyan context.

TABLE 8. **Kenya Artemia Cysts and Biomass Farming**

Name of Business Model	Kenya Artemia cysts and biomass farming
Category	**Details**
Diversified Income Opportunities	Artemia biomass, Artemia cysts, salt production, marine finfish and shellfish, planting of mangrove seedlings and trees in coastal ecosystems
Description	Integrated salt-Artemia aquaculture production, combining salt production and in some cases fish farming for added income
Total Production per Cycle	Cyst production is 3,031 g/ha/month in a semi-intensive system Artemia biomass production is 3,797 g/ha/month in a semi-intensive system. These have reached 33 kg/ha and 250 kg/ha, respectively.
Cycle Time	9 months per year (October–June) operation possible, with peak cyst production in the rainy season while the biomass declines with the onset of the rainy season. Fish production season is expected to take place within the three months when salinities drop—during the cold season between July and September
Productivity per ha	Cysts: ~ min of 3 kg/ha/month to 33 kg/ha per season Biomass: ~ min of 3.8 kg/ha/month and 250 kg/ha per season
Production Costs per kg	Cysts: US$7/kg Biomass: US$2/kg
Cost per ha per Cycle	Labor (2 workers per farm), water management, pond management, cyst inoculation, and cyst and biomass collection/harvesting—1 worker per day is paid KES 250 equivalent of US$2.
Selling Price (US$/kg)	US$62.5 for cysts US$4–5/kg for biomass
Revenue per ha	7 commercial farms with average 2 ha each and 9 small-scale farms with average 0.5 ha each—around US$590/ha for biomass or US$1,700 for cysts
Profit Margin	Margin on cysts around 89% and 56% for biomass
Investment Cost and ROI	Low investment cost and payback period of 2 years
Total Jobs Created	9 artisanal farms (1 is group owned while the other 8 are owned by individuals) of about 50 ha per farm and 7 commercial solar saltworks of about 3,000–6,000 ha (but no Artemia)
Women in Workforce	Around 40% of women involved in pond construction and pond management
Technology Needed	Salt ponds, Artemia cysts for inoculation, hatching equipment—aerators, buckets, pipes and so on—seawater pumps, water quality monitoring, raking equipment, and harvesting buckets
Environmental Conditions	Salinity: 80–150 g/L, high temperatures; hence, high evaporation rates; water increases in salinity as it moves from one pond to another through gravity as a result of evaporation
Customers and Markets	Shrimp, crab, marine finfish, ornamental hatcheries, ornamental fish markets, students, researchers, catfish farmers, commercial and artisanal salt farmers
Domestic vs. Export Market	100 percent is sold in the domestic market, with potential to grow and diversify
Untapped Potential	Kenya Artemia cysts and biomass farming, associated with market development

3.9. Recommendations

The following investment recommendations are from the Kenya case study. Continued investments in Artemia market development, product diversification, businesses, research, training, policy development, and sustainable production could unlock the sector's full economic potential, enhancing local supply, reducing import dependency, and supporting the growth of Kenya's aquaculture industry.

	Recommendations for Investment
Production Improvement Strategies	• Increase the area of Artemia artisanal production in Kenya. • Identify locally available waste products as direct/indirect food sources for Artemia. • Invest in producing high-quality Artemia, for example, the small-size cysts. • Improve cyst harvesting, processing, and packaging technologies. • Increase Artemia expertise in the country through exchange programs with other Artemia-producing countries. • Establish an Artemia Reference Centre for Africa to fast-track development of Artemia farming in Africa.
Policy and Regulatory	• Reduce import tariffs on Artemia cysts. • Provide incentives to local Artemia producers. • Incorporate Artemia-specific regulations in policies that are related to aquaculture, fisheries, and the blue economy. • Identify suitable locations and zones for Artemia farm investment.
Infrastructure and Technology	• Establish Artemia cyst processing businesses near the Artemia-producing zone/area. • Incorporate the Jua kali sector in developing specialized equipment for Artemia farming and other innovative equipment. • Develop value added products from Artemia biomass including human food, poultry, and livestock feeds. • Centralize cold rooms for storing harvested Artemia biomass for sale.
Market Development Strategies	• Conduct market development activities, including tilapia and catfish feed and diverse applications in animal feeds and human food. • Provide business support for Artemia businesses and product diversification (competitions and business incubators). • Conduct awareness campaigns to promote Artemia production and products. • Promote Kenya Artemia in local and regional Artemia markets.
Socioeconomic	• Support women and youth involvement and businesses in Artemia farming and along the value chain.
Climate and Environmental Resilience	• Promote best practices for environmentally sustainable Artemia production practices. • Strengthen climate resilience through design and promotion of integrated Artemia-salt farming systems.
Impact Potential	• Impact potential on coastal communities (jobs, new livelihood opportunities, and potentially nutrition) is high if the markets can be grown and Artemia businesses established.

4

THAILAND

4.1. Introduction and Overview of Artemia in Thailand

4.1.1. Establishment of Artemia culture in Thailand

Artemia culture in Thailand began in 1977 when DOF, with FAO and United Nations Development Programme (UNDP) support, initiated a Macrobrachium Development Centre in Chachoengsao Province to support giant freshwater prawn farming. Artemia nauplii were needed as live feed for prawn larvae, leading DOF officers to attend an international Artemia training course in 1978.

In 1978, DOF began local Artemia cyst production, inoculating a 0.24 ha pond with the San Francisco Bay *Artemia franciscana* strain. The first successful harvest of 10 kg of dry cysts came in 1979 after 45 days of culture. Thailand became the first commercial Artemia cyst producer in salt farms, inspired by a successful demonstration in the Philippines.

In 1980, DOF began promoting Artemia farming in salt farms across Chonburi, Chachoengsao, and Samut Songkhram Provinces in the vicinity of the Gulf of Thailand, later expanding to Petchaburi and Chantaburi in the east and Pattani in the south. Production of up to 600 kg of raw cysts was achieved from 5.7 ha of ponds. From 1992 to 1996, the Thai and Belgian governments conducted the “Artemia Project,” establishing a National Artemia Reference Centre at Kasetsart University.

4.1.2. Status of the Artemia sector and value chains

Today, commercial Artemia farms focus on producing biomass rather than cysts, prioritizing ease of production and reliable cash flow. There are 15–20 farms producing biomass on a commercial basis, with around 45 ha under cultivation. Collectively, they produced 340 tons of biomass worth US$330,000 in 2020–2021.

The shift to biomass production has been favored by the presence of a ready local market in the form of the rapidly growing aquaculture industry. Biomass is largely sold to marine shrimp, crab, and finfish hatcheries, which use it to condition their broodstock. Artemia farms can also supplement their income through the sale of high-salinity brine to the other farms and hatcheries.

Most farms lie adjacent to solar salt fields, where high evaporation rates facilitate the maintenance of high-salinity culture systems. The industry is concentrated in salt-producing provinces around the Gulf of Thailand (Samut Songkhram, Samut Sakhon, Petchaburi, and Chachoensao) due to DOF's historical efforts to introduce Artemia culture in these areas.

Thailand does not produce commercial quantities of Artemia cysts, and hatcheries are reliant on imports to provide feed for early-stage larvae of marine shrimp, crabs, and finfish. 482 tons of cysts were imported in 2020, with 90 percent sourced from China, Russia, Uzbekistan, and Kazakhstan, and the remainder from the United States (Aquafeed Media 2022).

However, a significant proportion of these cysts are processed, packaged, and reexported. In 2024, 129 tons of cysts with a declared value of US$6.24 million were exported from Thailand to destinations including Viet Nam, Indonesia, Sri Lanka, the Philippines, Bangladesh, and Pakistan (Volza 2025). It is likely that this is a substantial underestimate.

Brine has also become an important by-product of the salt and Artemia industry in Thailand, as shown in Box 1 (that also includes some notes from Viet Nam, where similar diversification has occurred).

BOX 1: Economic Opportunities from Brine as a By-Product in Thailand (and Viet Nam)

Brine as a Resource

1 m^3 of brine (120 g/L) mixed with 4 m^3 of freshwater produces 5 m^3 of high-quality seawater, which is superior to coastal seawater due to its lower dissolved organic matter (reducing Vibrio bacteria risks) and higher biosecurity (fewer pathogens).

Market Price and Seasonal Variation

- In Viet Nam, brine costs around US$1 per m^3 during the dry season but can double in price due to increased demand.
- Over 1,000 m^3 of brine per year is transported by boat via the Mekong River to Can Tho (80 km), supplying marine fish and crustacean hatcheries.
- In Thailand, the cost of brine depends on the delivery distance and mode of transport.

Brine Transportation Costs in Thailand

(based on farmer information from Nakhon Pathom and Suphanburi):

- Truck transport (28 m^3 capacity): Costs range from THB 3,800 to THB 6,000 (US$110–180) per trip, depending on the distance to the delivery site.

- Nakhon Pathom (~40 km from coast): Lower transport costs.
- Suphanburi (~120 km from coast): Higher transport costs.

Potential Economic Benefits:

- Using brine for hatcheries and aquaculture operations offers a bio-secure alternative to coastal seawater, which may improve survival rates in fish and shrimp hatcheries.
- Brine transport presents a growing economic opportunity, particularly for inland aquaculture hubs that require high-quality seawater.
- Investment in efficient brine transport logistics could optimize costs and expand the market for inland marine aquaculture in Thailand.

Thailand's Artemia sector is uniquely positioned within the global aquaculture landscape as one of the only countries farming Artemia biomass at scale rather than focusing on cyst production. Thailand has no natural Artemia stocks that can be harvested, so biomass must be farmed. This live biomass farming model—centered in salt-producing coastal provinces—converts traditional salt ponds into year-round Artemia production systems that yield 2–4.5 tons/ha/month. The value chain is largely domestic, supplying hatcheries for shrimp, crab, marine finfish, and ornamental species with fresh or frozen Artemia at prices between US$1.50 and US$1.78 per kg. With low production costs (US$0.15–0.50/kg) and minimal technology inputs, the model delivers rapid returns (1–2 years), employs 1–2 workers per ha (often women in post-harvest roles), and generates up to US$38,000 in annual revenue per farm. While Thailand imported 482 tons of Artemia cysts in 2020, the growth of the live biomass segment is helping strengthen local hatchery feed supply chains and create diversified rural income opportunities. As a whole, the sector demonstrates how biomass-based Artemia farming can complement or substitute cyst imports, serving as a practical, inclusive, and climate-resilient model for coastal aquaculture economies—one that remains underutilized globally but holds strong potential for replication.

4.2. Production Systems, Input Supply, and Technology

4.2.1 Current production practices

Artemia farming in Thailand is focused on the production of *Artemia franciscana* biomass in ponds, with naturalized seed stock originating from early inoculation projects in the 1980s and 1990s. Culture practices are divided into two major systems, which may be considered 'traditional' semi-intensive systems and 'developed' intensive systems with daily partial harvests.

Artemia Farming Production Systems in Thailand[2]

 ARTEMIA FARMING PRODUCTION SYSTEMS IN THAILAND	Traditional Semi-Intensive 	Developed Intensive 
Location	Samut Songkhram Province	Petchaburi and Chachoengsao Provinces
Pond Size and Depth	Smaller, shallow ponds (modified salt pans) 0.32–0.48 ha, depth 0.6–0.8 m	Larger, deeper ponds (modified shrimp ponds) 0.32–1.00 ha, depth 1.5 m
Salinity Management	Difficult to regulate during monsoon rains	Stable salinity, allowing year-round production
Seasonality	Largely seasonal	Year-round
Pond Management	Minimal management; basic fertilization	Frequent bottom raking; fertilization
Harvesting Method	Fine mesh nets (push net, hand-drawn trawl, bagged seine); lights attract Artemia for easy capture	Automated or manual harvesting with fine-meshed nets; low-speed paddle wheel and wooden guides direct flow into nets
Biomass Inoculation Rate	5–6 kg/rai (~31–38 kg/ha)	5–6 kg/rai (~31–38 kg/ha)
Salinity Range	75–90 ppt	75–90 ppt

Detailed examples of these systems are given in the Investment Opportunities and Case Studies section. The case studies provide examples of both systems being integrated into marine fish and shrimp hatcheries for live feed production, eventually becoming the main business or a profitable sideline. There is also potential to integrate Artemia cultivation into the substantial area of solar salt farms in production.

Salinity for Artemia biomass culture is normally maintained around 75–90 ppt to exclude predatory copepods, insects, or fish and competitors such as rotifers that may proliferate and compete for food with the Artemia. New ponds are inoculated with Artemia biomass (rather than cysts) from other farms at a rate of 5–6 kg/rai (~31–38 kg/ha).

4.2.2. Input supply chain

Farms can generally use cheap, locally available, and abundant inputs for farm operation. Farms were observed to construct much of their own harvesting gear including in some cases boats from locally sourced wood off cuts and bamboo, plastic sheets, and PVC pipes.

2 This map is for illustrative purposes and does not imply the expression of any opinion on the part of the World Bank concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

The main inputs required for Artemia biomass production are fertilizers, which are used to stimulate a bloom of halophilic algae and bacteria on which the Artemia can feed. Ponds are fertilized from 2–3 times a week to almost daily, according to need as assessed by the appearance of the plankton bloom.

Currently, ponds are mainly fertilized with low-cost agricultural by-products such as poultry manure (phosphorus source) and cassava residue from Ajinomoto production (nitrogen source), both of which are readily available at low cost. Other materials used to fertilize ponds include molasses, cow or pig manure, urea, or organic wastes fermented on farms to produce a nutrient-rich liquid. Farms were able to change their fertilization materials in response to quality or availability issues.

There may be some minor fuel and power costs to operate small boats, harvesting equipment such as paddlewheels, and pumps. The equipment requirements are very light since Artemia ponds do not require aerators, feeders, or other heavy gear and can be harvested with hand-drawn barrier nets.

Seed stock is only required during the commissioning of a new pond, which is achieved by introducing biomass from another farm (31–38 kg/ha), at minimal cost. Thereafter Artemia self-recruits and no further stocking is necessary.

4.2.3 Technology adoption

The state of technology adoption is relatively low, in keeping with the relatively small scale and simple nature of the system. Fertilization needs to be gauged by eye, and harvesting is largely conducted via hand-drawn nets and lights as attractors to make capture easier. Biomass is sold both live in oxygenated bags and in frozen block form, using simple packing methods and conventional freezer systems. There is little mechanization or processing and no digital tools in use.

Two pioneer farms (described in the business case studies below) have made significant innovations in their harvesting systems and in their integration of Artemia biomass production into hatchery operations for live feed production and wastewater treatment.

Automated harvester

One farm (Banchong Farm) has developed an automated harvesting device. The harvester consists of a low-speed electrically powered paddlewheel and wooden guide boards that direct water flow into a fixed net accessible by a small wooden pier. Harvesting simply involves fixing the net into position and turning the paddlewheel on. A single laborer can harvest the pond with 2–3 hours work per day. This is a simple, low-cost innovation that could easily be implemented on other artemia farms using local materials and existing equipment. The device is best suited to smaller deeper ponds typical of shrimp farming (< 1 ha in size and 1.5 m depth). It may not be suitable for shallow ponds due to disturbance of the sediment.

FIGURE 18. **Automated biomass harvester directs flow into a net (not deployed)**

Source: Mukami, FutureFish

Mobile harvesting boat

Suntri Farm, which operates a larger 4 ha pond, has developed a mobile harvesting boat for collecting biomass from Artemia aggregations across different areas. The boat is equipped with a push net mounted at the front, fixed in open position by rods and held above the bottom by runners. To prevent damage to the cod end of the net, which trails beneath the hull as the boat moves forward, it is powered by a small water jet engine. The operator drives the boat to Artemia aggregations and plows the net through them, with the catch gathering in the cod end.

This boat was designed and constructed on the farm using PVC pipes and locally available materials. It is best suited to harvesting large, shallow ponds (that is, former salt pans, 0.5–0.8 m depth) where multiple congregations of Artemia occur in different areas and the gear must be transported between them. The boat would not be easily replicated on other farms; some experience in design, engineering, and fabrication is required.

FIGURE 19. **Farm-made jet-powered harvesting boat with push net**

Source: Mukami, FutureFish

Farm-made protein skimmers

Suntri Farm also features farm-made protein skimmers in its biomass holding tanks. Protein skimmers are a well-established technology, but the farm has constructed highly performant units using a few sections of PVC pipe, a small pump, and aquarium aerators. The skimmers remove proteinaceous wastes through foam fractionation, before they can break down and pollute the tanks. The protein skimmers extend the maximum holding time of live biomass from one day to two. They are relevant where biomass is being held in recirculating tanks where water quality may degrade, but they are not relevant in systems where biomass is held in net cages within a larger pond. They could readily be produced using this or a similar design on farm for minimal cost.

FIGURE 20. Artemia biomass holding tank lined with a net cage and equipped with a farm-made protein skimmer to maintain water quality

Source: Mukami, FutureFish

4.2.4. Productivity enhancement

Reviewing the different production systems, management practices, choice of inputs and technical innovations indicates the following options for improving the productivity of Artemia biomass production in Thailand.

Existing enhancements

Cultivation in deeper, more compact shrimp-style ponds simplifies pond management and harvesting due to the smaller area for fertilization or raking, while granting the option to use automated harvesting equipment. The greater volume relative to surface area also facilitates maintenance of a stable salinity during the monsoonal rains, facilitating year-round biomass production.

The use of low-cost automated harvesting equipment (paddle wheel directing flow to a fixed net) makes harvesting extremely efficient, essentially turning it into a packing operation.

The move toward 'off the shelf' fertilization materials such as poultry manure, ami-ami, and molasses appears to have significantly reduced the cost of production from around US$0.50/kg to US$0.15/kg. On-farm fermentation of organic wastes remains an option if such are locally abundant and sufficiently cheap but require considerably more preparation time and management input, which is perhaps better spent elsewhere.

Farm-made protein skimmers can extend live biomass holding times in closed holding tanks by maintaining water quality. It is likely that by maintaining favorable holding conditions, the longevity of live Artemia during transport will also be extended.

Gaps

Internet of things (IOT)-based water quality management has the potential to refine pond fertilization and management strategies to optimize production. Farmers are presently fertilizing ponds based on visual assessment of the plankton bloom. This is a reactive approach in that fertilization is applied after the bloom begins to lose condition. Real-time or more frequent, quantifiable monitoring of nutrient levels may allow fertilization to be applied as needed rather than in response to lost productivity.

The integration of Artemia biomass and/or cyst cultivation with solar salt production, while deployed elsewhere in the world, remains an unrealized option in Thailand, which has around 4,300 ha of salt fields in the Gulf of Thailand provinces alone. A conservative figure of about 10 percent of this used for Artemia farming would result in 1,200 tons of fresh weight biomass per month. Artemia integration could provide higher-quality salt by removing algae and particulates, plus an additional revenue stream for salt works, most of which are small-scale, family-owned and operated. Salt farming is a low-margin business, and providing an additional revenue stream will enhance the resilience of producers.

Integration with solar salt works has the potential to create a greater number of jobs as farm design must be optimized for salt production in the first instance (shallow ponds) and harvesting is likely to require more resources. Thailand's solar salt-farming industry employs a significant number of women. Women often work in various roles including harvesting, sorting and packing, and processing of salt products; however, quantitative data are not available.

The production of a substantial quantity of local cysts would also reduce the reliance of Thailand's hatcheries and aquaculture sector on imported cysts, which are a major expense for shrimp, crab, and marine finfish hatcheries. There may be additional opportunities to cultivate Artemia in other areas that are affected by salinized land and unsuitable for agriculture.

FIGURE 21. **Value chain for Artemia farming in Thailand**

Input Supplies

Fertilizers (commercially available, locally produced agricultural by-products):
- Poultry manure ($0.15/kg)
- Ami-ami cassava residue ($0.034/kg)
- Molasses ($0.034/kg)

Type of Farm

Intensive biomass farm:
- Production cost: $0.15/kg
- Farm gate sale price: $1.78/kg

Semi-intensive biomass farm:
- Production cost: $0.12/kg
- Farme gate sale price: $1.12/kg

Both employ 1 part time staff 2–3 hours of labour per day.

Value addition

Intensive biomass farm:
- Packed in oxygenated bags and sold live

Semi-intensive biomass farm:
- Sold as frozen packets/ blocks

Market demand

Intensive biomass farm:
- Flat fixed price for all clients
- Most sold live to local hatcheries
- Small amount sold to traders for retail as ornamental fish food in Bangkok

Semi-intensive farm:
- All sold to Thai DOF on fixed contract

Source: Mukami, FutureFish

4.3. Policy and Regulatory Environment

4.3.1. Existing framework

In summary, there are no policies, regulations, and/or legal framework specific to Artemia farming in Thailand, as the sector is considered too small to warrant specific regulation and no adverse impacts have been reported. However, Artemia aquaculture is subject to Thailand's general regulations on aquaculture, environmental, biodiversity, biosecurity, and food safety. These have been reviewed in the accompanying report "Global Assessment of Governance Tools and Regulatory Frameworks."

In summary, a general legislative framework is in place for competent authorities to issue regulations necessary to govern the aquaculture sector, or to place restrictions and requirements on specific aquaculture industries, should the need arise. The main instruments and their relevance are listed in Table 9.

TABLE 9. **Legislation framework related to artemia farming in Thailand**

Instrument	Relevance
Royal Ordinance on Fisheries B.E. 2558 (2015)	General aquaculture management
Aquaculture Enterprises under Control B.E. 2559 (2016)	Management of specific sectors
The Animal Feed Quality Control Act B.E. 2558 (2015)	Animal feed quality and safety
Epidemic Act of B.E. 2558 (2015)	Health and biosecurity
Environmental Quality Promotion Act B.E. 2535 (1992)	General environmental protection
Public Health Act B.E. 2535 (1992)	Food safety
Notification of The Department of Fisheries on the Designation of Alien Aquatic Species for Cultivation B.E. 2564 (2021)	Declaration of pest species

4.3.2. Barriers and opportunities

Thailand's legislative framework for regulation of aquaculture is generally well developed, reflecting the substantial size of the industry and contribution to GDP. There are no obvious gaps or barriers likely to impede the development of Artemia farming, particularly considering the low-impact nature of the sector and the trend of integrating Artemia production into existing salt production and aquaculture systems.

Thailand does not offer subsidies or local production incentives for Artemia production. The industry has relatively low barriers to entry in that existing or disused shrimp ponds can be utilized for culture, there is no ongoing need to purchase seed due to self-recruitment, and feed costs are minimal. Thailand sets a tariff on the importation of Artemia cysts. The ceiling rate is 35 percent, but a 30 percent rate applies to World Trade Organization members, and exemptions (0 percent) apply to states covered by free trade agreements through the Association of Southeast Asian Nations (ASEAN), or bilaterally with Thailand. States with exemptions include all ASEAN members, Least Developed Countries (as designated by the World Trade Organization), plus Australia, Chile, China, Hong Kong SAR, China, India, Japan, Korea, New Zealand, and Peru.

Additionally, a duty drawback scheme is available under Section 29 of the Customs Act B.E. 2560 (2025). Importers can receive a refund of import duties paid on raw materials that are processed in Thailand and then exported as finished products. A substantial proportion of Thailand's imported Artemia cysts are subject to value added processing and reexported, which likely qualify for duty drawback.

Recently, concerns have been raised by the Thai aquaculture industry concerning apparent quality issues with imported cysts. It is not known whether there are genuine quality issues, or whether the cysts have been sourced from Artemia populations that have specific hatching requirements that are not known to end users. At the request of the FAO Sub-Committee on Aquaculture, the International Artemia Aquaculture Consortium has proposed developing a cyst certification scheme that would require documentation of optimum hatching conditions and other information. Discussions on development of a certification scheme are under way.

Importation of Artemia cysts is regulated, with controls on pathogen-free certification and sourcing from approved facilities. Only facilities inspected and approved by DOF are eligible to export Artemia products to Thailand. Due to recent concerns expressed by Thai hatcheries, DOF has begun conducting inspections of cyst processing and export facilities overseas.

4.4. Infrastructure and Capacity

4.4.1. Infrastructure

Thailand's existing infrastructure is deemed to be sufficient to support the expansion of Artemia culture without the need for further investment.

Artemia can readily be cultured within Thailand's existing aquaculture pond infrastructure and coastal saltworks, with minimal modifications. There is no need to construct dedicated Artemia culture facilities.

Due to the significant fishing and aquaculture industries, there are well-developed cold chain, cold storage, and seafood processing facilities, particularly in coastal areas. Road and transportation links are generally good. Biomass cultivation generally occurs in proximity to aquaculture development, which is the main market for the product.

4.4.2. Gaps and needs

Training and extension would be required to support expansion of the industry. While DOF's initial promotional work in the 1980s successfully initiated the industry, awareness in the solar salt and aquaculture industries is now low. The small number of farms offers limited visibility of Artemia production as a profitable opportunity to potential new entrants to the industry. Given that the technology is relatively simple and reliable, we anticipate that effective training and extension programs could be short and low cost, consisting of farm visits and lectures by DOF personnel.

4.5. Market Assessment and Demand

4.5.1. Local and export markets

Local markets

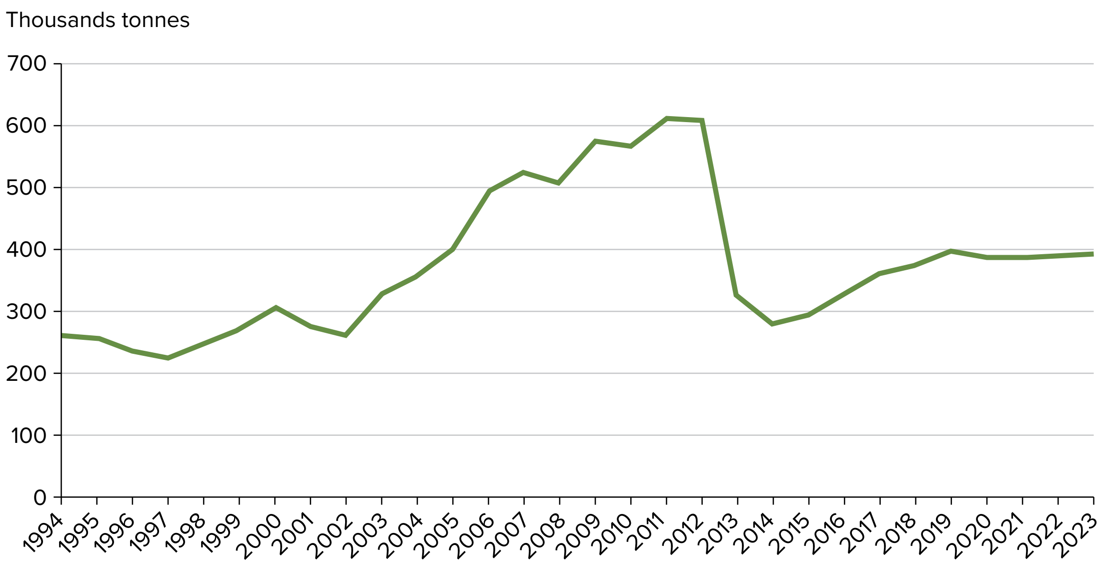
Thailand's Artemia production is focused on biomass. Around 340 tons of artemia worth US$330,000 was produced in 2020–2021. Of the total biomass produced, around 75 percent is used in shrimp hatcheries (broodstock feed) and fish and crab hatcheries (nursery feed), with the remaining 25 percent exported as frozen Artemia biomass for ornamental fish feed. A small amount is sold as live feed to local ornamental fish markets. It is not currently used to feed other animals or as a human food.

The limited empirical data on Artemia's nutritional profile has likely slowed its adoption as an alternative protein for terrestrial animal feeds and human consumption. If proven viable, Artemia biomass has significant market potential as a substitute for fishmeal in both terrestrial and aquatic feeds.

In Thailand, Artemia biomass processing is primarily conducted on site by farmers who cultivate Artemia in coastal areas, often integrating this activity with traditional salt farming. This approach minimizes the need for extensive downstream processing facilities, as the harvested biomass is typically sold directly to local aquaculture hatcheries. Given that freshly harvested Artemia biomass contains about 90 percent moisture and is rich in proteolytic enzymes, it is prone to rapid decomposition. To prevent spoilage, farmers promptly rinse and concentrate the biomass. Preservation methods include freezing or drying, ensuring the product remains suitable for use as live feed in aquaculture hatcheries.

The local market for aquaculture is currently constrained by disease issues affecting shrimp aquaculture, which has reduced demand. Farmed shrimp production peaked around 609,000 tons in 2011–2012 but crashed in 2013 due to a disease event (Acute Hepatopancreatic Necrosis Disease [AHPND]), reaching a low of 279,000 tons in 2014. Shrimp production remains suppressed at around 270,000 tons due to ongoing AHPND issues and intense international competition (Arunmas 2024).

FIGURE 22. Thailand farmed shrimp production from 1994 to 2023



Note: There are discrepancies between official and unofficial data.
Source: FAO 2022; DOF 2024.

Imports

Thailand does not produce commercial quantities of Artemia cysts but imports to supply marine shrimp, crab, and finfish hatcheries. It imported 482 tons of Artemia cysts in 2020, with 90 percent originating from China, Russia, Uzbekistan, and Kazakhstan and the remaining 10 percent from the United States (Aquafeed Media 2022).

Exports and reexports

A small amount of locally produced Artemia biomass is exported in frozen block form as an ornamental fish feed (Nissagavanich 2024).

A significant proportion of imported cysts are reexported by specialist companies after processing and packaging in Thailand. About 129 tons (likely an underestimate) with a declared value of US$6.24 million was exported in 2024 (Volza 2025). Export destinations in 2023–2024 included Viet Nam, Indonesia, Sri Lanka, the Philippines, Bangladesh, and Pakistan.

4.5.2. Pricing and competition

The price of Artemia biomass varies seasonally, as farms that are unable to maintain adequate salinity cannot produce during the monsoonal rains. Farms that can produce all year round may command a premium during the rainy season when availability declines and may also be able to negotiate long-term agreements with buyers.

TABLE 10. Typical sale price for different Artemia biomass products

Product	Typical price (US$)
Live	1.12–1.92/kg (average 1.34)
Frozen	1.28–1.6/kg (average 1.47)

Source: Wilkinson, own source.

Production cost is largely affected by the cost of agricultural waste products used to fertilize the ponds. Other products used to condition shrimp broodstock include polychaete works, squid, and mollusks. However, polychaete works and mollusks carry a significant risk of introducing serious shrimp pathogens. The disease outbreak (AHPND) depressing shrimp aquaculture in Thailand is believed to be due to infected polychaete worms imported as broodstock feed (Carling 2016). The hypersaline culture environment required by Artemia excludes most known shrimp pathogens.

4.5.3. End-user behavior

Artemia biomass is a highly regarded and favored food for conditioning shrimp broodstock in hatcheries, and for marine finfish nurseries. It is also favored as a conditioning food for the development of color in the ornamental fish industry and by hobbyists. The best results are obtained from live biomass.

Artemia biomass is not currently consumed as a human food in Thailand as it is not a traditional food, and availability is limited. However, Thai people do traditionally consume small marine and brackish water mysid shrimp (*Acetes* spp.) as a dried condiment, in some fermented products (kung ko), or as a flavoring in chili paste (nam prik kung ko). Kasetsart University is studying the potential to use Artemia biomass in the preparation of kung ko (pers. comm.)

There are unlikely to be cultural barriers to human consumption. The farmers we interviewed had all tried Artemia from their own curiosity and reported that it had a good flavor similar to swimming crab, which is highly popular in Thailand.

4.6. Socioeconomic Impacts and Inclusion

Artemia biomass farming is practiced on a small scale in Thailand and there are presently only about 15–20 farms. The expansion of the industry would offer new permanent and seasonal job opportunities to rural communities. Due to the light labor requirements, such positions would be suitable for most people including women and youth.

Biomass culture in dedicated ponds is not a labor-intensive industry due to the ease of collecting biomass for harvesting, including using automated harvesting equipment. For example, the Banchong and Suntri farms (refer case studies below) both employ a single laborer who spends 2–3 hours per day managing Artemia operations while producing 2–4 tons of biomass per ha per month. These farms can operate year-round, providing a continuous supply of Artemia to local businesses and continuous employment.

The integration of biomass and/or cyst culture with solar salt works has the potential to create a greater number of jobs, as farm design must be optimized for salt production in the first instance. Roughly speaking, such integration requires around 1–2 laborers per ha. The shallow ponds required for evaporation restrict the use of harvesting gear to manual net operation. The biomass within the salt farm requires additional management. Salt production and employment is seasonal, and it is likely that salinity will be too low to allow Artemia biomass cultivation during the monsoonal rains.

Thailand's solar salt-farming industry employs a significant number of women. Women often work in various roles including harvesting, sorting and packing, and processing of salt products; however, quantitative data are not available.

When integrated into another farming system, Artemia also plays a significant role in increasing economic resilience, offering lucrative returns with very small capital investment and low operational costs. In the case of Suntri Farm, the primary fish nursery business was discontinued to focus solely on Artemia due to the reliable cash flow, ease of management, and profitability. For Banchong Farm, the secondary revenue stream offered by Artemia biomass culture provides additional cash flow and financial stability and reduces the risks from disruption to the primary aquaculture activity.

The availability of Artemia biomass indirectly supports the hatchery production of marine shrimp, crab, and finfish seed required for operation of Thailand's aquaculture sector.

4.7. Climate Resilience and Environmental Considerations

4.7.1. Environmental risks

- Artemia are not known to pose a biodiversity risk. They can only establish populations in hypersaline water bodies where salinity is sufficient to exclude all predators, including fish, other crustaceans, and aquatic insects. Artemia are rapidly eliminated by predation in less saline ecosystems, with few, if any, natural habitats that could be colonized in Thailand.
- There are no native Artemia species in Thailand that could be displaced.
- Artemia cultivation is typically conducted on natural saline flats that are unsuitable for agriculture or other productive purposes, as access to seawater and high evaporation rates are required to maintain adequate salinity levels.

The presence of Artemia carries several environmental benefits:

- As filter feeders near the bottom of the food chain, Artemia improves water quality by reducing algal blooms and bacterial populations, clarifying water, and converting potentially polluting nutrients into biomass, which is exported on harvest.
- The integration of Artemia culture with solar saltworks has been shown to improve salt quality by removing algae and particulates from water, reducing contaminants, and increasing water clarity and reducing viscosity, thus facilitating the formation of salt crystals. Artemia biomass and cysts can also potentially be harvested by salt farms to generate an additional revenue stream.
- Artemia biomass provides a food source for coastal bird life.

4.7.2. Climate resilience

Climate change is unlikely to directly affect Artemia farming in Thailand. The sole cultivated species *Artemia franciscan*a is remarkably tolerant of varying salinity and temperature conditions, and in fact requires extreme salinity to survive. If water temperatures approach critical limits, management strategies such as the use of deeper ponds can be used to mitigate the effects. Farmers have also become adept at managing salinity during heavy rain, for example, by draining freshwater from surface waters.

It is possible that climate change will have indirect effects on Artemia farming through negative effects on natural Artemia habitats, which will reduce the availability of wild cysts, and through its effects on the broader aquaculture industry as a market for biomass.

4.8. Investment Opportunities and Case Studies

4.8.1. Key investment gaps and value chain development needs

A key factor limiting demand for Artemia biomass is the lack of more scientific data on its suitability for use as a protein source in animal feeds as a replacement or supplement for fishmeal and as a human food. If proven viable, Artemia biomass has significant market potential as an ingredient in feeds for livestock, both terrestrial and aquatic, and as a human food source.

Artemia biomass is widely recognized within the aquaculture industry as a high-quality food source for shrimp and fish and a favored conditioning food in shrimp hatcheries and marine finfish nurseries. Should this widely held but anecdotal view be validated through empirical research, it is likely to stimulate substantial interest by animal feed production companies. There are also opportunities to extend the use of biomass to culture of other high-value species, such as mud crabs.

At present, the demand for Artemia biomass in Thailand has been constrained by a serious disease that has affected the shrimp farming sector (mentioned previously). There is a need to find new applications for biomass to expand the addressable market. There are potentially large but as yet untested opportunities for biomass as an ingredient in both animal and human feeds. The following studies would clarify the economic potential of Artemia biomass:

1. Conduct a detailed nutritional profile of Artemia biomass to quantify its potential for use in animal feeds, and for human consumption. This study should include amino acid and lipid profiles, macro and micronutrient content, and anti-nutritional factors (if any).
2. Contingent on a favorable outcome in 1., investigate the potential for Artemia biomass to be an economically viable replacement or supplement to fishmeal in formulated animal feeds for both aquatic and terrestrial animals. Thailand has a large livestock industry (swine, poultry, cattle, aquaculture) and a substantial local animal feed industry. The compound feed market size is estimated at US$10.25 billion in 2024 and expected to reach US$12.78 billion by 2029 (Mordor Intelligence 2024).
3. Investigate consumer acceptance of Artemia biomass as an ingredient in processed foods such as shrimp cakes, seafood balls, and patties, as a condiment or ingredient in Thai shrimp and chili pastes. Mysid shrimp (small crustaceans not much larger than Artemia) are popularly used for such purposes and in sun-dried form in popular local dishes such as *som tam* (green papaya salad).
4. Contingent on a favorable result from 1. and 3., study the potential to further enhance the nutritional profile (for example, lipids) of Artemia biomass for human and/or animal consumption through dietary manipulation. Nutritional enhancement is already practiced in nauplii used as live feeds in hatcheries; in principle, it should also be possible for biomass also.
5. Engage with solar salt farms to trial integration of Artemia into seasonal saltworks in the Gulf of Thailand area with the aim to increase the income of salt farmers.
6. Trial the use of alternative Artemia strains that produce larger animals (1.5 cm and up) or parthenogenetic (female only) strains.
7. Conduct selective breeding to develop improved Artemia strains with superior size, growth rate and nutritional characteristics. Artemia is highly suitable for genetic improvement due to its short generation time, ease of handling and mass cultivation, and the ability to exchange and store genetic material for the long term using the resting cysts.

4.8.2. Financing and market access

There is limited need for major financing or market access assistance. Capital requirements for Artemia biomass and/or cyst production are extremely low since existing shrimp ponds or salt pan infrastructure can be used. Operating costs are also exceptionally low as commercial feeds are not required, due to indirect feeding through the use of agricultural wastes as direct and indirect (fertilizer) for the culture system.

Thailand imports a significant quantity of Artemia cysts, on the order of 500–600 tons/year (Aquafeed Media 2022) for use by local shrimp, crab, and marine finfish hatcheries. Developing local cyst production could reduce reliance on imports and enhance self-sufficiency in the aquaculture sector.

BOX 2: PROMISING BUSINESS MODEL

Intensive year-round biomass production integrated with a shrimp hatchery

New shrimp broodstock holding and hatchery facility, Banchong Farm

System

- Located in Chachoengsao Province, Thailand
- Specializes in giant tiger prawn (*Penaeus monodon*) hatchery
- Integrates intensive Artemia biomass production into its water treatment system
- Closed saltwater recycling system with zero discharge for biosecurity and cost reduction
- Water treated in 0.2–0.4 ha ponds with algae, seaweeds, and mangroves to assimilate nutrients
- Converted disused shrimp ponds with 0.69 ha surface area and 1.5 m depth
- High depth and low surface area allow stable salinity (70–120 ppt) during the monsoon, enabling year-round production.

Pond Management

- Near-daily fertilization with shrimp hatchery wastewater to stimulate phytoplankton and biofloc
- Additional nutrient sources: molasses (carbon), ami-ami (nitrogen), and poultry manure (phosphorus)
- Bottom dragging every second day to break down and resuspend organic materials

Harvesting and Handling

- Early morning harvesting when Artemia congregates near the surface due to low oxygen levels.
- Rotating paddlewheel and wooden guides direct water flow into a stationary fine mesh net.
- Harvested biomass is stored in pondside net cages before packing.

Production and Profitability

- 50–100 kg/day from a 0.6 ha pond
- Equivalent to 2.25–4.5 tons/ha/month
- Production cost: US$0.15/kg (down from US$0.50/kg in 2023)
- Selling price: US$1.78/kg (fixed flat rate of THB 60/kg for 30 years)
- Annual profit: ~US$39,000 from 23.7 tons of Artemia biomass

Sales and Market

- 10 kg/day used in the farm's hatchery
- 95% of the remainder sold to crab and marine fish hatcheries in nearby provinces at US$1.80/kg
- 5% sold daily to ornamental fish traders at Chatuchak Market, Bangkok

Advantages

- Solar panels covering 80% of the farm's power needs
- Discounted off-peak electricity contract with the Electricity Generating Authority of Thailand

Challenges

- Reduced demand due to Thai shrimp sector disease (AHPND), causing a 50% production decline

BOX 3: PROMISING BUSINESS MODEL

Semi-intensive year-round Artemia biomass production: Suntri Farm, Thailand

Artemia biomass ponds (modified salt pans) at Suntri Farm

System

- Petchaburi Province, Thailand, on 3.84 ha of modified salt pans
- Year-round Artemia production using a closed, zero-discharge system
- Salinity maintenance, including ability to adapt to heavy rainfall events

Pond Management

- Fertilized 2–3 times weekly with 50 kg/ha of chicken manure
- Boats drag chains across the pond bottom to prevent blue-green algae buildup

Harvesting and Handling

- Daily harvesting (~4 a.m.) using push nets in front of jet-powered boats.
- Pondside concrete tanks (100 kg capacity) with hapa nets and protein skimmers extend holding time from 1 to 2 days.
- Artemia are frozen in 500 g flat packets for efficient storage.

Production and Profitability

- Output: 3.5 tons/month (range: 2–4 tons)
- Price: THB 40/kg (~US$1.12) Production cost: THB 4.2/kg (~US$0.12)
- Profit: THB 35.8/kg (~US$1), totaling THB 125,000/month (~US$3,500)

Sale and Market

- Sold to Thai DOF, which is using it to feed larvae of swimming crabs (*Portunus pelagicus*) and mud crabs (*Scylla* spp.)

Advantages

- Favorable climate enables year-round production.
- Efficient management is ensured with jet-powered boats and skilled operators.
- Fixed supply agreement with the Thai DOF ensures stability.

Challenges

- Large, shallow pond makes management complex.
- Previous tilapia invasions required saponin treatment.

The Thailand Artemia Biomass Farming model represents a globally rare and innovative approach to Artemia aquaculture—focused not on cysts, as in most of the world, but on the year-round farming of live Artemia biomass in modified salt ponds. This system delivers diversified income through the integration of Artemia, salt, brine sales, and hatchery-linked outputs, while maintaining low production costs (US$0.15–0.50/kg) and rapid ROI (1–2 years). With yields of up to 4.5 tons/ha/month and high local demand from shrimp, crab, and ornamental hatcheries, the model has proven both profitable and inclusive—generating jobs, especially for women in post-harvest roles. Suitable for high-evaporation coastal zones, this model fills a critical gap in the regional live feed supply chain for aquaculture hatcheries and offers a replicable, climate-resilient solution for coastal livelihoods. Its success underscores the potential of biomass-focused Artemia farming, a strategy still largely untapped elsewhere in the world.

TABLE 11. Thailand Biomass Business Model

Name of Business Model	Thailand Artemia Biomass Farming
Category	**Details**
Diversified Income Opportunities	Artemia biomass, salt production, brine sales, and shrimp and marine hatchery integration
System Summary	Year-round Artemia biomass farming in modified salt ponds, supplying local hatcheries and ornamental fish markets
Total Production per Cycle	Biomass: 2.25–4.5 tons/ha/month (semi-intensive)
Cycle Time	Year-round operation possible, with peak production in dry season
Tons per ha per Cycle	Biomass: 2–4 tons per ha per cycle
Production Cost per kg	US$0.12–0.15/kg
Cost per ha per Cycle	Labor (1–2 workers per ha), fertilization, and water management
Selling Price (US$/kg)	Live biomass: US$1.75–1.78/kg, Frozen biomass: US$1.50–1.63/kg
Revenue per ha	US$3,500–9,600
Profit Margin	Annual revenue: Up to US$27,000–38,000 per farm, around. Profit until end user can exceed 50%, with processors taking 30–40%
Investment Cost and ROI	Low investment cost and payback period of 1–2 years
Employment per ha	1–2 workers/ha
Total Jobs Created	15–20 commercial farms, 45 ha under production, 340 tons biomass (2020–2021)
Women in Workforce	Women involved in post-harvest processing, sorting, and packing
Technology Needed	Buckets, nets, fertilization systems, aeration, and IOT-based water quality monitoring
Environmental Conditions	Salinity: 80–150 g/L, high-evaporation zones near salt pans
Main Markets	Shrimp, crab, and marine finfish hatcheries and ornamental fish markets but huge potential across many species and for terrestrial animal feeds
Domestic vs. Export Market	75% sold domestically to hatcheries, 25% exported (mainly frozen biomass)
Untapped Potential	Thailand does not produce cysts; 482 tons of Artemia cysts were imported in 2020, mostly from China, Russia, Uzbekistan, and Kazakhstan. Potential for integrating Artemia cyst production in salt farms.

4.9. Recommendations

The following investment recommendations are from the Thailand case study.

	Recommendations for investment
Production Improvement Strategies	• Research on potential to further enhance the nutritional profile (for example, lipids) of Artemia biomass for human and/or animal consumption through dietary manipulation. • Nutritional enhancement is already practiced in nauplii used as live feeds in hatcheries; in principle, it should also be possible for biomass, also, allowing Artemia biomass to be tailored for different applications.
Policy and Regulatory	• Policy and regulatory support will be required for the development of new biomass products for animal feed and human nutrition markets (for example, novel feed ingredients and human food registration, and research investment).
Infrastructure and Technology	• Engage with more solar salt farms to trial integration of Artemia culture into seasonal saltworks in the Gulf of Thailand area with the aim to increase the income of salt farmers. • Engage with coastal hatcheries and aquaculture farms to expand integration of Artemia biomass culture for live food production and sale.
Market Development Strategies	• Develop a detailed nutritional profile of Artemia biomass to enable assessment of its potential for use in animal feeds and for human consumption (including amino acids, lipid profile, macro and micronutrients, and anti-nutritional factors, if any). • Partner with animal feed production companies to investigate the economic viability and performance of Artemia biomass as an alternative protein source to fishmeal in formulated livestock and aquaculture feeds. Thailand has a large livestock industry (swine, poultry, and cattle) and the capacity to rapidly scale Artemia production and substantial local animal feed industry. The compound feed market size is estimated at US$10.25 billion in 2024. • Work with food processing companies to investigate the economic viability and consumer acceptance of Artemia biomass inclusion as an ingredient in human foods such as shrimp cakes, seafood balls, and patties, or as a condiment. • Artemia may also be an alternative to mysid shrimp *Acetes* sp. (small crustaceans) that are used in sun-dried form as a condiment in popular Thai cuisine such as som tam (green papaya salad) or as an ingredient within value added Thai chili, curry, and fermented shrimp pastes.
Socioeconomic	• No specific recommendations
Impact Potential	• Impact potential on employment and job creation is significant in saline-affected regions, particularly as an alternative for more salt farmers in the upper Gulf of Thailand.

5

VIET NAM

5.1. Introduction and Overview of Artemia in Viet Nam

5.1.1. Establishment of Artemia culture in Viet Nam

Artemia was introduced to Viet Nam by government institutes—the Nha Trang Marine Research Institute, the Seafood Research Institute, and the Research Institute for Aquaculture III (Dung and Tri 1990; Quynh and Lam 1987). In 1984, Can Tho University's Faculty of Fisheries, in collaboration with Ghent University (Belgium), imported and studied San Francisco Bay (SFB) Artemia to support aquaculture, including as part of a giant prawn project.

With FAO-backed support from Ghent University's Artemia Reference Center, the Artemia Research Center was founded at Can Tho University in 1986. That year, *Artemia franciscana* (SFB) was introduced to salt fields in Vinh Chau, where studies on cyst and biomass production were conducted in former Bac Lieu and Vinh Chau. By 1989, cultivation techniques were stabilized and transferred to salt farmers in Vinh Chau District (Soc Trang Province) and Dong Hai Farm (Bac Lieu),[3] boosting their income.

The success of pond culture for cyst production led to the establishment of the Artemia-Shrimp Research and Development Center at Can Tho University in 1991. Artemia farming was scaled up, making Vinh Chau and former

3 Effective July 2025, Bac Lieu and Soc Trang were merged into Ca Mau and Can Tho, respectively.

Bac Lieu key suppliers of high-quality cysts for domestic and international markets (Anh et al. 1997; Hoa 2002; Hoa et al. 1994), significantly improving local livelihoods. Since 1996, VLIR-UOS (Belgium) has supported refining cultivation techniques, boosting productivity, and expanding extension services in former Soc Trang-Bac Lieu salt fields. The model has since been successfully replicated in Kien Giang, Duyen Hai, Ho Chi Minh City, Vung Tau, and Cam Ranh.

FIGURE 23. Artemia farming in Vinh Chau-Bac Lieu solar saltworks[4]

Source: Van Hoa, FutureFish

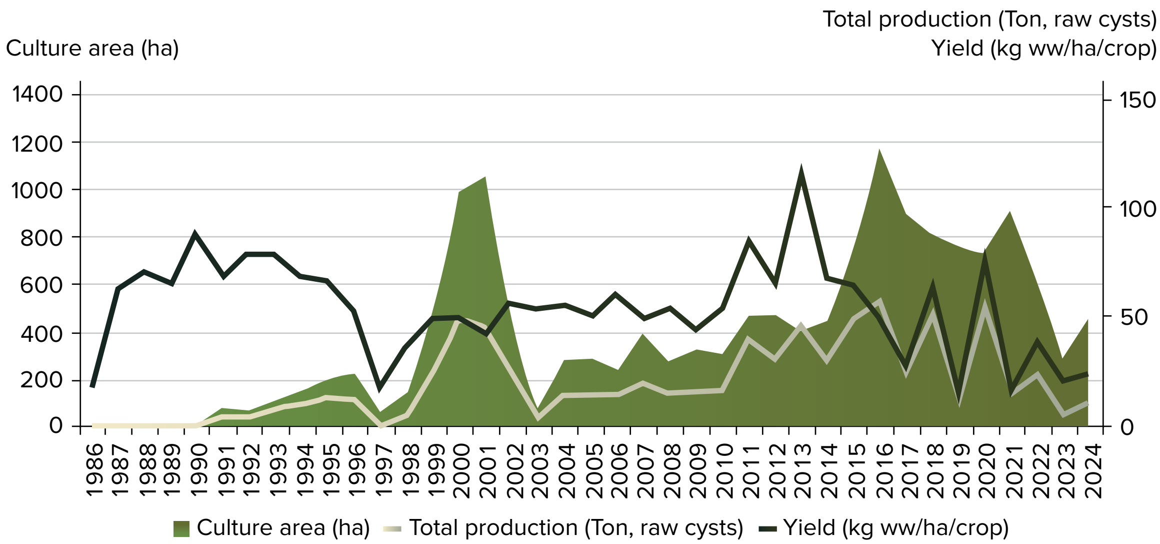
5.1.2. Overview of the Artemia sector and value chain

Although Artemia trials were successful in different locations, the commercial production of Artemia is concentrated in two key provinces, former Soc Trang and former Bac Lieu, where suitable conditions exist. The area receives high nutrient loads in the Mekong Delta and suitable green water, with the dominance of Bacillariophyta and Chlorophyta that are suitable for Artemia. Around 10–30 tons of cysts (finished products) and approximately 500 tons of fresh biomass are produced. Based on the survey, there is a domestic and foreign market share at a rate of 50/50 percent for cysts while biomass is mainly sold in central Viet Nam as the need for the nurseries of snail (spotted babylon snail), white-leg shrimp, swamp eel, and ornamental fishes. The current Artemia cyst production in Soc Trang and Bac Lieu is presented in figure 24 while biomass production started a few years back, and total production per year is around 500 tons (wet weight).

In Viet Nam, Artemia production has become increasingly erratic due to a combination of climatic and land use pressures. Unpredictable weather patterns—such as unseasonal rainfall, extreme heat, and sudden temperature shifts—have significantly disrupted the hatching and reproductive cycles of Artemia, leading to reduced cyst yields in recent years. At the same time, the rapid expansion of white-leg shrimp farming and the development of wind energy infrastructure have encroached on traditional Artemia farming zones, further shrinking the available production area. These overlapping challenges have made year-on-year yields highly variable, undermining the reliability of Viet Nam's Artemia supply and highlighting the need for more resilient and diversified production systems.

4 This map is for illustrative purposes and does not imply the expression of any opinion on the part of the World Bank concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

FIGURE 24. **Artemia cyst production in former Soc Trang and Bac Lieu (Viet Nam)**



Source: Van Hoa, FutureFish

The post-harvest Artemia cyst value chain is anchored by a few key processors who transform smallholder production into a high-value export commodity. After harvest, farmers sell raw cysts—typically fetching around VND 1 million/kg (~US$40/kg)—to processors such as the Vinh Chau-Bac Lieu Artemia Cooperative, Vinh Nga company. These actors handle the critical post-production stages: cleaning, grading, drying, and vacuum packing, upgrading the product into a form that meets international hatchery standards.

The Vinh Chau-Bac Lieu Artemia Cooperative, in particular, plays a dual role as both a buyer and a technical service provider, working with over 200 smallholders across 300 ha. It offers breeding stock, production guidance, and guaranteed offtake, acting as a critical intermediary that lowers risk for producers while ensuring quality and volume for buyers. Once processed, cysts are sold for VND 3–3.5 million/kg (~US$120–140/kg), with retail and export prices reaching VND 4.5 million/kg (~US$180/kg) and up to VND 5.3 million/kg (~US$215/kg), respectively.

Power within the value chain is concentrated at the processing and export levels, where decisions around product standards, market access, and pricing are made. Farmers remain largely price-takers, relying on cooperatives and processors to reach high-value markets. However, by embedding services and long-term relationships into their model, cooperatives help rebalance power and build inclusion into the chain.

Currently, around 50 percent of Vinh Chau's processed Artemia cysts are exported, with the remainder sold domestically. Yet domestic demand remains limited due to the high cost of locally produced cysts, which are often twice the price of imported alternatives—mostly from China and the US—that sell for as low as US$90–100/kg. As a result, most processors and cooperatives are increasingly export oriented, targeting hatchery markets in countries willing to pay a premium for high hatch-out rates and traceability. This creates a paradox where Viet Nam is both a producer and an importer of Artemia cysts—highlighting the segmented nature of the market and the importance of positioning the Vinh Chau cysts as a high-quality niche offering rather than a low-cost commodity.

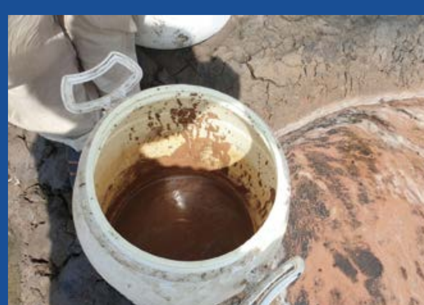
The high quality of Artemia cysts produced in Vinh Chau is well recognized both domestically and internationally. However, the premium price—approximately US$200 per kg—limits their use to niche applications, such as feeding species with small mouths like mud crabs, or for export to high-value markets in Japan and Europe. In contrast, the domestic market predominantly relies on lower-cost imported cysts from countries such as Russia, China, and Uzbekistan, typically priced at US$50–60 per kg. While these imported cysts are of inferior quality and can negatively affect the survival and performance of postlarvae and fingerlings, their affordability makes them more attractive to cost-sensitive hatcheries and farmers. As a result, the challenge is not necessarily lack of awareness but rather price sensitivity and limited purchasing power in the domestic aquaculture sector.

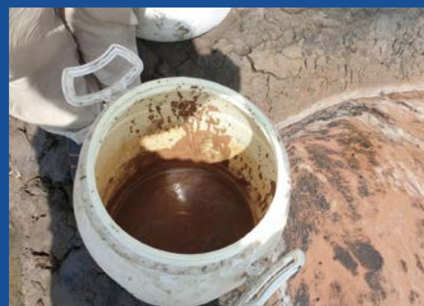
5.2. Production Systems, Input Supply, and Technology

Various farming systems have been tested in the solar saltworks of former Soc Trang and Bac Lieu, including static systems; flow-through systems; and monoculture, integrated, single-cycle, and multi-cycle systems. Currently, the static monoculture system is considered the most suitable, primarily focusing on cyst production, as cysts have become the primary commodity of interest for local aquaculture hatcheries. Initially, the primary market was freshwater prawn hatcheries but later expanded to include penaeid shrimp, Asian seabass, and mud crab hatcheries.

Although multiple Artemia farming systems exist, monoculture systems aimed at cyst production remain the most prevalent. These systems can be implemented at varying scales (semi-intensive and intensive), each offering different profitability margins, as detailed in Table 12.

TABLE 12. Artemia cyst farming models in Viet Nam[5]

 ARTEMIA (CYST) FARMING MODELS IN VIET NAM	Traditional (semi-intensive) 	Intensive 
Location	Area with saline water ~ 80 ppt	Near the sea or brine is available from groundwater
Culture technique	One cycle	Multi-cycle process, based on the reproductive activity of Artemia
Pond construction	Manually	Mechanical construction
Pond area	0.5–1.0 ha	0.3 ha
Water depth of Artemia pond	25 cm, fluctuating environment	50 cm or deeper, stable environment
Pond aeration	No	Yes

 ARTEMIA (CYST) FARMING MODELS IN VIET NAM	Traditional (semi-intensive) 	Intensive 
Fertilization area (%)	0–20%	20–30%
Water depth of fertilizer pond	≥ 30 cm	≥ 60 cm
Stocking density	100 N/L	100–300 N/L
Pond monitoring	Salinity only	Salinity, temperature, oxygen, turbidity, nitrogen, and phosphorus algae
Pond raking	Yes	Yes
Green water supplying (as feed)	Compensation for evaporation; no algae control	Compensation for evaporation; algae control (density and composition)
Artemia population	High mortality at the end of season (high water temperature)	Stable population
Direct fertilization	Yes (1–2 ton/ha/crop)	Only fertilization in green pond
Supplementary feeding	During food shortage, rice bran as main feed (~15% protein)	Daily feeding by formulated feeds (30% protein)
Water quality	Deterioration toward the end of season	Stability
Crop prolongation	Uncertainty	Stability
Artemia population performance	Well developed at early season only	Well developed throughout the season
Productivity	Well in early season, then declining in the mid-season and ceasing at the end of season	Stability throughout the season
Production Costs US$/ha	US$2,500–3,000/ha	US$4,000–6,000/ha
Reproduction	Females bearing small broods (fecundity) and intended to release nauplii (ovoviviparous reproduction)	Medium to high fecundity (broodsacs); cyst reproduction to be maintained
Artemia population	To be technically maintained throughout the season	When cyst production is less than 0.2 kg/ha/day, reinoculation will take place
Yield (cyst)	Maximum 100 kg/ha (raw cysts)	Maximum 200 kg/ha or higher (raw cysts)
Profits (US$/ha)	US$3,000/ha/crop (4–6 months)	US$6,000–7,000/ha/crop (4–6 months)
Organic accumulation	Yes, regular pond renovation	Negligible (low renovation cost)
Pollution	Yes, less sustainable production	Sustainability
Farming experience/skill	Newcomer/starter	Skilled farmers (>3–5 years)

5 This map is for illustrative purposes and does not imply the expression of any opinion on the part of the World Bank concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

5.2.1. Current production practices

Various farming systems have been tested in the solar saltworks of former Soc Trang and Bac Lieu over the years, including static systems; flow-through systems; and monoculture, integrated, single-cycle, and multi-cycle systems. Currently, the static monoculture system is considered the most suitable, primarily focusing on cyst production, as cysts have become the primary commodity of interest for local aquaculture hatcheries. Initially, the primary market was freshwater prawn hatcheries but later expanded to include penaeid shrimp, Asian seabass, and mud crab hatcheries.

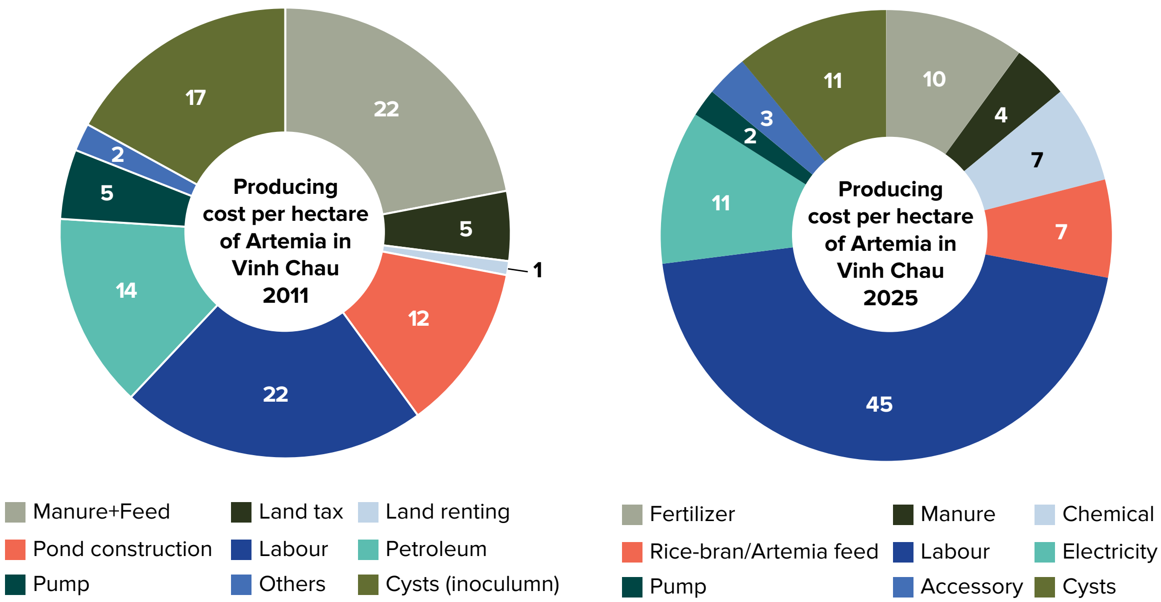
Although multiple Artemia farming systems exist, monoculture systems aimed at cyst production remain the most prevalent. These systems can be implemented at varying scales (semi-intensive and intensive), each offering different profitability margins, as detailed in Table 12.

Artemia farming typically occurs in modified salt ponds during the dry season. Once the evaporated seawater reaches around 80 g/L salinity, all Artemia predators naturally die off, allowing for the inoculation of freshly hatched Artemia nauplii. Artemia feeding involves direct or indirect fertilization of the ponds, primarily using chicken manure combined with fertilizers such as urea and DAP to produce nutrient-rich 'green water'. Occasionally, ground rice bran is also provided as supplementary feed. Currently, a formulated Artemia feed developed by Can Tho University can be used either as the primary feed in indoor cultures or as supplemental feed in outdoor systems during periods of green water shortage.

To culture Artemia in ponds, it is necessary to apply manure and inorganic fertilizers—such as urea and DAP—to promote the growth of green water (single-celled algae that serve as Artemia feed). Fertilizer usage has improved significantly in recent years, with manure application reduced from 5 tons to approximately 1.5 tons per ha. However, the recent occurrence of harmful algal blooms is largely attributed to intensive marine shrimp farming in surrounding areas, which discharges substantial amounts of organic waste into the environment. This nutrient overload is considered a primary driver of current water bloom issues. Additionally, the combination of organic-rich water and rising temperatures linked to climate change has led to the proliferation of toxic algae, posing a serious threat to Artemia production in salt fields.

Artemia's complete life cycle from inoculation to maturity is 10–12 days, at which point females release either nauplii (ovoviviparous reproduction) or cysts (oviparous reproduction). Under favorable conditions, cyst production continues for several months. In conventional farming systems, Artemia cyst production can reach 50–60 kg (wet weight) per ha during the approximately four-month dry season. More intensive cultivation practices can significantly boost yields, producing 150–200 kg of cysts per ha. Biomass production, targeting primarily adult Artemia, employs similar cultivation protocols and can yield over 1,000 kg per ha per month. It is common for a single hectare to produce approximately 4–5 tons of Artemia biomass over the 3–5 months of the dry season.

FIGURE 25. **Production cost per hectare of Artemia in Vinh Chau (Viet Nam)**



Source: Van Hoa, FutureFish

FIGURE 26. **Cyst collecting in Artemia farm (in solar saltworks)**

Source: Van Hoa, FutureFish

5.2.2. Input supply chain

Artemia farming takes place during the dry season alongside salt production in former Soc Trang, from December to May. During the wet season (June–November), when water salinity drops, farmers engage in other productive activities, particularly extensive or improved extensive shrimp and fish farming to generate additional income.

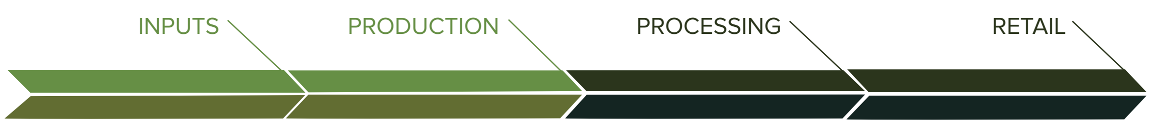
Table 13 illustrates the production cost for 1 ha of Artemia farming, with a detailed breakdown of inputs and their contributions to production costs. The main inputs to Artemia production are available locally.

TABLE 13. Production cost for 1 ha traditional extensive Artemia farming

Item	Cost per ha (US$)
Soil works (pond modification, excavation...)	397
Land lease	4
Inoculumn (cysts for stocking)	269
Fertilizer	329
Feed (shrimp pellet, rice bran, trash fishes)	42
Water pump (diesel engine, electric motor)	120
Fuel (gasoline, diesel)	67
Total	**1,229**

Source: Van Hoa , own source.

FIGURE 27. Value chain map of Artemia farming in Viet Nam



Input Supplies

Soil, land use, inoculum, fertilizer, feed, waste water, fuel

Total $1229/ha

Type of Farm

Farmer in more intensive system develops cysts at $20/kg

Sells for $40/kg

Value addition

Middle man buys and cleans and sells the cysts

Buying at $40/kg

Selling at $50/kg

Market demand

Processors are also retailers

They enrich the cysts

They buy at $50/kg

They can sell 20% for export at 200–250/kg

And 80% is sold at $200/kg

Source: Van Hoa, FutureFish

The main costs for Artemia production are cysts for inoculating ponds and fertilizers and feed, each accounting for more than 30 percent of total costs. Farmers reduce production costs by maintaining survival rates and utilizing green water or effluent associated with nearby shrimp or fish farms.

Table 14 summarizes data from former Soc Trang on household income, based on interviews with 120 farmers. Total household income ranged from VND 130 million to VND 160 million per ha of water area (approximately US$5,200–6,500 per household per year), with nearly 70 percent of their total income generated from Artemia farming, but supplemented also by shrimp and fish produced during the rainy season. The diversity of the Artemia farming systems in Soc Trang contributes to income stability and household resilience.

TABLE 14. Average income per household per year in Soc Trang (US$ per year)

Average income per household per year	2021	2022	2023	Average	%
Vinh Phuoc (n = 60)					
• Artemia cysts	3,364	3,748	3,328	3,480	66.5
• Artemia biomass	84	100	84	89.33	1.7
• Shrimp/fish	1,656	1,656	1,544	1,618.67	30.9
• Salt	16	16	96	42.67	0.8
			Sum	5,230.67	100
Lai Hoa (n = 60)					
• Artemia cysts	5,068	4,920	3,680	4,300	66.2
• Artemia biomass	120	114.4	114.4	114.40	1.8
• Shrimp/fish	1,876	1,794	1,650	1,722.00	26.5
• Salt	320	388	320	354.00	5.4
			sum	6,490.40	100

5.2.3. Technology adoption

Many farmers have received training from Can Tho University and have also developed based on their own experience, reaching the point where most farmers can now operate their Artemia systems without major technical difficulties. In consultations with farmers during this research, topics commonly raised are (a) increasing access to finance; (b) ensuring stable markets; and (c) maintaining consistent purchasing prices. The Artemia biomass market fluctuates each year, and farmers lack facilities for cold storage due to high costs, including expensive electricity for freezers.

5.2.4. Productivity enhancement

Integrated systems with salt production are technically feasible, but due to the low profitability of salt, farmers prefer monoculture of Artemia. Some trials using effluent from intensive white-leg shrimp culture for Artemia production have shown promising results as fertilizer. Nutrient-rich shrimp effluent—containing organic matter, floc particles, and uneaten feed—can support Artemia growth alongside algae and reduce fertilizer costs.

TABLE 15. **Income and profit between mono and integrated Artemia-salt system**

Description	Unit: Million VND/ha/crop					
	Soc Trang (n = 40)		Bac Lieu (n = 30)		Total (n = 70)	
	Artemia mono culture (n = 22)	*Artemia*-salt (n = 18)	*Artemia* mono culture (n = 15)	*Artemia*-salt (n = 15)	*Artemia* mono culture (n = 37)	*Artemia*-salt (n = 33)
Income	68.61±35.56	119.73±43.06	29.98±16.21	93.51±45.34	39.75±16.56	107.81±45.39
Profit	41.48±34.31	84.85±48.14	7.73±20.2	68.61±39.94	15.52±17.54	77.47±2.97
Ratio profit	1.67±1.28	3.17±2.55	1.3±3.38	2.74±1.35	1.08±2.17	2.97±2.72

Source: Van Hoa, own source.

R&D of Artemia farming in Viet Nam has primarily focused on increasing the efficiency of Artemia cyst harvesting. Meanwhile, research on Artemia biomass (juveniles and adults) has only gained attention in recent years as a means to diversify Artemia-based products. Although Artemia biomass has long been used in many countries as feed for shrimp, fish, crabs, and other aquatic species due to its high nutritional value (60 percent protein by dry weight) and energy content, its potential has only recently been explored in Viet Nam. Feeding Artemia biomass instead of newly hatched nauplii reduces the need for larvae to chase and consume as many prey items per unit of time to meet their nutritional requirements, which can lead to improved growth rates and physiological conditions. This has been demonstrated in the larval rearing of species such as lobsters, shrimps, mahi-mahi, flounder, and seabass. For seabass larvae (*Lates calcarifer*), using Artemia biomass in hatcheries and nurseries has reduced Artemia cyst consumption by up to 60 percent, significantly lowering the total cost of larval feed. In early-stage larval rearing of lobsters (*Homarus* spp.), replacing nauplii with Artemia biomass has been shown to significantly reduce cannibalism.

Alongside Artemia cyst farming, the Faculty of Fisheries at Can Tho University has conducted experimental farming and trial production of Artemia biomass in the Vinh Chau-Bac Lieu salt fields, achieving productivity levels of 2–4 tons/ha per crop (fresh). Biomass farming presents promising profit potential, as farmers can collect both biomass (the main product) and cysts, with cyst collection estimated at 30–50 percent of the yield compared to cyst-only farming models (Anh et al. 1997; Brands et al. 1995; Thao 1992). However, Artemia biomass farming has yet to be widely applied or developed at a local or national scale in Viet Nam due to several challenges. These include unstable pond management and biomass harvesting techniques, a lack of suitable processing methods for different cultured species (fresh, frozen, dried, or processed forms), and, most critically, the absence of a large-scale or consistent market for Artemia biomass.

5.3. Policy and Regulatory Environment

5.3.1. Existing framework

There is currently no dedicated government policy or regulatory framework specifically governing Artemia production and value chains in Viet Nam. This may be because there are no native Artemia populations in the country, and its farming has only been established through academic and private sector collaborations. Artemia farming in Vinh Chau (former Soc Trang) and former Bac Lieu was introduced and developed through a joint program between Can Tho University and Ghent University (Belgium), leading to the establishment of sustainable Artemia farming practices. The sector operates under various models, including cooperative arrangements and PPPs, enabling smallholder farmers to benefit from financial and technical support.

While Artemia cyst production and imports must comply with Vietnamese National Standard TCVN 11754:2016, which specifies technical requirements and testing methods for dried and decapsulated Artemia cysts used as aquatic feed, there are no specific policies governing Artemia biomass farming or investment promotion frameworks tailored to Artemia businesses. However, government authorities recognize the value of Artemia farming and provide training and advisory support to farming communities in these regions.

5.3.2. Barriers and opportunities

The absence of a clear regulatory framework for Artemia farming in Viet Nam creates uncertainty for investors and producers, particularly for biomass production and expansion efforts. While aquaculture in general is a priority sector for the Vietnamese government, Artemia farming lacks targeted investment policies, subsidies, or incentives that could facilitate growth. Imported Artemia cysts are of high quality but expensive, while wild-harvested cysts suffer from seasonal fluctuations in both quality and quantity, creating supply chain inconsistencies. Additionally, contract farming arrangements—which are increasingly common in the Artemia sector—can face challenges when market prices fluctuate, leading to disputes between private sector buyers and smallholder farmers.

Despite the lack of direct policy support, Vietnamese Artemia farmers have successfully adapted their production systems and continue to expand. Potential regulatory improvements could focus on climate adaptation strategies, such as brine storage, higher stocking densities, and the use of shrimp farm effluent as a low-cost, nutrient-rich feed source for Artemia farming, reducing reliance on artificial fertilizers. Since live Artemia biomass is highly valued, especially for hatcheries and ornamental fish markets, policies promoting cold storage and efficient distribution systems could enhance its marketability and increase farmer profitability. Given that the introduction of Artemia does not pose biodiversity risks in Viet Nam, formalizing governance tools and business development policies would support the sector’s sustainable expansion and integration into broader aquaculture value chains.

5.4. Infrastructure and Capacity

Artemia farming in former Soc Trang, former Bac Lieu, and Vinh Chau faces growing land competition due to expanding renewable energy projects and intensive white-leg shrimp (*Litopenaeus vannamei*) farming, limiting expansion opportunities.

Although processing, drying, and freezing techniques for Artemia cysts exist, biomass production remains small-scale and traditional, with limited cold storage capacity. High electricity costs prevent many farmers from maintaining freezing facilities, making it difficult to preserve biomass and causing post-harvest losses.

Unlike tidal-based aquaculture, Artemia farming relies on engineered water control systems (sluice gates, canals, and pumps) for salinity regulation. However, many small-scale farmers lack efficient water exchange systems, leading to salinity, nutrient, and disease management challenges. While using shrimp farm effluent for Artemia production shows potential, infrastructure for scaling up integrated systems is still lacking.

Investing in land use planning, water management systems, cold storage, and processing facilities is essential to enhance the sustainability and profitability of Artemia farming in the region.

5.5. Market Assessment and Demand

In Viet Nam, Artemia cysts and biomass are marketed to shrimp hatcheries and aquaculture feed producers, and biomass has potential for greater application in markets for human consumption and feed. Each sector has varying characteristics and demand.

- **Cysts:** Demand is high, especially from shrimp hatcheries, but Vinh Chau Artemia cysts, despite their superior quality (small size and high HUFA content), are mainly exported or sold to niche domestic buyers at premium prices. Most hatcheries prioritize cost savings in postlarvae production, relying on cheaper, lower-quality imported cysts (99 percent of the market), while domestic cysts represent only 1 percent.
- **Biomass:** Used by local hatcheries and nurseries as frozen feed for shrimp and fish larvae, with annual consumption around 500–600 tons (wet weight). Live Artemia is preferred for its nutritional benefits, boosting larvae growth and survival. However, limited cold storage and distribution infrastructure hinder market expansion.
- Although there have been local initiatives in Vinh Chau and Bac Lieu to develop Artemia-based food products, these remain small-scale. The availability of affordable, familiar shrimp and fish has prevented wider adoption, while lack of processing infrastructure and market development further restricts growth.

TABLE 16. Quality of different cyst sources compared to Vinh Chau Artemia cysts

Cyst sources	Diameter (µm)		Nauplii length (µm)	Nauplii volume (10^{-3}µm^{3})	Dried Weight (µg)	20:5n3 (%)
	Non-decapsulated	Decapsulation				
China (Tientsin)	274.4	257.8	515	13,097	3.09	1.3–15.35
Brazil, Macau	228.7	213.8	447	8,314	1.68	3.9–5.8
Iran, Urmia	258.1	245.7	-	-	-	-
Philippines, Barotac Nuevo	228	-	429	7,991	1.69	8.6
Sri Lanka, Puttalam	269.8	-	-	-	-	-
SFB	234.6	202.4	422.00±18.50	-	1.63	1.8–12.44
GSL	-	-	-	-	2.42	0.3–3.55
Thailand, Bangpakong	-	-	-	-	5.3	-
Vinh Chau	227–230	196.3	432.69±24.58	-	-	12.4–13.1

Source: Van Hoa (own source.

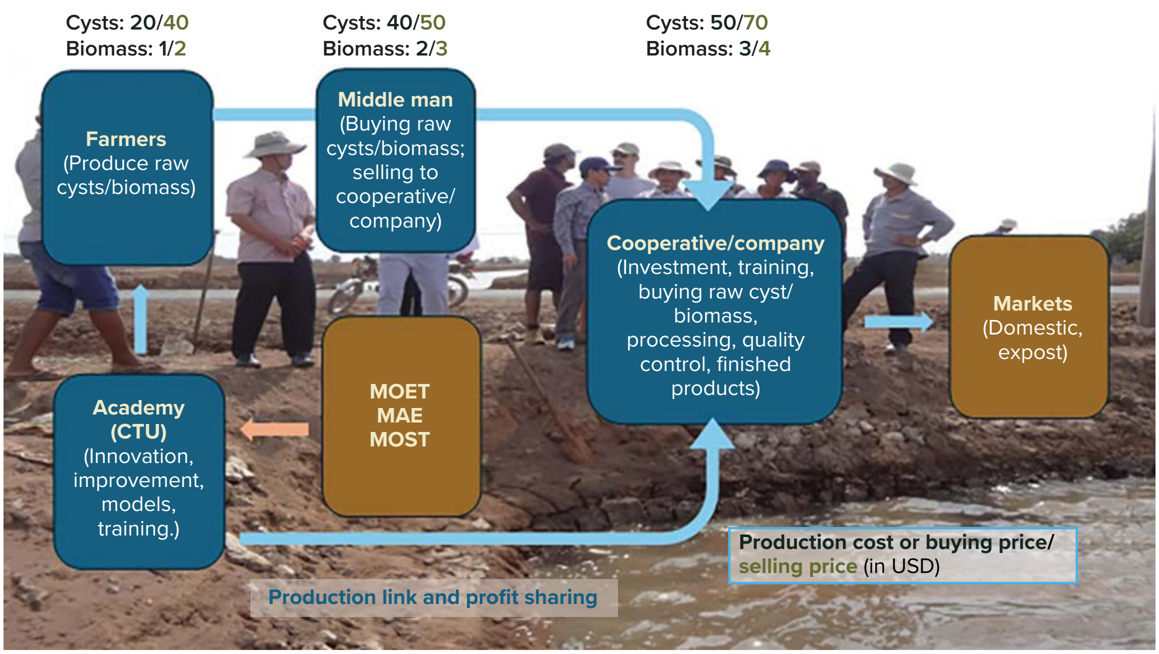
In 2023, Viet Nam produced only 9 tons of Artemia cysts (6 tons in former Bac Lieu and 3 tons in former Soc Trang), while importing 667 tons, covering over 99 percent of total supply. Imports arrive from the US, China, and Russia. Despite the superior quality of Vinh Chau Artemia cysts, they are less used due to higher prices. Hatcheries prefer cheaper imported cysts (US$80–100/kg) with a 90 percent hatching rate despite their lower quality.

Viet Nam's marine shrimp industry produces 170–190 billion postlarvae annually, driving consistent demand for Artemia cysts, which is expected to grow alongside shrimp production. The internationally recognized Vinh Chau Artemia brand offers expansion potential for both domestic and export markets.

Viet Nam's brackish water shrimp farming area is also projected to reach 750,000 ha in 2025, with 1.3–1.4 million tons of total shrimp production, including over 1 million tons of white-leg shrimp. The sector's export turnover is forecasted at US$4–4.3 billion and will continue to drive greater demand for high-quality Artemia, underscoring the market and business opportunity for Artemia.

Figure 28 provides some of the links within the Artemia value chain, with cooperatives playing important roles as intermediaries between farmers and the markets. Can Tho University has also played a critical role in research and training and contributing innovation and improvement to the Artemia farming system models.

FIGURE 28. Linkage among farmers and cooperative/company



Source: Van Hoa, FutureFish
Note: MOET = Ministry of Education and Training; MAE = Ministry of Agriculture and Environment; MOST = Ministry of Science and Technology.

5.6. Socioeconomic Impacts and Inclusion

Women play a significant role in Artemia processing (60–80 percent of total employment), but only 5–10 percent of the workforce engaged in farming, which is traditionally male-dominated. The sector also faces an aging workforce, with over 90 percent of farmers ages 30+ due to youth migration to cities seeking better jobs.

Integrated salt-Artemia or salt-Artemia-shrimp systems offer diverse revenue streams but require significant investment and large land areas, limiting adoption by small-scale farmers. Transitioning to advanced systems with mechanized control and skilled labor requires substantial investment and training, highlighting the need for financial support to improve productivity and sustainability.

The economic efficiency from Artemia farming is much higher compared to traditional salt production, which can increase income by 3–5 times. However, only farmers with technical investment and sufficient capital can produce a yield of more than 100 kg of Artemia cysts/ha/crop while most of the remaining farmers have difficulties in investment and farming techniques, so the average yield is only 50–70 kg/ha/crop.

Currently, the number of high-productivity farmers accounts for no more than 30 percent of the total number of Artemia farming households. To expand production and to improve the economic efficiency of Artemia farming will need capital support and training for improving productivity and profitability.

5.7. Climate Resilience and Environmental Considerations

Climate change in the Mekong Delta is expected to cause increasingly unpredictable weather, threatening agricultural production and potentially leading to revenue losses, particularly for salt and Artemia farmers (Tuấn 2011). Both rely on stable temperature and salinity conditions. For Artemia, frequent rainfall and salinity drops below 80 ppt foster predators, disrupt Artemia food availability, and lower cyst production. Extreme heat above 40°C, combined with high salinity, also causes mass mortality, leading to significant losses (Hoa et al. 2007).

Unpredictable weather also disrupts early season saltwater pond preparation, reducing farming time and shortening the Artemia production cycle. In 2017, a climate anomaly caused a 50–60 percent drop in productivity, increased costs by 20–30 percent, and led to a 58 percent profit decline (Can Tho University survey).

Adaptive strategies such as better water management, improved pond design, and integrated farming models are essential to mitigate risks and ensure long-term sustainability. Farmers have responded by stocking Artemia earlier, using brine storage, supplementary feeding, and even experimenting with lower salinity. Some have introduced pond roofing systems to regulate temperature.

Additionally, shrimp farm effluents can harm Artemia productivity, necessitating a separate water supply for Artemia farms. The integrated Artemia-salt farming system offers climate resilience, with Artemia improving salt quality and brine regulating salinity. Investing in infrastructure and integrated farming can enhance resilience, productivity, and profitability.

5.8. Investment Opportunities and Case Studies

The Soc Trang and Bac Lieu saltworks, spanning over 1,000 ha, present significant potential for expanding Artemia farming. However, production remains small-scale, with support from the private sector and cooperatives. Increased investment could boost productivity and meet the growing demand for high-quality Artemia cysts and biomass.

Integrated Artemia-salt farming systems once generated higher profits, with farmers earning over US$3,000 per season. However, declining salt prices have led many farmers to switch to monoculture Artemia farming for better returns.

Despite producing high-quality cysts, Soc Trang and Bac Lieu's cysts are not widely used locally due to their high price (US$200/kg) compared to cheaper imported cysts (US$50–100/kg). Domestic demand for Artemia cysts is 667 tons annually, but only 1 percent of local production is used, with imports making up 99 percent. To make domestic cysts more competitive, investment strategies include the following:

- Access to affordable credit: Farmers need low-interest loans or capital from the state bank to invest in improved production techniques and infrastructure.
- Training and technical support: Capacity building on climate adaptation strategies (for example, brine storage and improved pond management) can enhance resilience and productivity.
- Cooperative participation: Farmers who join cooperatives receive better access to inputs, technical advice, and market opportunities.
- Fair benefit distribution in the supply chain: A more equitable value chain could improve incentives for domestic production.
- Investment in post-harvest processing and storage: Strengthening purchasing, processing, and preservation infrastructure would improve product quality and market reach.
- Market expansion for high-quality cysts: Efforts to promote and expand sales of Vietnamese Artemia cysts to niche markets that prioritize quality over price could increase demand.

In addition, integrated white-leg shrimp and Artemia farming has shown promise, with shrimp effluent providing nutrients for Artemia, reducing fertilizer needs, and enhancing productivity. Expanding these integrated models can offer both environmental and economic benefits.

With targeted investments in finance, technology, infrastructure, and market development, Viet Nam has the potential to strengthen its Artemia sector and reduce dependence on imported cysts while maximizing the value of domestically produced Artemia.

5.8.1. Promising business models

The Viet Nam model is dominated by cyst production producing a high-value product, with smaller quantities of biomass production. The model integrates Artemia cysts and biomass production with salt farming, offering diversified income streams and market potential. The model is dominated by small-scale farmers, who can modify farming systems depending on market conditions and opportunity.

The model outlined in Table 17 highlights key aspects of the production cycle, including yields, costs, revenue potential, and the role of women in the workforce. It shows the viability of scaling up production, particularly in intensive systems, while addressing challenges such as competition from cheaper imported cysts. The strategic use of technology and environmental conditions will also play a crucial role in improving efficiency and profitability.

TABLE 17. Viet Nam Artemia-Salt Pond Farming

Name of Business Model	Viet Nam Artemia-Salt Pond Farming
Category	**Details**
Diversified Income Opportunities	Artemia cysts, biomass, salt production, and brine sales
Description	Seasonal Artemia farming in modified salt ponds during the dry season, producing high-value cysts and biomass with strong domestic and export market potential for cysts
Total Production per Cycle	Cysts: 50–70 kg/ha (wet weight), with potential improvement to 100–150 kg/ha Biomass: 4–5 tons/ha per cycle
Cycle Time	4–5 months (dry season) - or all year in more intensive systems with deeper ponds and water availability
Tons per ha per Cycle	Cysts: 50–70 kg (150–200 kg in intensive systems) Biomass: 4–5 tons
Production Cost per kg	US$15–20/kg (raw cysts, wet weight) selling by farmers
Cost per ha per Cycle	Stocking (inoculum) and feed (~30 percent each) Labor: 2–3 people / ha
Selling Price (US$/kg)	Cysts: US$200/kg (high-quality Viet Nam cysts) Imports (cheaper cysts from US, China, and Russia): US$50–100/kg
Revenue per ha	US$3,000/ha but up to US$7,000/ha in more intensive systems Biomass and brine: Additional revenue streams
Profit Margin	Profit until end user can be more than 60 percent, but in Viet Nam gets sold to processor at around 30–50 percent profit
Investment Cost and ROI	Potentially high cost but could pay back after 1–2 years
Employment per ha	2–3 workers/ha
Total Jobs Created	1,000–2,000 jobs (for more seasonal systems)
Women in Workforce	~20 percent in Viet Nam at production level but mostly women involved at processing level
Technology Needed	Buckets, rakes, pipes, scoop net, brine transport systems but can require higher technical equipment such as cyst processing set (including 1) separation funnel, 2) centrifuge, 3) fluidized bed dryer, 4) sieving machine and 5) canning equipment)
Environmental Conditions	Salinity: 80 g/L at Artemia stocking Temperature: Suitable for Artemia growth in dry season Brine sales: 1 m^3 brine = US$1–`2 Seawater quality improvement: 1 m^3 brine + 4 m^3 freshwater = pathogen-free seawater for hatcheries
Main Markets	Crab, marine fish, and shrimp hatcheries
Domestic vs. Export Market	In Viet Nam, about 50 percent cysts are sold domestically, 50 percent exported
Untapped Potential	Viet Nam hatcheries prefer cheaper imported cysts (~US$50–100/kg vs. Viet Nam's US$200/kg) but local crab hatcheries require the higher-quality cysts. With optimized costs, Viet Nam Artemia cysts could expand their market share in domestic and export markets.

5.9. Recommendations

The following investment recommendations are from the Viet Nam case study.

	Recommendations for investment
Production Improvement Strategies	• Upgrading of production systems, especially to improve brine ponds for brine storage, to sustain current culture systems or to start earlier in the stocking for the next season (right after rainy season), particularly to cope with climate change variabilities (for example, earlier rain season or late dry season for next year). Results will include better productivity and profitability and product diversity (for example, small cysts, high nutrient content/quality).
Policy and Regulatory	• Coastal planning and integration: Support planning for Artemia farming areas by (local) government. Link coastal planning to capital support from banks or credit institutions. • Invest in salinity mapping and climate risk tools to guide future Artemia pond expansion in saline-affected and coastal areas.
Infrastructure and Technology	• Build a year-round cyst/biomass Artemia farming technique (for example, deeper pond design and brine storage). • Use different sources of organic waste to produce cyst/biomass, reducing costs and providing more opportunities for expansion. • Support new research and technologies to partially replace fishmeal to produce shrimp/fish pellets. • Co-finance the establishment of community-based Artemia processing units (cleaning, grading, vacuum packing) to improve quality and shelf life. • Invest in solar-powered drying and chilling facilities to extend the post-harvest window and reduce spoilage.
Market Development Strategies	• Support the development of a national premium Artemia cyst brand (for example, Vinh Chau Gold Standard) tied to hatch-out rate certification, traceability, and sustainability credentials. • Facilitate entry into niche premium hatchery markets in Europe, Japan, and Korea that pay a premium for high-performance cysts. • Promote Viet Nam as a regional Artemia supplier through trade delegations, international aquaculture fairs, and PPPs. • Reduce reliance on imported low-cost cysts by supporting domestic hatcheries to trial and adopt higher-quality local Artemia. • Provide temporary matching subsidies or performance-based procurement schemes to hatcheries buying local Artemia.
Socioeconomics	• Expand the cooperative model (for example, Vinh Chau-Bac Lieu Artemia Coop) to new salt-producing coastal regions through training, governance support, and start-up capital. • Develop integrated Artemia-salt farming training centers to build farmer capacity in sustainable farming, harvesting, and quality control. • Target female-led or Khmer ethnic minority households for inclusion in Artemia production models with tailored microfinance, extension, and marketing support upon determination of their meeting the ESS7 criteria provided for under the World Bank Environmental and Social Framework (ESF). • Support community development funds or revolving loan schemes anchored around Artemia cooperatives to build local resilience.
Impact Potential	• Impact potential on employment and job creation is significant in saline-affected regions.

6

SCALABLE BUSINESS MODELS AND INVESTMENT APPROACH

To identify opportunities for Artemia farming in Africa, and elsewhere, this section draws on insights from four Artemia models in Asia and value chain insights from the case studies. The Kenya model above is an example of a country in Africa using the Viet Nam and Thailand cyst and biomass models, respectively, with varying degrees of success.

The four models below represent a spectrum of production systems, from small-scale artisanal farming to larger, commercially integrated operations, with different applicability (see Table 18). The main characteristics of each model are as follows:

1. **China Model (Industrial Solar Saltworks Integration):** Large-scale Artemia production within industrial solar saltworks, leveraging existing infrastructure to co-produce Artemia cysts and biomass alongside salt. This model demonstrates the potential for Artemia farming in large saltworks (with the benefit of improving the quality of salt) but is more capital-intensive.
2. **Thailand Model (Biomass Farming for Aquafeed):** A continuous Artemia biomass production system in modified salt ponds, with year-round harvests supplying shrimp, marine fish hatcheries, and aquafeed processors. It is a low-tech, high-yield approach.
3. **Viet Nam Model (Salt Pond Cyst Production):** A semi-intensive model where Artemia is farmed in salt ponds during the dry season, yielding high-value cysts for both domestic hatcheries and export. This requires some processing expertise but is suitable for scaling in artisanal and commercial settings.
4. **Bangladesh Model (Artisanal Salt-Artemia Farming):** Farmers integrate Artemia production into seasonal salt ponds, producing both cysts and biomass alongside salt. This model is low-cost, is suited for smallholder participation, and provides a climate-resilient livelihood.

TABLE 18. **Characteristics of found scalable Artemia business models**[6]

Category	China 	Thailand 	Viet Nam 	Bangladesh 
Name of Business Model	China Artemia (Biomass and Cysts) Large Solar Saltworks Model	Thailand Artemia Biomass Pond Farming	Viet Nam Artemia Cysts and Salt Pond Farming	Bangladesh Year-Round Artemia-Salt Farming
Products and Total Production per Cycle	Cysts: 500–600 tons annually Biomass: 200,000–300,000 tons annually	Biomass: 2.25–4.5 tons/ha/month	Cysts: 50–70 kg/ha (wet weight), potential for 100–150 kg/ha Biomass: 4–5 tons/ha per cycle	Cysts: ~17 kg/ha per cycle (120 kg total over 7 ha in 4 years) Biomass: 1.3–1.4 tons/ha per cycle
Cycle Time	April to November (seasonal production)	Year-round operation possible, peak in dry season	4–5 months (dry season)	January–May (dry season) or year-round if doing tilapia/shrimp in rainy season
Tons per ha per Cycle	Cysts: Large salt ponds (30–60 ha per pond) Biomass: High-yield, large-scale collection	Biomass: 2–4 tons per ha per cycle	Cysts: 50–70 kg/ha (150–200 kg in intensive systems) Biomass: 4–5 tons	Cysts: ~17 kg/ha Biomass: 1.3–1.4 tons/ha
Cost per kg	Biomass: US$0.30/kg	UIS$0.15–0.50/kg	US$15–20/kg	Around US$36/kg for cysts and US$1.4/kg for biomass
Selling Price (US$/kg)	Cysts: Premium price (150 percent higher than inland cysts) Live biomass: US$1–2/kg	Live biomass: US$1.75–1.78/kg Frozen biomass: US$1.50–1.63/kg	Cysts: US$200/kg (high-quality Viet Nam cysts) Imports: US$50–100/kg	Cysts: US$50–100/kg Live biomass: US$4–5/kg
Revenue per ha	US$6,000–30,000 per year	Up to US$38,000 per farm per year	Cysts: US$10,000 per ha per season Biomass: Additional revenue stream	Estimated US$8,000 per ha per season
Profit Margin	30–50%, Stable due to high demand; cysts sold at a premium due to better hatchability and nutritional value	Profit until end user can be 50–90%, with processors taking 30–40%	30–50% for farmers but processors take a further 60%, meaning total margin is over 90%	40–50% but variable and dependent on local demand and production efficiency

6 These maps are for illustrative purposes and do not imply the expression of any opinion on the part of the World Bank concerning the legal status of any country or territory or concerning the delimitation of frontiers or boundaries.

6.1. Lessons Learned for Scaling and Investment in Artemia

6.1.1. Integration with Existing Production Systems Drives Adoption—but Requires Context Fit

- Models that integrate Artemia into existing salt, shrimp, or aquaculture operations (Viet Nam, Bangladesh, China) lower entry costs and speed adoption.
  - **Opportunity:** Target saline or salt-affected areas where salt/aquaculture is already established, using Artemia to diversify income and improve resource efficiency.
  - **Risk:** Integration only works if seasonal cycles align (for example, Bangladesh's dry season Artemia vs. monsoon shrimp) and infrastructure (brine management, pumps, ponds) is adaptable. Misaligned cycles or infrastructure incompatibility can undermine returns.

6.1.2. Market Pull Is Critical — Production Without Demand Is Not Viable

- Viet Nam and Thailand's success is anchored in strong, proximate hatchery demand, while Kenya struggles due to the absence of a local market.
  - **Opportunity:** Anchor investments to clusters with a high density of hatcheries or feed processors, securing offtake agreements before scaling.
  - **Risk:** Overestimating export potential—cyst markets are price-sensitive, consolidated, and dominated by a few major suppliers; without QA and marketing infrastructure, competing globally is difficult.

6.1.3. Biomass Markets Are Underdeveloped but High Potential

- Most countries prioritize cysts, yet Thailand's hatcheries demonstrate robust willingness to pay for biomass. Bangladesh shows biomass is simpler and faster to produce.
  - **Opportunity:** Develop local and regional biomass supply chains targeting shrimp, crab, marine finfish, ornamental fish, and even poultry/pig feeds.
  - **Risk:** Lack of cold chain or preservation methods will limit reach; biomass is perishable and loses value rapidly without processing.

6.1.4. Processing and Biosecurity Infrastructure Is a Key Bottleneck

- China's dominance is built partly on sophisticated cyst processing and QA systems, while Kenya and Bangladesh remain dependent on central facilities (KMFRI in Kenya).
  - **Opportunity:** Invest in decentralized, small- to medium-scale processing hubs with biosecurity protocols, which can service multiple farms.
  - **Risk:** Poor processing reduces hatchability, making the product unsellable; without strong QA, reputational risk rises quickly.

6.1.5. Institutional and Knowledge Dependence Can Stall Growth

- KMFRI in Kenya and WorldFish in Bangladesh illustrate how technical institutions seed industries but can create reliance.
  - **Opportunity:** Build embedded training and certification programs within producer cooperatives or private companies to reduce attrition risk when trained staff leave.
  - **Risk:** If knowledge remains concentrated in a few experts or agencies, scaling will not be possiblek when they are unavailable or funding ends.

6.1.6. Land Tenure and Farmer Incentives Matter for Investment Security

- In Bangladesh, 81 percent of salt farmers rent land seasonally—they have little incentive to invest in infrastructure.
  - **Opportunity:** Use cooperative/cluster farming models or long-term lease agreements to unlock investment readiness.
  - **Risk:** Without tenure security, any capital investment (for example, pond deepening, pumps) risks being stranded.

6.1.7. Seasonality Shapes Returns and Financing Models

- All five countries face seasonal constraints from rainfall, salinity shifts, or temperature changes.
  - **Opportunity:** Deploy working capital finance aligned to production cycles, and invest in R&D for year-round production (for example, deeper ponds, indoor/tank systems).
  - **Risk:** Year-round production is not always technically or economically viable; forcing it can lead to losses if operating costs exceed seasonal profit peaks.

6.1.8. Quality and Strain Management Are Essential for Competitiveness

- China's high-value cysts are differentiated by hatchability and nutritional content; Viet Nam maintains productivity with careful strain management.
  - **Opportunity:** Develop national or regional Artemia reference centers for seed/strain supply, QA, and genetic management.
  - **Risk:** Without genetic control, strain performance declines over time, eroding market competitiveness.

6.1.9. Diversification of End Uses Increases Resilience

- Human food, animal feed, and aquafeed applications can buffer against volatility in cyst markets.
  - **Opportunity:** Invest in R&D for Artemia-based food ingredients, nutraceuticals, and pet feed applications.
  - **Risk:** Non-aquaculture markets require complex regulatory approval (food safety, novel ingredient), increasing time to market.

6.1.10. Environmental Management Protects Both Supply and Reputation

- Mismanaged fertilization in China's salt ponds causes downstream salt quality issues; unplanned expansion in Bangladesh could affect wetlands.
  - **Opportunity:** Promote 'climate-smart' and environmentally benign production, which also opens environmental, social, and governance-aligned financing.
  - **Risk:** Poor environmental practices risk regulatory crackdowns and loss of social license, particularly in sensitive coastal or wetland zones.

6.2. Investment Criteria and Priorities

Each business case provides attractive returns to investment and potential for impact on jobs throughout the value chain. Investors evaluating Artemia aquaculture opportunities with these models can prioritize countries using several key criteria, which are considered important for success. The key criteria are as follows:

- **Hypersaline Ecosystems:** Presence of natural salt lakes, evaporation ponds, salt pans, or salterns is fundamental. Artemia thrive in hypersaline waters (typically >70 g/L salt) where predators are few. For example, Senegal's dry Sahel climate enables salt ponds in Fatick and Lac Rose to evaporate quickly creating brine-rich environments ideal for Artemia. Regions with low rainfall and high evaporation (coastal lagoons, salt flats, inland desert lakes) provide the best conditions for scaling up Artemia production.

- **Existing Aquaculture Industry:** A strong aquaculture or mariculture sector creates immediate demand for Artemia cysts and biomass as hatchery, nursery, and maturation feed. Countries with significant shrimp farming or fish hatcheries are a priority. For instance, Egypt produces ~2 million tons of farmed fish (tilapia and so on) annually and has started farming marine shrimp (~2,100 tons in 2020)—their hatcheries import Artemia cysts currently. Nations such as Nigeria (~300,000 tons aquaculture, Africa's second largest) and Uganda (third largest, ~50–100,000 tons) have booming fish farms and many hatcheries for catfish/tilapia that rely on live feed for fry. Proximity to these industries means an Artemia venture will find ready markets (hatcheries and nurseries) to absorb production. The presence of mariculture (marine fish or shrimp and crab hatcheries as in Tunisia or Kenya) is a particularly strong signal, as Artemia cysts are essential for those operations and local availability of biomass opens opportunities to improve cost-effectiveness.
- **Aquafeed and Livestock Feed Markets:** The broader animal feed industry can be a further opportunity to maximize Artemia utilization, though market development will be required. Artemia biomass (rich in protein, omega-3, and minerals) can be processed into ingredients for fish feed or poultry/aquaculture diets. Regions with feed mills and high demand for animal feed protein are attractive. For example, Zambia has become a net exporter of fish feeds in Southern Africa, and its animal feed industry produces over 100,000 tons/year. The Aller Aqua feed factory in Zambia has the capacity to do well over 50,000 tons of aquafeed per year. While Zambia does not have many good locations for artemia farming, neighboring Botswana and Namibia do. Similarly, Nigeria's and Ethiopia's large poultry sector (producing millions of tons of feed) could potentially absorb Artemia as a high-nutrient novel ingredient.
- **Human Nutrition and Food Security Potential:** Artemia (brine shrimp) is not a traditional food in many countries, but its biomass could be dried and processed as a protein supplement. In regions around hypersaline lakes where communities face malnutrition or protein scarcity, Artemia farming might contribute to nutrition indirectly. For example, in Senegal's saline zones, erratic rainfall has hurt agriculture, and salt harvesting has become a livelihood of last resort. Here, integrated Artemia farming could offer an additional protein source (either via income to buy food or possibly direct use in fortified foods). High rates of child malnutrition or protein deficiency in saline-affected communities indicate a social impact opportunity for Artemia projects. Investors may prioritize areas where Artemia production aligns with opportunities for human food (for example, enhancing diets or developing nutritional supplements from Artemia biomass).
- **Regulatory and Research Support:** A conducive policy environment and local know-how can greatly enhance success. Priority should go to countries whose governments and institutions support aquaculture development or have conducted Artemia research. Uganda and Kenya, for instance, have universities and pilot projects studying Artemia in salt lakes (Nkambo, 2019) to supply their growing aquaculture sectors (Sserwada et al., 2018). Government initiatives such as Zambia's Aquaculture Enterprise Development Project (Zhang et al., 2024) signal official backing for related investments. Likewise, Tunisia's history of artisanal salinas and interest in diversifying saltworks could mean less red tape for an Artemia venture. Key regulatory factors include permits for use of salt ponds, biosecurity rules on introducing Artemia species, and support for exporting aquaculture products. An investor-friendly locale will have clear guidelines and possibly incentives (for example, export zones or research partnerships) for new Artemia production enterprises.

These criteria are summarized in Table 19 and have been used in the following section to assess potential countries in Africa and other regions where potential exists for Artemia aquaculture investment.

TABLE 19. **Investment criteria and indicators**

Investment Criteria	Indicators
Hypersaline and Salt-Affected Ecosystems	Presence of salt lakes, ponds, salt pans, solar saltworks, and evaporation ponds
	Salinity levels (for example, >70 g/L)
	Seasonal vs. year-round hypersalinity
	Salt-affected areas with no agricultural productivity
Existing Aquaculture Industry	Annual aquaculture production volume (tons)
	Key farmed species (tilapia, catfish, shrimp, prawn, crab, marine fish)
	Number of fish farms/hatcheries
	Growth trends in aquaculture sector
Aquafeed and Livestock Feed Markets	Annual aquafeed production volume (tons)
	Terrestrial feed market size (poultry, livestock, pet food)
	Fishmeal import/export dependency
	Feed mill capacity and processing infrastructure
Human Nutrition and Food Security Potential	Per capita fish consumption (kg)
	% of animal protein from seafood
	Malnutrition rates in target regions
	Presence of small shrimp/crustaceans in local cuisine
	Evidence of Artemia used in food products
Regulatory and Research Support	Presence of aquaculture development plans
	Biosecurity regulations for Artemia farming
	Local research institutions working on aquaculture (and/or engaged with Artemia)
	Government incentives or trade policies for aquaculture

6.3. Investment Risks

While the potential for Artemia production in Bangladesh and other countries is promising, several investment risks must be carefully considered. These risks fall under four broad categories: climatic, technical, market, and institutional.

6.3.1. Climatic and Environmental Risks

Artemia production is highly sensitive to climatic variability. Unpredictable weather patterns—such as unseasonal rainfall, excessive humidity, or sudden temperature fluctuations—can significantly disrupt cyst production and biomass yields. Climate-related challenges, as observed in countries such as Viet Nam, have led to erratic year-on-year outputs. In Bangladesh, increased monsoon intensity or salinity dilution from flooding may limit the seasonal window for successful Artemia cultivation in salt pans.

6.3.2. Technical and Operational Risks

Successful Artemia production requires precise management of salinity, aeration, harvesting techniques, and biosecurity. Without adequate training, capacity building, and monitoring systems, there is a risk of inconsistent production and potential losses. Farmers unfamiliar with Artemia pond culture may underperform without technical support or extension services. Moreover, Artemia yields can vary based on strain selection and pond management practices, leading to variability in quality and quantity.

6.3.3. Market and Price Risks

Although demand for Artemia cysts and biomass is strong, the market is highly price sensitive. Imported cysts—often of lower quality—are sold at significantly cheaper rates (US$50–60/kg) compared to locally produced, higher-quality cysts (US$150–200/kg). This price gap can limit domestic uptake, especially by smaller hatcheries and nurseries. Overproduction or poor coordination of supply can also depress local prices if market access or export channels are not well developed.

6.3.4. Institutional and Regulatory Risks

Artemia production operates at the interface of salt farming, aquaculture, and environmental policy. Lack of clear regulatory frameworks, overlapping jurisdictional mandates, or absence of incentives for integrated systems can hinder large-scale uptake. Furthermore, weak enforcement of quality standards may allow low-grade imports to outcompete local producers, undermining market confidence.

6.4. Investment and Impact Potential

Applying the criteria above, we have systematically prioritized countries and saline regions where Artemia farming has a higher potential for success, aligning production with market demand and existing infrastructure. We have prioritized the potential for Artemia farming in Africa and the applicability of the models assessed during the in-depth case studies, pointing to locations where Artemia farming can be sustainably scaled, ensuring both economic viability and positive social outcomes. The tables below provide summaries of business models by region, with detailed country-by-country assessments provided in Annexes 2–5, starting with Africa but also identifying other country locations in Asia, Latin America, and the Middle East.

TABLE 20. Summary of Artemia business models by region

Region/Country	Bangladesh Model	Thailand Model	Viet Nam Model	China Model	No Artemia farming possible, but large market
Africa					
Botswana	✔	✖	✖	✔	✖
Egypt, Arab Rep.	✖	✖	✔	✔	✖
Ethiopia	✔	✖	✖	✖	✖
Ghana	✔	✔	✔	✖	✖
Kenya	✔	✔	✔	✔	✖
Madagascar	✔	✖	✔	✖	✖
Mozambique	✔	✔	✔	✔	✖
Namibia	✖	✖	✖	✔	✖
Nigeria	✔	✔	✖	✖	✖
Rwanda	✖	✖	✖	✖	✔
Senegal	✔	✔	✖	✖	✖
Federal Republic of Somalia	✔	✖	✔	✖	✖
Tanzania	✔	✔	✔	✔	✖
Tunisia	✖	✖	✔	✔	✖
Uganda	✔	✔	✔	✖	✖
Zambia	✖	✖	✖	✖	✔
Latin America					
Bolivia	✔	✔	✔	✖	✖
Brazil	✖	✔	✔	✔	✖
Chile	✖	✖	✔	✖	✖
Ecuador	✖	✔	✔	✔	✖
Peru	✔	✖	✔	✖	✖
Asia					
India	✖	✔	✔	✖	✖
Indonesia	✔	✔	✔	✖	✖
Philippines	✔	✔	✖	✔	✖
Middle East					
Iran, Islamic Rep.	✖	✖	✔	✖	✖
Saudi Arabia	✖	✔	✔	✖	✖
United Arab Emirates	✖	✖	✖	✔	✖

Each country is assessed against the key investment criteria in Table 21, covering Africa, Asia, Latin America, and the Middle East (further details in Annexes 2–5).

TABLE 21. High-level assessment by region/country against key investment criteria

Region/Country	Hypersaline Ecosystems	Existing Aquaculture Industry	Aquafeed and Livestock Feed Markets	Consumption and Markets	Regulatory and Research Support
Africa					
Botswana	✔	✖	✔	✖	✖
Egypt, Arab Rep.	✔	✔	✔	✔	✔
Ethiopia	✔	✖	✔	✖	✖
Ghana	✔	✔	✔	✖	✔
Kenya	✔	✔	✔	✖	✔
Madagascar	✔	✔	✔	✔	✔
Mozambique	✔	✔	✔	✔	✔
Namibia	✔	✖	✔	✖	✖
Nigeria	✔	✔	✔	✖	✔
Rwanda	✖	✔	✔	✖	✔
Senegal	✔	✖	✔	✔	✖
Federal Republic of Somalia	✔	✖	✔	✖	✖
Tanzania	✔	✔	✔	✖	✔
Tunisia	✔	✔	✔	✔	✔
Uganda	✔	✔	✔	✖	✔
Zambia	✖	✔	✔	✖	✔
Latin America					
Bolivia	✔	✔	✔	✖	✖
Brazil	✔	✔	✔	✖	✔
Chile	✔	✔	✔	✖	✔
Ecuador	✔	✔	✔	✖	✔
Peru	✔	✔	✔	✖	✔
Asia					
India	✔	✔	✔	✔	✔
Indonesia	✔	✔	✔	✔	✔
Philippines	✔	✔	✔	✔	✔
Middle East					
Iran. Islamic Rep.	✔	✔	✔	✔	✔
Saudi Arabia	✔	✔	✔	✖	✔
United Arab Emirates	✔	✔	✔	✖	✔

7

CONCLUSION AND NEXT STEPS

The Artemia country studies in this report present the Artemia value chains in five case study countries: Bangladesh, China, Kenya, Thailand and Viet Nam. The findings confirm that Artemia can be successfully produced through aquaculture as cyst or biomass products in saline environments, providing important and critical products for aquaculture, with the potential for wider application and product development as aquafeed and human food. Market development for aquafeed and human food beyond current uses will substantially expand markets and investment opportunities.

The country cases show that productivity and profitability of Artemia aquaculture favorably compare with traditional salt production, providing new income and livelihoods for people living in salt regions, as separate business activities or integrated with salt production. The value chains for Artemia aquaculture products, from input provision and production to processing and marketing all provide business and employment opportunities.

A key factor for success is access to markets. The 'traditional' markets in aquaculture hatcheries can and will expand, but the greatest opportunities and impact will come from Artemia applications in animal feeds and human nutrition. The value chain studies provide insights into needs and opportunities for investment, in sustaining and future growth within existing countries and beyond.

The case studies identify important opportunities for investment that include working capital and infrastructure for farm and storage improvements, training and extension activities, product diversification, and post-harvest and market product development, including novel aquafeed ingredients and human food applications.

The case studies also provide examples of four systems or business cases with potential for wider application and scaling, including (i) Integrated Artemia-Shrimp Farming (Viet Nam Model); (ii) Solar Saltworks-Artemia Integration (China Model); (iii) Artemia Biomass for Aquafeed and Livestock Feed (Thailand Model); and (iv) Smallholder Artemia Pond Culture (Bangladesh Model). The potential scalability of these models is assessed in countries in Africa, Latin America, Asia, and the Middle East, and potential priority investments identified. The assessment shows significant opportunities for scaling of the models globally in hypersaline ecosystems, provided the market, regulatory, and research environment is in place.

The next steps will involve feedback on this draft report and preparation of a comprehensive investment synthesis and strategy to progress the priorities and opportunities for Artemia.

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ANNEXES

Annex 1. List of Stakeholders Interviewed

#	Region	Country	Organization	Name	Title	Date of Interview	Gender	Sector
1	Asia	Thailand	Banchong Farm	Banchong Nissagavanich	Owner	January 22, 2025	Male	Shrimp hatchery, Artemia biomass
2	Asia	Thailand	Suntri Farm	Tanan Sanggontanagit	Owner	January 29, 2025	Male	Artemia biomass
3	Asia	Viet Nam	Vinh Nga Company	Thai Thi My Nga	Director	February 12, 2025	Female	Cyst processor, trading
4	Asia	Viet Nam	Baclieu-Vinhchau Artemia Cooperative	Cao Thanh Van	Chairman	February 12, 2025	Male	Cyst production, processor, trading
5	Asia	Viet Nam	Baclieu Farm	Danh Xin	Owner	February 12, 2025	Male	Cyst production
6	Asia	Viet Nam	Vinhchau Farm	Huynh Ke	Owner	February 12, 2025	Male	Cyst production
7	Asia	China	Artemia Association of China	Gao Song	Vice Chairman	January 22–23, 2025 February 17, 2025	Female	Industry association
8	Asia	China	Artemia Association of China	Zhang Bo	Secretary in General	February 17, 2025	Male	Industry association
9	Asia	China	Tianjin INVE Aquaculture Co., Ltd.	Wang Jing	Sales Assistant	February 18, 2025	Female	Processor trader
10	Asia	China	Bohai Aqua Co., Ltd.	Zhang Rongqi	Artemia Production Manager	January 26–27, 2025	Male	Farming (commercial) processor
11	Asia	China	Bohai Aqua Co., Ltd.	Li Jinchen	General Manager	February 18, 2025	Male	Farming (commercial) processor
12	Asia	Bangladesh	WorldFish	Muhammad Meezanur Rahman	Technical Lead, Artemia4Bangladesh	February 17, 2025	Male	Aquaculture
13	Asia	Bangladesh	WorldFish	Main Uddin Ahmad	Managing Director, MKA SPF Hatchery	February 25, 2025	Male	Shrimp hatchery
14	Asia	Bangladesh	WorldFish	Al Shahriar	Research Assistant, WorldFish	February 24, 2025	Male	Aquaculture

#	Region	Country	Organization	Name	Title	Date of Interview	Gender	Sector
15	Asia	Bangladesh	WorldFish	Azharul Islam Shabuj	Research Assistant, WorldFish	February 24, 2025	Male	Aquaculture
16	Africa	Kenya	KMFRI - Mombasa	Joncy Luyesi	Principal Laboratory Technician	February 26, 2025	Female	Mariculture
17	Africa	Kenya	KMFRI - Shimoni	Dr. Anthony Nzioka	Senior Research Scientist and Assistant Director, Mariculture	February 26, 2025	Male	Mariculture
18	Africa	Kenya	Dan Aquatics	Dan Odiwuor	Proprietor	February 27, 2025	Male	Ornamental fish hatchery
19	Africa	Kenya	Pwani Fish Farm and Hatchery	Paul Murage	Proprietor	February 27, 2025	Male	Freshwater fish hatchery
20	Africa	Kenya	Crab Alive Fish Farm	Justin Aniere	Farm's Chief Executive Officer	March 18, 2025	Male	Mud crab hatchery
21	Africa	Kenya	Private farmer	William Mangale	Proprietor	March 18, 2025	Male	Artemia farmer
22	Africa	Kenya	Private farmer	Joseph Guyo	Proprietor	March 18, 2025	Male	Artemia farmer
23	Africa	Kenya	Private farmer	John Mtawali	Proprietor	March 18, 2025	Male	Artemia farmer
24	Africa	Kenya	Private farmer	William Ndurya	Proprietor	March 18, 2025	Male	Artemia farmer
25	Africa	Kenya	Private farmer	Swaleh Abedi	Proprietor	March 18, 2025	Male	Artemia farmer
26	Africa	Kenya	Kadzuhoni Mangrove Conservation Group	Harrison Mwayele	Group chairperson	March 18, 2025	Male	Artemia farmers group

Annex 2. Investment Cases in Africa

Below are concise profiles of priority countries, highlighting their saline ecosystems, relevant industries, and market indicators for Artemia farming potential.

Botswana

Inland Salt Pans, Livestock Feed Potential, and Alternative Protein Opportunity

- **Appropriate model for scaling:** For Botswana, the China/GSL model is the most applicable, focusing on harvesting Artemia from large natural salt pans and managing those wild stocks. Botswana's context—huge seasonal salt lakes with no existing aquaculture industry—means Artemia would be gathered in extensive systems rather than farmed in ponds by smallholders. While a Bangladesh-style community model is less relevant (few artisanal salt farmers operate in Makgadikgadi), there is scope for local involvement via cooperatives of indigenous communities (for example, around Nata Sanctuary) to participate in the harvest. Overall, scaling in Botswana would revolve around natural Artemia resource management rather than intensive farming—aligning with the Chinese model of state or private company-run exploitation of Artemia from large saline lakes.
- **Saline geography:** Botswana's primary Artemia habitat is the Makgadikgadi Pans, an immense complex (~30,000 km^2) of shallow hypersaline flats in the Kalahari Desert. Within Makgadikgadi, the largest basins are Sua Pan (Sowa) and Ntwetwe Pan. These pans fill with water during the rainy season (December–April) and evaporate in the dry season, creating brine conditions ideal for Artemia. Indeed, flamingos breed there by feeding on algae and brine shrimp, whose cysts lie dormant in the dry mud. Other saline locales include smaller pans such as Nxai Pan (seasonal, adjacent to Makgadikgadi) and perhaps portions of the Okavango Delta's salt islands (though those are minor). Additionally, Botswana's only commercial salt production facility at Sua Pan (BotAsh [Botswana Ash] mine) maintains artificial evaporation ponds for soda ash extraction (earthobservatory.nasa.gov).
- **Salt industry:** Botswana's salt industry is relatively small but notable due to BotAsh operation at Sua Pan, which produces soda ash (~300,000 MT/year) and salt as a by-product. The Walvis Bay export route allows Botswana to ship soda ash and salt regionally. Other salt production in Botswana is traditional and limited—local communities occasionally collect salt crusts from pans for livestock and domestic use. The company could treat Artemia cyst harvesting as a secondary revenue stream alongside soda ash, much as some Asian saltworks do. Historically, Makgadikgadi was known to produce salt exploited by local society (Matshetshe 2001), indicating local familiarity with harvesting from these pans—that cultural knowledge could extend to Artemia cyst collection with appropriate guidance.
- **Aquaculture industry:** Botswana has a very limited aquaculture sector. Being landlocked, there is no marine aquaculture; freshwater fish farming (tilapia, catfish) exists at a small scale, primarily in inland ponds and a few reservoir cage operations. Therefore, Artemia farming in Botswana would not be driven by local aquaculture needs but by export markets and possibly supporting aquaculture in neighboring countries. (For instance, South Africa has some aquaculture hatcheries that import Artemia—or the largest tilapia feed factory is in neighboring Zambia.)
- **Aquafeed and livestock feed markets:** With virtually no domestic aquafeed manufacturing, any Artemia biomass in Botswana would likely target livestock or niche markets. Botswana's cattle industry is significant (beef exports), but cattle feeds rely on grass and supplement blocks. However, the poultry sector is growing, and high-protein feed ingredients are valued. Dried Artemia biomass (50–60 percent protein) could be tested in poultry or pig starter diets as a protein and omega-3 source.
- **Consumption and markets:** Botswana's population traditionally relies on livestock (beef and goat) and some freshwater fish; per capita fish consumption is very low. Artemia has no role in direct human nutrition here—it is not consumed by people, and

there is no historical precedent of using brine shrimp as food. The greater Makgadikgadi ecosystem does support humans indirectly (for example, salt and birdlife), but brine shrimp were only valued as flamingo fodder until now. If Artemia were harvested, a remote possibility is using them as a protein supplement in humanitarian food blends (given Botswana's efforts to address malnutrition in some communities), but significant cultural and processing hurdles exist.

- **Regulatory and research support:** Botswana has robust environmental and wildlife conservation regulations, which would extend to Makgadikgadi Pan management. Any Artemia harvesting would likely fall under the Department of Wildlife and National Parks (since Makgadikgadi includes wildlife sanctuaries) or the mining commission (if considered a mineral/salt resource). There is currently no Artemia-specific policy, but lessons can be drawn from Botswana's management of salt and soda ash extraction, which is tightly controlled. Botswana is a signatory to Ramsar Convention (the Nata Delta is a Ramsar site), implying any commercial use of brine shrimp must ensure no harm to wetland ecology. On the positive side, Botswana's government is generally supportive of sustainable utilization of natural resources (for example, community-based natural resource management for wildlife). If Artemia harvesting can be shown to benefit local communities without harming flamingos, it could earn policy support as a form of sustainable blue economy in an inland context.
- **Opportunities:** Botswana's Artemia resources present a chance to diversify its economy. The global Artemia cyst market is lucrative (valued ~US$55–95 million annually)—even capturing a small share could bring significant revenue. Makgadikgadi's Artemia cysts, if harvested sustainably, could position Botswana as Africa's leading Artemia exporter, given the scale (the pans could rival midsize producers). This would create seasonal employment in remote rural areas such as Boteti and Nata: Locals could be hired for cyst collection and processing over several weeks each year when water recedes—similar to how fishermen around the Aral Sea shifted to Artemia harvesting as an income (dialogue.earth). There is also potential for regional trade: Neighbors with developing aquaculture (Namibia, South Africa, and Zambia) might prefer to buy cysts from Botswana (lower shipping costs and regional integration) than import from outside Africa. From a conservation perspective, involving local people in Artemia management gives them a stake in preserving the salt pan ecosystem (rather than, say, seeing it drained or disrupted by other industries). Lastly, there is an opportunity for branding and ecotourism: Botswana could highlight that its Artemia is harvested in a wildlife-friendly manner from one of the world's natural wonders, complementing the tourism narrative of the great flamingo migrations.
- **Constraints:** Significant constraints exist for Botswana. Environmental sensitivity is paramount—Makgadikgadi is an important bird area; overharvesting Artemia cysts could starve flamingo chicks and other species that rely on brine shrimp blooms. Another challenge is the ephemeral nature of the resource: Rainfall variation may cause boom-bust cycles in Artemia production. In drought years, the pans might not fill enough to sustain large Artemia populations; in very wet years, water might linger and introduce predators that reduce Artemia.

Egypt

Massive Aquaculture, Top Salt Producer, and Some Mariculture

- **Appropriate model for scaling:** Viet Nam + China models - Large-scale Artemia cyst production capabilities can support extensive marine aquaculture operations.
- **Saline geography:** Egypt offers extensive saline environments: from coastal solar ponds along the Mediterranean and Red Sea, to inland lakes. Key sites include the North Coast lakes (Maryut, Edku, and Manzala)—large brackish lagoons (though not hypersaline)—the Siwa Oasis salt lakes in the Western Desert (high salinity due to evaporation in a closed basin), and man-made saltworks in Sinai and around Alexandria. Being the largest salt producer in Africa (~2.88 million tons in 2019), Egypt has many evaporation pond complexes. For example, saltworks at Port Said and in the Red Sea governorate yield huge quantities of salt and host hypersaline conditions ideal for Artemia. Some research indicates Artemia presence in certain Egyptian salt lakes historically. With hot dry summers, Egypt can support multiple cycles of Artemia production in a year if water management is controlled.
- **Salt industry:** Egypt's salt industry is vast and mature. Producing nearly 3 million tons/year, it supplies domestic needs (food, chemical, industrial) and exports. There are dozens of salt companies: major operations in the northern lakes and desert depressions. The industry value is significant (likely US$100+ million). Thousands of workers are employed across mining, evaporation, and processing. Given the scale, even a fraction of pond area dedicated to Artemia farming (or dual use) could yield large volumes of cysts and biomass. Some Egyptian saltworks already produce Artemia from some trials run in the 1990s (El Nasr Artemia); harnessing it deliberately is the opportunity.
- **Aquaculture and feed:** Egypt is Africa's aquaculture giant—~1.6–2.0 million tons of farmed fish per year (over 60 percent of all farmed fish on the continent), primarily Nile tilapia, carp, and mullet, grown in the Nile Delta region. It accounts for ~85 percent of Egypt's fish supply. While most of this is freshwater fish not requiring Artemia, Egypt has begun expanding into marine aquaculture: There are marine fish farms (sea bass, bream) and shrimp farms under development. Notably, a megaproject in the Suez/Sinai aims to produce *shrimp* (targeting 6,000 tons shrimp and 13,800 tons fish per year in one new complex). In 2020, Egypt's farmed shrimp output was ~2,100 tons (bluelifehub.com)—small but growing rapidly from virtually nothing. These marine hatcheries *need Artemia cysts*. Additionally, Egypt has numerous ornamental fish breeders and research centers that use Artemia. The **aquafeed industry** in Egypt is huge (producing hundreds of thousands of tons of fish feed annually). Integration of Artemia meal into feed is less likely given fishmeal alternatives but not impossible for specialty broodstock diets.
- **Consumption and market:** Egyptians eat ~20+ kg of fish per capita, with tilapia being a common affordable protein. Shrimp is a luxury food; a lot of wild catch shrimp is exported for higher prices, and some is imported for the local high-end market. The large aquaculture production is aimed at maintaining food security—keeping fish prices low for the populace. Artemia cysts for hatcheries are entirely imported (Egypt likely imports dozens of tons of cysts annually, given the scale of hatchery operations for tilapia, carp which sometimes use Artemia for larvae, marine fish, and shrimp). A domestic Artemia source could find a ready market, from government-run hatcheries to private ones. Malnutrition in Egypt is relatively low in terms of protein-calorie (though some micronutrient issues persist); Artemia's role would be indirect via more robust aquaculture output (which improves nutritional availability). Government support for aquaculture R&D is strong, so an Artemia venture might receive facilitation.
- **Regulatory and research support:** Egypt has both native (*A. salina*) and introduced (*A. franciscana*) Artemia, with some saltworks naturally hosting Artemia. The General Authority for Fish Resources Development (GAFRD) supports Artemia research, and past projects analyzed cyst quality. Environmental laws regulate species introductions, especially after *A. franciscana* spread into salt ponds in the 1990s.

- **Opportunities:** Tapping into Egypt's massive aquaculture industry is the big prize. For an investor, producing Artemia in Egypt could immediately serve the largest concentration of fish hatcheries in Africa, reducing their reliance on imported cysts (which can be volatile in supply). Moreover, any surplus could be exported to other Middle East and North Africa countries. The extensive saltworks, such as those in Sinai or along the Mediterranean coast, could double as Artemia farms with minor modifications—offering efficient scaling.
- **Constraints:** Ensuring Artemia cyst quality to meet the expectations of Egypt's advanced hatcheries (some operated with international partners) is crucial; poor quality would not be accepted. Also, competition from established global Artemia suppliers (US, China, and so on) means the venture must be cost-competitive or provide fresher products (such as live Artemia or biomass) that imports cannot. There may be regulatory hurdles in using saltworks that are government run or military owned for a new purpose; partnerships would be key. Lastly, environmental considerations in Egypt's northern lakes (which are also natural fisheries habitats) mean Artemia farming should avoid disrupting local ecosystems or artisanal fisheries.

Ethiopia

High-Salinity Lakes, Nascent Aquaculture, and Massive Poultry

- **Appropriate model for scaling:** Bangladesh model - Small-scale Artemia production in salt lakes can provide biomass for local feed and aquaculture applications.
- **Saline geography:** Ethiopia is endowed with some of the most extreme hypersaline sites on Earth in the Afar Depression. Lake Afdera (Afrera) in Afar is a saline lake from which significant salt is extracted; salinity is very high and stable (with an inflow of hot springs). The Afar region also includes the expansive Danakil Salt Flats (Dallol area)—although salt is mined here from solid crusts rather than evaporated from ponds. Nonetheless, at the edges of these flats and in man-made pools, brine water exists that could support Artemia. Additionally, Ethiopia's Rift Valley has alkaline lakes (Shala, Abijata, and Chitu) that support flamingos—one study noted brine shrimp surviving in Lake Chitu's diluted waters (Ogello et al. 2014), indicating native or introduced Artemia presence. Overall, Ethiopia has ample *salt water* but often in remote, hot locations. Artemia ponds could be established adjacent to existing salt operations (to share brine resources).
- **Salt industry:** Ethiopia has a historic and large salt production. Lake Afdera produces 70–80 percent of Ethiopia's salt (Yusufali et al. 2024). Modern estimates suggest around **1.3 million tons of salt are extracted annually** by about 750 registered miners in coordinated efforts. If so, Ethiopia rivals Egypt in salt output. This includes traditional camel caravan mining and newer mechanized plants. Salt is a vital commodity domestically, especially in the arid saline part of the country (and for export to East African neighbors). Market value is relatively lower (raw salt is cheap, but volume is high). If Artemia farming is coupled with these salt operations, it could utilize existing brine and labor during periods when salt harvesting is paused (for instance, during the hottest months when salt mining might slow due to extreme heat, Artemia could be growing).
- **Aquaculture and feed:** Ethiopia's aquaculture is very limited currently—a few hundred tons of mostly Nile tilapia and African catfish grown in ponds or lakes (pilot projects). Being landlocked, there is no marine aquaculture. However, Ethiopia has a large population with protein needs and many water bodies where fish farming could expand. For now, aquaculture feed and hatchery infrastructure are minimal. The near-term market for Artemia inside Ethiopia would therefore be small (some research centers or a handful of fish hatcheries might use it). **Terrestrial feed:** Ethiopia has a huge livestock sector, but feeds are primarily agro-industrial by-products; incorporating Artemia meal might not be economically sensible except perhaps for high-value sectors (such as poultry breeders or dairy calves) if priced competitively with fishmeal.
- **Consumption and market:** Fish consumption in Ethiopia is among the lowest in Africa (≤2 kg per capita), partly due to cultural preferences and limited supply. Malnutrition is a severe issue in many regions (including Afar, where pastoralists struggle with food security). Interestingly, Artemia biomass might have a humanitarian angle here: For example, it could potentially be processed into a protein supplement for undernourished populations in Afar if proven safe and acceptable. But this would require significant R&D in food processing and acceptance. More directly, any Artemia produced would likely be aimed at *export* (generating foreign exchange) or sold to other African countries that have aquaculture (for example, Kenya and Egypt). The global Artemia market would readily buy quality cysts, so Ethiopian production could find buyers abroad while local demand catches up.
- **Regulatory and research support:** Ethiopia's hypersaline lakes (for example, Lake Afdera) could support Artemia, but no research or documentation exists confirming its presence. Aquaculture policies focus on freshwater fish, and Artemia is not regulated. If Artemia is naturally found, future research could determine its farming potential.
- **Opportunities:** Ethiopia's Afar region could host large-scale Artemia ponds, essentially turning some of the salt flats into Artemia cultivation during part of the year. The intense sun and heat could produce cysts quickly. An investor could collaborate with existing salt companies (some are setting up processing plants) (thereporterethiopia.com) to add Artemia as a side business. With Ethiopia's push for industrialization, an Artemia export business aligns with adding value to natural resources.
- **Constraints:** The remote, extremely hot environment of Afar means operations are challenging (worker conditions and maintaining equipment). Also, without local aquaculture use, the business depends entirely on export markets which can fluctuate. Logistically, getting the product out of Afar (trucking to Djibouti port, for instance) adds cost. Regulatory support might be needed to allow a foreign or private entity to use salt lake water for Artemia (these resources are often tightly controlled for salt and mining rights). Moreover, political instability or conflict (as seen in recent years in Ethiopia) could pose risks to operations in these regions.

Ghana

Coastal Salt Producer, Strong Tilapia, and Growing Catfish Industry

- **Appropriate model for scaling:** Bangladesh + Thailand + Viet Nam models - Promoting biomass production for aquaculture hatcheries and potential cyst processing for local and regional use.
- **Saline geography:** Coastal Ghana has extensive lagoons and salt pans, especially in the Greater Accra, Volta, and Central regions. The Songor Lagoon (Ada) and Keta Lagoon are major sites of solar salt extraction. Additionally, smaller saltworks exist near towns such as Elmina and in the western region. These coastal flats have high salinity during the dry season and are conducive to Artemia cultivation (brine shrimp often colonize salt pans naturally via bird vectors). Ghana's climate (distinct wet and dry seasons) allows salt and potentially Artemia production in the dry months. Inland Ghana does not have notable salt lakes (most inland waters are fresh).
- **Salt industry:** Ghana is one of West Africa's largest salt producers at 250,000–300,000 tons/year. It has the potential to produce up to 2.2 million tons with further investment. The industry includes thousands of artisanal salt miners and a few large concessions (for example, modern salt works under Electrochem Ghana Ltd at Songor, aiming to massively scale output) (miif.gov.gh; electrochemghana.com). Annual salt sector revenues are estimated around US$12 million for ~80,000 tons (older figures), implying current 250,000 tons is worth ~US$30–50 million. Major sites such as Songor involve hundreds of local workers. These saltworks present an excellent opportunity to integrate Artemia farming, as they already manage brine in sequential ponds—conditions where Artemia could be introduced with little disruption to salt yields.
- **Aquaculture and feed:** Ghana's aquaculture has grown rapidly. Production rose from ~25,000 tons in the 2010s to ~64,000 tons in 2020 and 132,000 tons in 2022, recovering after some setbacks with fish diseases and supply disruptions during the COVID-19 pandemic. This makes Ghana among the top producers in Africa (tilapia in floating cages on Lake Volta account for the bulk, with some catfish farming). There are numerous fish farmers (from large companies to smallholders) and a robust network of hatcheries producing fingerlings—all potential clients for Artemia (for larval rearing, especially if Ghana diversifies into new species). **Aquafeed:** Ghana's feed milling capacity has expanded to ~100,000 tons/year). Local feed production and import substitution are a priority, meaning interest in novel ingredients such as Artemia meal could be high if cost-effective. **Terrestrial feed:** Ghana has a sizable poultry industry; any surplus Artemia biomass could be tested in that market as well.
- **Consumption and market:** Fish is critical in the Ghanaian diet, contributing a significant portion of animal protein (Ghana's per capita fish consumption hovered ~20–25 kg historically). There is unmet demand—Ghana imports fish to cover a deficit of several hundred thousand tons. Shrimp and crustaceans are not staples, but there is niche demand (hotels and urban consumers) often met by imports or local marine catch. Aquaculture focus is tilapia for local markets. Malnutrition in coastal salt-producing areas is less about caloric intake and more about micronutrients (there have been iodine-deficiency issues historically, hence salt iodization programs). Artemia farming here would be more about economic empowerment and supporting aquaculture growth than direct nutrition.
- **Regulatory and research support:** An FAO-backed aquaculture framework for Ghana suggested that some salt ponds (at salinities ~100–110 ppt) "could be stocked with cysts of the brine shrimp" to produce Artemia alongside salt (fao.org). The idea is that cheap local Artemia would greatly benefit aquaculture as live feed. Ghana's large areas of coastal salt works were identified as potential dual-use sites for fish and brine shrimp culture.
- **Opportunities:** Ghana's combination of *salt infrastructure and aquaculture demand* make it highly attractive for Artemia investment. For instance, salt flats in Ada could be inoculated with Artemia, yielding cysts that local tilapia hatcheries (and the wider West African region) currently import. The government's push to diversify exports and its openness to aquaculture innovation are positive signs.
- **Constraints:** The salt industry is being modernized; integrating Artemia would require convincing salt companies that it would not contaminate salt quality or reduce output (Artemia actually can improve saltworks ecology by consuming organic matter resulting in crystallization of higher salt quality). Competition from Senegal (another West African Artemia source if developed) could arise. Additionally, processing and storing Artemia cysts in the humid tropical climate will need care to maintain quality for export.

Kenya

Coastal Salterns, Soda Lakes, and Expanding Aquaculture

- **Appropriate model for scaling:** Bangladesh + Thailand + Viet Nam models - Utilizing artisanal Artemia farming in seasonal salt pans and biomass production to meet local hatchery demand.
- **Saline geography:** Kenya has coastal solar saltworks mainly in the Malindi–Magarini area (Kenya's north coast). These saltworks (for example, Kurawa, Kensalt) cover large flats where seawater is evaporated—ideal for Artemia introduction. In fact, *Artemia franciscana* was introduced in Kenyan saltworks in the 1980s and has established self-sustaining populations and resulted in improved salt quality. Additionally, Kenya's Rift Valley has alkaline soda lakes (Nakuru, Bogoria, and Magadi) known for supporting brine organisms. Lake Magadi's salinity can support brine shrimp or related species, though extreme alkalinity may pose challenges. Overall, Kenya offers both man-made and natural hypersaline environments suitable for Artemia farming trials.
- **Salt industry:** Produces around 24,000 tons of salt annually (ranked seventy-eighth globally). Major operations are private companies along the coast; artisanal salt extraction is minor. There are a handful of medium-scale saltworks employing local communities. The industry value is a few million US dollars and could expand. The presence of established salt companies means potential partners for Artemia integration (co-producing Artemia in evaporation ponds).
- **Aquaculture and feed:** Kenya's aquaculture production is modest but growing—roughly 18,000–24,000 tons of farmed fish per year in recent times (mostly tilapia and catfish). After a surge in the 2010s due to government programs, production stabilized around 15,000–20,000 tons. The number of fish farmers is in the thousands (largely small pond farmers inland, plus some cage farming in Lake Victoria). There are specialized aquaculture hatcheries for tilapia, catfish, and ornamentals, some of which already use Artemia cysts. Kenya also has a few marine hatcheries (for shrimp, crabs, and marine fish) operated by research institutes and private investors. The aquafeed market is small but there are local feed mills (one mill capacity ~35,000 tons feed/year, partly for fish feed). The terrestrial feed industry is sizable (Kenya has a strong poultry/dairy sector), so if Artemia biomass were abundant, it could be included in high-protein feed formulations.
- **Consumption and market:** Per capita fish consumption ~4–6 kg nationally (higher in communities around Lake Victoria and coast). Fish makes up about 20 percent of animal protein for those communities. Kenya imports a lot of seafood (including ~US$20 million+ of frozen fish annually) to meet demand, so boosting local aquaculture is a priority. Shrimp consumption is relatively small; any farmed shrimp is negligible, and wild-caught prawns mostly serve upscale markets. However, ornamental fish export is notable—Kenya exports aquarium fish and already uses Artemia to improve breeding of high-value species. Malnutrition is an issue in arid inland counties (though not directly tied to salt sites). Along the coast, salt-farming communities have limited alternative livelihoods, so income from Artemia could improve living standards and nutrition.
- **Regulatory and research support:** The government, through KMFRI and universities, has actively supported Artemia research and utilization. In fact, Kenya was one of the first African countries to intentionally introduce Artemia for aquaculture purposes. Kenya's Fisheries Management and Development Act (2016) includes strict provisions against unapproved species introductions. It is illegal to introduce any exotic aquatic species into Kenyan waters without permission. Today, Kenya's approach is to manage the established *A. franciscana* in its salt ponds rather than introduce new strains. Artemia is recognized for its dual value: It improves salt pond water quality and yield (by grazing algae) and provides a high-value aquaculture feed product.
- **Opportunities:** Kenya is a prime candidate for Artemia farming given that Artemia already exists in its saltworks. Investors could collaborate with salt companies to harvest Artemia cysts as a by-product, supplying East African hatcheries (Kenya, Tanzania, and Uganda) that currently rely on imports. Local research expertise (for example, at KMFRI) is available to guide projects.
- **Constraints:** Coastal land use and environmental regulations may require careful management to avoid conflicts (for example, with bird conservation at Rift lakes or mangrove areas near saltworks). Scaling up will need demonstration of profitability to convince salt producers to divert effort into Artemia. Also, competition from imported cysts (which are cheaper due to scale) means Kenyan Artemia must target niche high-quality markets (for example, crabs) or reduce costs through volume.

Madagascar

African Shrimp Powerhouse, Vast Saline Wetlands, Artemia Market Potential

- **Appropriate model for scaling:** Madagascar could pursue a Viet Nam-style model for Artemia farming, fostering seasonal cyst production by coastal salt farmers, while also leveraging its established shrimp industry for eventual biomass use. Like Viet Nam's Mekong Delta, Madagascar's west coast has a defined dry season suitable for Artemia in salt ponds, and local farming communities (*tannés* salt flats users) could integrate Artemia as an off-season crop. The country's aquaculture is dominated by large industrial shrimp farms, but those enterprises import all their Artemia needs (globalseafood.org).
- **Saline geography:** Madagascar offers diverse saline habitats. On the west coast, extensive salt flats known as *tannés* lie behind mangroves (for example, around Mahajamba and Morondava). These flats, used for salt production, flood seasonally and could support Artemia during evaporative cycles. Southern Madagascar hosts many small salt pans and coastal lagoons near Toliara, where 100+ small producers operate (Randremana et al. 2019). Inland, notable hypersaline lakes include Lake Tsimanampetsotsa in the southwest, a soda lake with flamingos—parthenogenetic Artemia and *Artemia franciscana* have indeed been found in Madagascar. While such a lake is protected, it confirms the suitability of Madagascar's climate for Artemia. Additionally, large-scale saltworks in the north (likely near Diego Suarez) produce nearly half of the country's salt; its evaporation ponds present ready-made Artemia habitat if managed properly.
- **Salt industry:** Salt production in Madagascar is sufficient for domestic needs and modest export, totaling a few hundred thousand tons per year. There is one major salt producer in the north covering 40–50 percent of supply, ~8 medium-scale producers in the midwest (30–35 percent), and over 100 small producers in the south (20–25 percent). This structure means both large, mechanized salt farms and rudimentary pans coexist. The big northern saltworks (likely near Bekily or Diego) could integrate Artemia at scale, much as Chinese salt operations do—using ponds at intermediate salinity to culture brine shrimp. Meanwhile, the legion of small southern producers, often working seasonally, could adopt low-tech Artemia pond methods). Madagascar exported about US$3.95 million in salt in 2022, mainly to regional markets (the Seychelles, Mauritius, and the Comoros), indicating active production and trade.
- **Aquaculture industry:** Madagascar has one of Africa's most developed aquaculture sectors, centered on shrimp farming. By the early 2000s, four large farms (Aqualma, and so on) operated ~1,660 ha of ponds, producing 5,500+ MT of *P. monodon* shrimp annually. Production may have peaked around 2008 (~7,000 MT) before disease (White Spot Syndrome Virus [WSSV] in 2012) caused setbacks. All farms have hatcheries (collectively hatching 100–300 million postlarvae/year) and broodstock facilities, which rely on imported Artemia cysts and formulated feeds. Besides shrimp, Madagascar cultivates some sea cucumbers, seaweed, and tilapia (freshwater) in smaller volumes. The shrimp hatcheries are heavy Artemia users, given *P. monodon*'s larval feeding needs—traditionally sourcing high-quality cysts from GSL or Asia. There is no local Artemia production currently to supply these hatcheries; any shortfall in imports could critically affect them.
- **Aquafeed and livestock feed markets:** The country's aquafeed production is limited—as of 2001, all shrimp feed was imported (from Asia and the Seychelles). A feed mill was planned in 2002, but local feed manufacturing remains small scale or nonexistent for shrimp. For fish such as tilapia, some small feed mills exist, or on-farm feed mixing occurs. Artemia biomass could thus be a valuable input if local feed production develops. For example, a future shrimp or marine fish feed plant could incorporate dried Artemia biomass as an attractant or nutritional booster. In the interim, Artemia biomass might be sold wet or frozen to hatcheries (for nursery-phase feeding of fish fry or as an enrichment carrier). **Livestock feed:** Use of Artemia in Madagascar is uncharted—poultry and zebu cattle are more common, and they typically use agricultural by-products.

- **Consumption and market:** Malagasy cuisine features a variety of seafood—fish is a staple in coastal regions, and shrimp/prawns are consumed locally though much of the farmed shrimp is exported for foreign revenue. There is no direct human use of Artemia in Madagascar; the local diet does include small shrimps from estuaries or lakes (often dried for flavoring dishes), but brine shrimp from salt ponds have not historically been harvested for food. If Artemia were produced in quantity, one speculative use could be as an animal protein supplement to address malnutrition (Artemia are rich in protein and micronutrients), perhaps ground into flour and added to foods—though acceptability would need study.
- **Regulatory and research support:** Madagascar's government has historically supported aquaculture development (for example, through the 1998–2001 Master Plan for shrimp farming and formation of the Aquaculture and Fisheries Ministry). While Artemia-specific policy is absent, broader frameworks (such as the *Agence Malgache d'Aquaculture*) could accommodate Artemia projects. Biosecurity laws after the 2012 WSSV outbreak likely apply to live feed too, so any Artemia introductions would be vetted to avoid pathogen transfer.
- **Opportunities:** Madagascar stands to gain economically and ecologically from Artemia farming. With its large shrimp farming sector (albeit just two main farms), producing Artemia domestically could save foreign currency on cyst imports and reduce the risk of supply disruptions. It could also improve hatchery output by providing ultra-fresh, high-hatch Artemia produced nearby. Artemia production can also integrate with Madagascar's conservation efforts: By managing salt ponds for Artemia, those habitats might be maintained in ways beneficial to waterbirds (flamingos feed on Artemia, so a managed harvest could ensure enough food remains for them while still collecting surplus cysts). There is an opportunity to brand Malagasy Artemia cysts, leveraging the country's biodiversity image (for example, natural Artemia from the Indian Ocean). Moreover, training and employing local women and youth in Artemia harvesting and processing could have social benefits. If the Artemia enterprise grows, Madagascar could even explore Artemia-based products (chitin from shells, beta-carotene extracts, and so on) for pharmaceuticals and nutraceuticals, diversifying its blue bioeconomy.
- **Constraints:** Several challenges could impede Artemia farming in Madagascar. Climate and hydrology pose a major constraint: The country's coasts have pronounced wet seasons (often cyclones) that can dilute or flush out salt ponds, making year-round Artemia culture difficult. Production will be seasonal and possibly inconsistent across years. Another issue is the dominance of large shrimp corporations—while they have the expertise and need for Artemia, their focus is on core shrimp business; persuading them to invest in Artemia production or to buy from local small producers will require clear economic incentive. Coordination between industrial and community players may be lacking. On the smallholder side, technical know-how is minimal—extensive training and extension services must be set up for illiterate or semiskilled salt workers to master Artemia cultivation and cyst handling. Economic viability is sensitive to global prices: If GSL harvests are high and prices drop, a nascent Malagasy Artemia industry could struggle to compete.

Mozambique

Emerging Mariculture, Expanding Aquaculture, Coastal Salt Ponds

- **Appropriate model for scaling:** Mozambique's Artemia farming is best suited to a Bangladesh-style model, leveraging small-scale salt farmers for dual production of salt and Artemia. Past pilot projects have already introduced Artemia in Mozambican salt ponds, though continuity was challenged by market issues (imb.umt.edu.my).
- **Saline geography:** Mozambique's extensive coastline (2,700 km) hosts numerous saline environments suitable for Artemia. Key sites include traditional solar salt pans in Maputo Province, central regions such as Sofala/Beira, and the north (Nampula and Cabo Delgado). These coastal evaporative ponds experience high salinities in the dry season, creating conditions for Artemia growth similar to other monsoonal regions. Inland, Mozambique has few major salt lakes; the focus is on coastal lagoons and salt flats. Notably, parthenogenetic Artemia have been reported at Mozambican saltworks (Kaiser et al. 2006).
- **Salt industry:** Salt production in Mozambique is an established cottage industry. The country was historically a salt exporter and today has 300+ producers clustered in Maputo, Nampula, and Cabo Delgado. Most operations are small, sun-dried pans, though a few larger works (for example, in Nacala-a-Velha) are expanding with modern processing (clubofmozambique.com). Annual output is modest but sufficient for domestic needs. Integrating Artemia would build on parallel production: Solar saltworks can yield Artemia as a by-product without hindering salt output. Past efforts, including a dedicated Artemia demonstration farm, showed gradual cyst production growth until an external shock (shrimp disease) disrupted demand. With salt sector revitalization (for example, iodization programs) and available infrastructure, these ponds can be repurposed or dual purposed for Artemia farming with minimal new investment.
- **Aquaculture industry:** Aquaculture in Mozambique remains in early stages, though the natural potential is high. A report prepared for the World Bank in 2002 shows the main focus has been on marine shrimp (*Penaeus monodon*) farming (Sadek et al. 2002), which saw one commercial farm (20 ha producing ~60 MT/year in the early 2000s) and planned expansions to ~900 ha. However, a WSSV outbreak in 2011 halted shrimp operations (for example, Aquapesca in Zambezia). Freshwater fish farming (tilapia, catfish) is small but growing, with total farmed seafood ~3,200 MT in 2021 (Akazawa et al. 2014). Hatchery capacity is limited—the lone shrimp hatchery historically imported Artemia cysts. Thus, current reliance on Artemia is low, but that reflects constrained aquaculture, not the lack of need.
- **Aquafeed and livestock feed markets:** Mozambique's aquafeed industry is nascent. Most fish/shrimp feeds have been imported or mixed on-farm due to limited local feed mills. Artemia biomass could find a role as a specialty feed ingredient: For instance, live or frozen Artemia can be used in marine finfish nurseries or as broodstock feed. The country's livestock sector (poultry and tilapia) could also trial Artemia meal as a protein supplement.
- **Consumption and market:** Seafood is an important protein source in Mozambique, with shrimp playing a role mainly as an export and luxury product. Locals in coastal areas consume fish routinely, but brine shrimp are not part of the human diet. There is no cultural precedent for eating Artemia (unlike some Asian cuisines that use small shrimp in pastes), and Artemia would likely contribute indirectly via improved aquaculture output. However, by supporting aquaculture, Artemia farming could bolster food security—for example, enabling more local shrimp/fish production for domestic consumption.
- **Regulatory and research support:** Mozambique has signaled support for aquaculture and related innovations. A draft Aquaculture Development Strategy and Aquaculture Act have been formulated since the 2000s. Biosecurity regulations were strengthened after the WSSV outbreak in shrimp farms, illustrating the government's responsiveness to aquaculture health issues (rr-africa.woah.org). While Artemia is not yet specifically addressed in policy, the government-run Aquaculture Research Center (CEPAQ) has been involved in Artemia trials.
- **Opportunities:** Integrating Artemia production in Mozambique diversifies income for salt producers and coastal communities—a form of climate-smart aquaculture that adds value without needing extra land. Regionally, Mozambique could become a supplier of Artemia cysts to other African countries where use is rising but local production is nil. Its Indian Ocean ports give access to Asian markets too, if quality and volumes become competitive. There is also synergy with the country's blue economy and food security goals: Locally produced Artemia can jump-start hatcheries for shrimp and fish.
- **Constraints:** Despite the promise, several challenges could constrain Artemia farming in Mozambique. A major issue is the volatility of aquaculture demand—the 2011 shrimp disease outbreak caused local Artemia use to collapse, stranding producers. Environmental factors are another concern: Mozambique's heavy summer rains and cyclone risks mean Artemia production will be seasonal and occasionally disrupted (monsoonal climates yield Artemia only in the dry season).

Namibia

Solar Saltworks, Untapped Artemia Resources, Regional Trade Gateway

- **Appropriate model for scaling:** Namibia is well positioned to adopt a China-style model for Artemia, incorporating production into its large commercial saltworks. The country already has extensive solar sea-salt facilities (the biggest in sub-Saharan Africa) run by companies that could integrate Artemia as a secondary crop.
- **Saline geography:** Namibia's coast is hyper arid with ideal conditions for solar evaporation. Key sites include the Walvis Bay Salt Works (near Walvis Bay Lagoon) covering thousands of hectares of ponds, the Swakopmund Saltworks, and smaller operations at Cape Cross and Lüderitz. These coastal pans are filled with seawater and sequentially concentrated, creating gradients where Artemia thrive in middle concentrations. Indeed, records confirm parthenogenetic Artemia populations at Namibian saltworks, meaning brine shrimp already live in some evaporation ponds naturally. Additionally, inland Etosha Pan in northern Namibia is a large salt depression that occasionally holds water—it could support Artemia in wet years (flamingos breed there too), though its unpredictability and location in a national park make it less feasible for exploitation. The climate (foggy but low rainfall) allows near-continuous evaporation, so unlike monsoonal areas, Namibian salt ponds can support year-round Artemia populations. Water temperatures are cooler (Benguela current influence), possibly favoring certain Artemia strains (likely parthenogenetic or *Artemia franciscana* introduced).
- **Salt industry:** Namibia is a major salt producer. Walvis Bay Salt Refiners is the largest solar sea-salt producer in Africa, covering ~3,500 ha and exporting 800,000–900,000 MT of salt per year via Walvis Bay port. Salt is one of Namibia's top export commodities by volume. The industry consists of a few large companies using modern methods: sea water pumped into concentrator ponds, moved through successive evaporation stages, then harvested as crystal salt. This setup is very amenable to Artemia integration—typically, Artemia can be introduced in the concentrator ponds where salinity is high enough to deter fish but not yet at gypsum saturation. Namibia's saltworks already exhibit the classic reddish ponds colored by halophilic algae and brine shrimp. Outside Walvis Bay, medium operations in Swakopmund and Sandwich Harbour produce table salt and industrial salt. These companies have the infrastructure (pumping, harvesting machinery, and storage) that could be partly repurposed to collect Artemia cysts during certain months. Because the salt industry is export focused and quality conscious, any Artemia venture would need to maintain salt purity. This is feasible as Artemia are usually harvested before final salt crystallization. An advantage is that Namibia's salt companies are experienced in international trade and quality certification, so adding an aquaculture feed product to their portfolio is within their capacity.
- **Aquaculture industry:** Namibia's aquaculture is modest and primarily marine shellfish. The main activity is oyster and mussel farming in Walvis Bay and Lüderitz, which collectively produce a few hundred tons. There have been trials with marine finfish (for example, dusky kob, abalone) and freshwater aquaculture (tilapia in northern Namibia), but scale remains small.
- **Aquafeed and livestock feed markets:** Namibia has a small aquafeed plant mainly for tilapia and a few feed mills for livestock. Artemia biomass could potentially be marketed as a specialty feed ingredient domestically: for example, as a broodstock feed for aquaculture or a live feed for ornamental fish breeders. The livestock sector (poultry) might experiment with Artemia meal if available. However, given Namibia's low population and limited livestock intensification compared to bigger markets, any such usage would be small-scale. A more likely scenario is exporting Artemia biomass (if produced in volume as a by-product of cyst harvesting) to South Africa, which has a bigger feed industry. Alternatively, converting excess Artemia into fish meal or pet food is possible—Artemia are highly nutritious, so they could be added to pet fish or reptile feeds. If Namibia were to focus on biomass production (adult brine shrimp), one local use could be in the bait industry (frozen brine shrimp as bait for line fishing or as feed at aquariums).
- **Consumption and markets:** Namibians have a moderate per capita seafood consumption (notably higher in coastal communities). They enjoy marine fish, oysters, crabs, and so on, but brine shrimp are not eaten. Given their tiny size, it is unlikely Artemia would be used for direct food except perhaps as a novelty ingredient (for example, protein powder or salted shrimp flavoring).

- **Regulatory and research support:** Namibia's governance and research capacity in fisheries is relatively strong (through the Ministry of Fisheries and Marine Resources and the National Marine Information and Research Center). While Artemia has not been a focus, Namibia did participate in the History of Artemia in Africa webinar (2022), indicating emerging interest. Legally, any new Artemia venture would need to comply with environmental regulations.
- **Opportunities:** Namibia has a golden opportunity to become a supplier of Artemia for the African region and beyond. By capitalizing on its existing salt infrastructure, it can produce Artemia at a lower incremental cost (the ponds and water supply are already there) and potentially high quality (pristine marine water yields clean product). This could reduce Africa's reliance on imported cysts, aligning with continental goals. For the salt companies, selling Artemia cysts (which can fetch tens of thousands of US dollars per ton for high grade) could significantly boost profits without needing additional land—a compelling business case. Namibia's strategic location on the Atlantic and well-developed port of Walvis Bay means it can ship products efficiently to Europe or the Americas (shorter transit than Asian suppliers to those markets). There is also an opportunity to integrate eco-friendly branding: Artemia produced using just sun, wind, and seawater in Namibia's deserts—a sustainable narrative that global aquaculture companies may find attractive. For local communities, although saltworks are mechanized, increased activity (such as Artemia harvesting and processing) could create new jobs, from seasonal harvesting teams to lab technicians for quality control.
- **Constraints:** Potential constraints for Namibia include environmental risks, market competition, and corporate priorities. Environmentally, while salt ponds are artificial, they border ecologically sensitive wetlands (Walvis Bay Lagoon is a Ramsar site for flamingos and shorebirds). Changes in pond management to maximize Artemia (for example, altering salinity regimes) must ensure that bird foraging habitat is not negatively affected.

Nigeria

Huge Aquaculture and Feed Market, Limited Salt Resources

- **Appropriate model for scaling:** Thailand + Bangladesh + Viet Nam models - Targeting biomass production to support the country's large catfish hatchery industry, with potential for cyst production.
- **Saline geography:** Nigeria has a vast coastline but, due to high rainfall in the south, it has few solar salt sites. There are some inland salt flats/springs in the arid areas of the north (for example, Ebonyi State's Uburu/Okposi salt lakes and Kano's saline wells) historically used for salt making. These are small-scale and seasonal. Coastal salt production is minor—Nigeria's humid coastal delta is not ideal for salt pans without expensive infrastructure. Thus, natural hypersaline environments are scarce. Any Artemia farming would likely need to be in engineered ponds (perhaps in the far north where evaporation is higher or integrated with any planned saltworks or aquaculture facilities).
- **Salt industry:** Africa's most populous nation *relies on imports* for salt. Nigeria imports in the order of 500,000–600,000 tons of salt annually (worth over NGN 155 billion in 2 years, ≈US$200 million), mainly from Brazil and Namibia. Local production is very limited—perhaps a few tens of thousands of tons from traditional methods in the north and small refineries. For example, Namibia exported ~13.93 million kg (13,930 tons) of salt to Nigeria in 2022, and other imports fill the rest. The number of traditional salt makers in Nigeria might be a few hundred (for example, rural women in Ebonyi still boil brine to make salt in small quantities or see traditional salt villages such as keana). Industrial salt makers are practically absent (though Dangote Group has at times indicated interest in local salt projects). In summary, Nigeria currently lacks the solar salt infrastructure that naturally supports Artemia cultivation.
- **Aquaculture and feed:** Nigeria is the second-largest aquaculture producer in Africa (~300,000 tons/year), dominated by freshwater catfish (which accounts for ~64 percent of Nigeria's fish farming) and tilapia (Manyise et al. 2024). There are thousands of fish farms, mostly small- to medium-scale ponds and tanks spread across the country, as well as some larger integrated operations. **Aquafeed** production has grown accordingly—Nigeria has numerous feed mills (some dedicated to fish feed, others producing multispecies feeds). Catfish are often fed commercial floating pellets; this feed industry likely produces well over 100,000 tons annually. Notably, Nigeria has even exported fish feed to neighboring countries. Nigeria's hundreds of catfish hatcheries have used Artemia nauplii to feed fry in the first weeks, as it greatly improves survival and growth. These hatcheries relied on imported Artemia cysts (often from the USA or Asia), supposedly importing around 100 tons. However, due to high prices and supply variability, there is no known importation of cysts or biomass today. That said, this represents a *large and immediate market* for any local Artemia cyst production: Even a fraction of Nigeria's ~300,000 ton aquaculture output corresponds to billions of larvae needing feed. Additionally, any future venture into marine aquaculture (Nigeria has been exploring shrimp farming and tilapia mariculture in brackish water) would further raise demand for Artemia. **Terrestrial feed:** Nigeria's animal feed market is one of the largest in Africa due to its poultry industry. Total formal feed output is several million tons (with poultry, fish, and pig sectors). Artemia biomass, if produced at scale, could be trialed as a protein-rich feed ingredient here more easily than anywhere else in Africa.
- **Consumption and market:** Nigerians consume a lot of fish in total (given population ~220 million), but per capita fish consumption is around 8–11 kg. Fish constitutes a vital protein especially in coastal and riverine communities. There is a significant fish supply gap, leading to over US$1 billion in seafood imports annually (including frozen fish). Shrimp and crustacean consumption is not mainstream, but Nigeria does have a notable wild shrimp fishery in the Niger Delta—these prawns are largely exported, while some shrimp is imported for restaurants. Malnutrition is prevalent in parts of Nigeria (especially the arid north and conflict-affected areas), but tying Artemia farming to food relief is indirect; more relevant is that boosting aquaculture (via Artemia supply) can improve food security.

- **Regulatory and research support:** Nigeria's fisheries and aquaculture policy emphasizes improving local feed resources and hatchery outputs, but it has not specifically targeted Artemia farming. Any initiative to introduce or farm Artemia would fall under Nigeria's general regulations on aquatic species and biosecurity. By law, the import or introduction of live aquatic organisms requires government permits and risk assessment (to prevent pests or diseases).
- **Opportunities:** Nigeria is a *prime market* for Artemia products. An investor could establish Artemia farms in high-evaporation pockets (perhaps using inland saline groundwater in the north or by creating evaporation ponds near coastal lagoons in the southwest) and be assured of local demand. Importing Artemia from Senegal which has the biggest opportunities for integrated salt-artemia production could also be an option. With Nigeria's import bills for cysts and feeds, a local or regional Artemia source could undercut imports on price and logistics from places such as the USA and Asia. The sheer scale of Nigeria's hatchery sector (catfish fry, ornamental fish breeders, and so on) could absorb significant quantities of cysts.
- **Constraints:** The lack of naturally occurring hypersaline water bodies means higher start-up costs (need to transport seawater or concentrate brine from boreholes). Climate is a challenge: The south is too wet (risk of rain diluting ponds), while the north has evaporation but security concerns in some areas and distance from hatchery customers. Market competition is not a big issue (imports would be replaced), but ensuring consistent quality (hatchery-grade cysts) would be key to gaining trust. Regulatory-wise, Nigeria encourages local feed production, so an Artemia venture might get support, but water use permits and land acquisition for salt ponds would need to be managed carefully.

Rwanda

Landlocked, High Altitude – Limited Saline Areas but Fast-Growing Aquaculture Industry

- **Saline geography:** Rwanda has virtually no natural hypersaline ecosystems. It is a highland country with freshwater lakes (Kivu, Muhazi, and so on) and hot springs but no salt lakes or coastal area. There are some small mineral-rich springs, but no salt production industry. Thus, Rwanda does not naturally accommodate Artemia farming without creating artificial salt ponds. Potential could exist to utilize wastewater from industries or build evaporative ponds in the dry Eastern Province, but this would be a greenfield approach.
- **Salt industry:** None to speak of. Rwanda imports all its salt needs (mostly from neighboring Tanzania or from Ethiopia via trade). No solar saltworks, no salt farmers.
- **Aquaculture and feed:** Rwanda's aquaculture is nascent but growing as part of a food security strategy. Recent production is in the order of a few thousand tons of fish per year. There are rapidly emerging large commercial cage farms on Lake Kivu producing tilapia and efforts to expand pond culture of tilapia and catfish elsewhere. The government has actively promoted fish farming to increase protein intake. A few hatcheries have been established for Nile tilapia fingerlings. These hatcheries could use Artemia for larval rearing if available but currently likely rely on imported feed or Artemia cysts in small quantities. The animal feed industry in Rwanda is small (poultry feed production is rising with livestock programs, but overall volumes are low compared to neighbors).
- **Consumption and market:** Fish consumption per capita is low (5 kg) but the government aims to raise it. Most fish consumed are imports from Uganda or Tanzania. Because of widespread malnutrition and stunting in children (around 38 percent stunting rate historically), Rwanda views fish farming as crucial to improve diets. Artemia could play a role indirectly by enabling more efficient aquaculture (healthier fry, higher fish yields). Direct human consumption of Artemia is unlikely to be culturally acceptable or necessary. Shrimp/crustacean imports are virtually zero; only a small expatriate demand for such seafood.
- **Regulatory and research support:** The national strategies (for example, Strategic Plan for Aquaculture Development) focus on increasing fish production and improving feed and seed, though mainly for conventional species. Artemia farming is not addressed in Rwandan policy since the country has no suitable saltwater habitats.
- **Opportunities:** Rwanda might not be a production site for Artemia, but it is a potential market for Artemia products. As aquaculture expands, Rwandan hatcheries could import cysts produced in other African countries (for example, Artemia from Kenya or Tanzania) instead of from outside Africa, if cost-effective.
- **Constraints:** No natural Artemia habitat, meaning any attempt to farm Artemia in Rwanda would require artificial saltwater ponds and imported brine or salt—likely not economical. Thus, Rwanda's role may be more as a consumer of regional Artemia supply to boost its aquaculture, rather than a producer.

Senegal

West African Leader in Salt, Untapped Artemia Potential but Nascent Aquaculture Industry

- **Appropriate model for scaling:** Bangladesh + Thailand models - Utilizing artisanal Artemia farming in seasonal salt pans, with biomass targeted for local feed and hatchery markets.
- **Saline geography:** Senegal boasts large hypersaline environments, notably Lac Retba (Lake Rose) near Dakar—a highly saline lake famed for its pink color (due to Dunaliella algae) and *extreme salinity (~40 percent in dry season)*. Artemia is known to thrive in similar conditions (for instance, Artemia populations exist in Mauritanian salt lakes and likely in Retba as well, given the presence of algae and brine). In addition, the Saloum Delta and Fatick region have many shallow salt pans and brine lagoons used for salt harvesting. Senegal's climate (a long dry season and high evaporation) yields ideal conditions for Artemia. The country's location on the Atlantic means ocean water could also be used to charge Artemia ponds if needed.
- **Salt industry:** Senegal is the largest salt producer in West Africa, with ~450,000 tons/year. Major production comes from Lac Retba and surrounding flats, as well as artisanal sites in St. Louis and Saloum. Around one-third of production (≈150,000 tons) is by small-scale harvesters (adrianguerin.com)—men and women manually crystallizing salt in ponds. The salt sector provides livelihoods for an estimated 50,000 people (directly and indirectly) and is a key export commodity, as well as crucial for domestic supply and regional trade. Market value is significant regionally (tens of millions of US dollars). Saltworks in Senegal are typically seasonal—during the dry season the brine is concentrated and salt harvested, leaving an opportunity in the rainy season (or between salt harvest cycles) to grow Artemia. Even concurrently, certain ponds can be managed for Artemia cyst collection before salt crystallizes. This existing base of salt infrastructure and labor is a strong foundation for Artemia farming with minimal new construction.
- **Aquaculture and feed:** Senegal's aquaculture sector is relatively small but has high potential. Current production is a few thousand tons of fish (tilapia, catfish) from riverine cage farms and small ponds, plus some oyster farming. There have been attempts at shrimp farming on a pilot scale in the Sindou area but no large commercial success yet. The government has an interest in expanding aquaculture to reduce reliance on declining marine fisheries. **Aquafeed:** There is little local feed manufacture; fish farms use imported or locally mixed feeds. **Feed market (terrestrial):** Senegal has a notable poultry industry around Dakar; however, high-quality protein ingredients are imported (fishmeal from local catches is available but costly). Artemia biomass could potentially serve as a substitute for some fishmeal if volumes allowed.
- **Consumption and market:** Senegalese are among Africa's top consumers of seafood per capita—fish is central to the diet (the national dish *Thieboudienne* is fish and rice). Per capita fish consumption is ~28 kg. However, much of this is supplied by marine fisheries (now overfished) and imports. There is a modest market for shrimp/lobster in urban areas, but the average person consumes small pelagic fish and tilapia. Artemia cysts are currently not produced locally; any hatcheries or research facilities import them. If Senegal were to develop shrimp farming (which is plausible given the coast and delta conditions), local Artemia would be in high demand. In the saline peanut basin and northern arid zones, malnutrition rates can be high due to poverty and limited diet diversity. Salt-farming communities often earn low incomes and could benefit if Artemia farming raises earnings or provides a secondary crop or source of animal-source protein. Also, improving aquaculture via Artemia could increase availability of affordable fish for nutrition.
- **Regulatory and research support:** Senegal has natural Artemia populations in Lake Retba and coastal salt pans but no formal Artemia farming. Government policies support sustainable aquaculture, but Artemia is not explicitly regulated. Research on Artemia has been minimal, though FAO previously noted potential for cyst harvesting in Senegal's salt ponds.

- **Opportunities:** Senegal's salt ponds are low-hanging fruit for Artemia introduction. For example, Lac Retba could be managed to produce Artemia cysts in tandem with salt: Before salt precipitates, workers could harvest brine shrimp cysts from the water surface or brines could be diverted to Artemia ponds for cyst and biomass harvesting. This could not only supply any emerging local hatcheries (Senegal or neighbors such as Ivory Coast/Ghana's shrimp hatcheries) but also be exported globally given West Africa's port access. The government and nongovernmental organizations (NGOs) are already engaged in iodized salt programs and value addition (nutritionintl.org). Artemia production could be synergistic, adding value and jobs (especially for women who dominate salt harvesting).
- **Constraints:** Training is needed to ensure artisanal harvesters can handle and process cysts (which require different techniques than salt). International competition and quality standards are a factor when exporting cysts. Also, market development is necessary—local demand for Artemia is currently low since aquaculture is small; so the venture might initially rely on export sales or catalyze a local shrimp hatchery industry to consume the product. Regulatory-wise, Senegal would likely be supportive, but permits might be needed for bioprospecting in natural lakes such as Retba (which is also a tourist attraction; any activity must maintain the lake's famed Pink Lake appeal).

Federal Republic of Somalia

Extreme Salinity, Rich Coastal Fisheries, Potential for Artemia Integration

- **Appropriate model for scaling:** The Federal Republic of Somalia (including the self-declared Somaliland region) has immense Artemia farming potential best approached with a **China/industrial model** given its expansive salt flats and coastline. The country's history with large-scale salt production (for example, the Hafun Salt Factory, once the world's largest) indicates the feasibility of big solar operations, which aligns with a high-capacity Artemia production model. The Bangladesh or Viet Nam smallholder model is less suited here due to security and infrastructure issues—instead, a centrally managed, investment-heavy model (possibly PPP) would work, as was envisioned in recent plans to develop huge saltworks in Somaliland (somalilandchronicle.com).
- **Saline geography:** The Federal Republic of Somalia boasts one of the longest coastlines in Africa (~3,300 km) along both the Gulf of Aden (north) and the Indian Ocean (east/south). Key saline environments include coastal salt flats and marshes in Somaliland/Puntland (notably around Hafun, Tukur Bay, and Berbera), where high-evaporation and past Italian-built salt pans exist; inland depressions contiguous with the Danakil Desert (though mainly in Ethiopia/Djibouti, some brine seeps may extend into northwest Somalia); and saline lakes—Somalia proper has fewer inland salt lakes than nearby Ethiopia, but small saltwater pools in the Jubba Valley or central plains might exist. The most significant is the Hafun Peninsula in northeast Puntland—historically chosen for massive saltworks due to its unique geography (a low-lying lagoon easily flooded by sea). That site produced hundreds of thousands of tons of salt and almost certainly had Artemia naturally (brine shrimp often colonize salt ponds via birds). The climate in northern Somalia is extremely arid (annual rainfall < 100 mm in some parts), ensuring brines concentrate easily—ideal for continuous Artemia growth, perhaps even year-round.
- **Salt industry:** The Federal Republic of Somalia's salt industry, once thriving pre-1990, largely collapsed due to civil war and lack of investment. Historically, the Hafun Salt Factory in the 1930s produced up to 200,000–500,000 MT of salt per year, exporting globally. In recent times, salt production is small-scale: Local entrepreneurs produce salt at a handful of sites along the coast (for example, near Berbera, Zeila, and along Puntland's shores) but volumes are low and quality is variable. Additionally, in Puntland, Hurdiyo and Jad—areas near Hafun—still contain remnants of the Italian salt infrastructure that could be rehabilitated. The salt industry in the Federal Republic of Somalia thus has two faces: a legacy of large-scale potential and a current state of rudimentary operation.
- **Aquaculture industry:** Decades of instability left the Federal Republic of Somalia's aquaculture virtually nonexistent, but the potential is significant. There have been some recent initiatives: small-scale fish farming trials (tilapia in brackish ponds near the Jubba River) and interest in sea cucumber farming in Somaliland (the Seawater Greenhouse project near Berbera uses evaporative cooling and produces salt and possibly aquaculture trials). Marine aquaculture such as shrimp farming is not currently practiced, though the Federal Republic of Somalia's coast could support shrimp if infrastructure existed. Hatcheries for marine fish or shrimp are absent; thus, current Artemia demand domestically is effectively zero.
- **Aquafeed and livestock feed markets:** There is essentially no aquafeed industry in the Federal Republic of Somalia—any fish farming uses imported feed or farm-made formulas. The livestock sector, especially camels, goats, and sheep, is huge, but the animals graze or eat simple feed; formulated commercial feed for poultry exists at a very small scale for local chicken farms. If Artemia biomass were produced in quantity, one imaginative use could be for camels or goats as a mineral/protein lick (dried Artemia are high in salt and nutrients) for animals near coastal areas, though this is speculative and likely not cost-effective compared to traditional salt licks. The idea of using Artemia as part of integrated farming with chicken or ducks could be piloted—for instance, ducks in salt ponds could eat Artemia and then be harvested, essentially converting Artemia protein to poultry protein. In the near term, though, the Federal Republic of Somalia's pressing needs in feed are more about staple ingredients (grains and oilseed cake) and not specialty items such as Artemia.

- **Consumption and markets:** Somali cuisine heavily features livestock (camel and goat) and some fish among coastal communities. Shrimp or other crustaceans are not widely consumed traditionally. Somalis do use a dried fermented fish paste called *owgho* in some regions; hypothetically, Artemia could be fermented into a savory paste, but this is purely hypothetical and would likely face cultural resistance. More realistically, Artemia could contribute to human nutrition through livestock: If used in chicken feed, it could improve eggs or meat quality consumed by Somalis.
- **Regulatory and research support:** Governance in the Federal Republic of Somalia is complex—Somaliland operates an autonomous administration with its own investment and fisheries policies, while the Federal Government's reach elsewhere can be limited. In Somaliland, a regulatory framework for salt and potential marine resources exists, as seen by the formal memorandum of understanding with investors for salt extraction. For Artemia, specific regulations are absent. However, any large salt/artemia project would require environmental clearances (Somaliland's environmental law would consider impacts on coastal ecosystems, migratory birds, and so on). On biosecurity, introducing *Artemia franciscana* (if not already present from the past) should be done carefully, but given migratory birds, Artemia likely already populate any suitable water in the region naturally.
- **Opportunities:** The potential for Artemia farming in the Federal Republic of Somalia is there and aligns with its broader economic needs. If stability holds in areas such as Somaliland, the country could become a top-tier Artemia producer by virtue of huge suitable areas and ideal climate. This represents a high-value export that diversifies an economy otherwise reliant on livestock and diaspora remittances. The proximity to the Middle East (major aquaculture growth region) offers a natural market next door. Domestically, an Artemia/salt operation could create hundreds of jobs (as the 1930s Hafun operation did: 2,000 Somalis employed).
- **Constraints:** The challenges in the Federal Republic of Somalia are daunting. Security and political instability remain the biggest constraints—large investments or projects cannot proceed in conflict-prone areas, and even in relatively stable Somaliland, investors need assurance of long-term stability and contract enforcement. Next, infrastructure deficits: Remote salt sites lack electricity, roads, and port facilities. For example, Hafun's old salt export was via a pier—rebuilding such infrastructure is expensive and time-consuming, potentially delaying ROI on Artemia. From a market perspective, quality control and reputation are concerns: establishing a new source will require proving that Somali cysts meet hatchery requirements. If early shipments have issues (poor hatch rate and impurities), trust could be hard to rebuild.

Tanzania

Coastal and Inland Salt Resources, Moderate Aquaculture

- **Appropriate model for scaling:** As Tanzania is a major aquaculture producer and potential consumer of Artemia production in regional countries, Artemia cysts and biomass could support shrimp and finfish hatcheries while the country can also utilize artisanal Artemia farming in seasonal salt pans and biomass production to meet local hatchery demand.
- **Saline geography:** Extensive salt resources both on the coast and inland. Along the Indian Ocean coast (Pwani, Lindi regions, and Zanzibar), numerous solar salt pans exist. Notably, Pemba Island (Zanzibar) has significant artisanal salt farming—about 2,000 tons/year produced by women's cooperatives—and could host Artemia in its ponds. Tanzania has hypersaline lakes such as Lake Eyasi and Lake Natron (though Natron's extreme alkalinity favors algae over Artemia). Uvinza in western Tanzania has brine springs historically yielding salt. These sites offer potential small-scale Artemia habitats if managed.
- **Salt industry:** Tanzania's annual salt production is modest (est. 34,000 tons in recent stats, though this may undercount artisanal output). The country exports some salt (~US$5.6 million value in 2019). Many producers are small; for example, Pemba's 2,000 tons come from dozens of ponds, and experts see potential to triple output with better tools. The number of salt farmers is in the hundreds (Pemba) to low thousands nationwide, often in rural communities. Industrial saltworks exist on the mainland coast, in the Tanga region, but at a smaller scale than in North Africa.
- **Aquaculture and feed:** Aquaculture is still developing—roughly 20,000–30,000 tons/year of fish (mainly tilapia and African catfish) produced recently. (Official 2020 figure ~36,000 tons, though other estimates vary). Tanzania has both freshwater farming and some marine culture (seaweed is big, fish farming is limited). Seafood consumption is significant in coastal areas (fish is a staple), but overall per capita fish supply is around 8–12 kg. There is currently only one major shrimp farm on Mafia Island, and a few mariculture trials have taken place near the coast. Aquafeed production is small—farmers often rely on farm-made feeds. A handful of feed mills produce pelleted tilapia feed, but volumes are low. Terrestrial animal feed market is moderate (Tanzania has a large livestock sector), so any Artemia biomass not used in aquaculture could be trialed in poultry or pig rations.
- **Consumption and market:** Tanzanians consume locally caught fish (especially along Lake Victoria and the coast). Shrimp/crustacean consumption is low; the country has a wild shrimp fishery in the Rufiji delta but imports very little shrimp. Artemia cysts might be used by the few marine hatcheries (for shrimp or marine finfish) and by tilapia hatcheries aiming to improve fry survival. Malnutrition is prevalent in some drought-prone, salt-producing regions (for example, communities around inland salt lakes often face food insecurity). Artemia farming in such areas could diversify incomes and indirectly improve nutrition (via higher incomes or potential use of Artemia as livestock feed to boost local food production).
- **Regulatory and research support:** Tanzania has a robust legal and policy framework for aquaculture. The Fisheries Policy 2015 and Aquaculture Development Strategy 2018 explicitly support aquaculture expansion, including hatchery inputs. Notably, the government has removed import duties on key inputs such as formulated feed and live feeds (algae, rotifers, *Artemia* cysts) to encourage the sector's growth. The Fisheries Act 2003 and its regulations stipulate that no live fish or aquatic organism (including non-native *Artemia*) may be imported or introduced without official authorization. This means any attempt to inoculate *Artemia* into new sites undergoes government scrutiny to prevent invasive species issues. Artemia was not historically native to Tanzania, but recent research has documented its presence in coastal salt works. A 2017 survey found *Artemia* in about half of the coastal salt pans examined in Tanga and other regions (Mlingi et al. 2019).
- **Opportunities:** Utilize existing salt ponds (for example, in Zanzibar or Bagamoyo) for pilot Artemia culture, supplying the small but growing aquaculture sector and regional marine hatcheries (Kenya and so on). Integrating Artemia could add value for artisanal salt farmers (a second crop aside from salt).
- **Constraints:** The aquaculture market is currently limited in size; without a major hatchery demand, scaling Artemia may require exporting cysts or biomass. Also, infrastructure such as cold storage for biomass or processing for cysts might be lacking. Regulatory processes for coastal operations and environmental permits (especially in Zanzibar's sensitive ecosystems) must be navigated.

Tunisia

Established Salt Industry, Marine Aquaculture Presence

- **Appropriate model for scaling:** Viet Nam + China models - Integrating Artemia into solar saltworks for cyst harvesting and biomass cultivation to supply the regional aquaculture industry.
- **Saline geography:** Tunisia abounds in saline environments. It has vast coastal salt flats and inland chotts (seasonal salt lakes). The Chott El Djerid in southern Tunisia is one of the world's largest salt pans. Coastal saltworks near Sfax (for example, Thyna) and in the Kerkennah Islands produce large quantities of salt. Additionally, smaller traditional salinas dot the coast. These are classic Artemia habitats—in fact, brine shrimp (Artemia salina species) are native to Mediterranean salterns. Tunisia's warm, dry climate (especially in the south with long evaporation seasons) is highly suitable for Artemia culture.
- **Salt industry:** Tunisia is a top African salt producer, with about 2 million tons in 2019, expected to rise to 2.5 million by 2025. It ranked ~thirtieth globally with ~1.13 million tons in earlier years but has since nearly doubled output. The industry has a mix of industrial operations (for example, COTUSAL, a major company historically run with foreign partnership, producing salt from Sfax and Djerid) and artisanal saltworks (though traditional salinas have declined since the 1950s). Salt exports are significant: Tunisia exported ~1.58 billion kg (1.58 million tons) of salt, worth US$26.5 million, in a recent year, mainly to Europe (for deicing and chemical industries). The number of people employed in salt production is substantial—from miners in the chotts to seasonal workers in coastal salterns—likely several thousand. These extensive salt facilities offer immediate potential to integrate Artemia: Large evaporation ponds could be inoculated and managed to harvest cysts without disturbing salt crystallization. Indeed, some Tunisian research has likely already looked at Artemia as a natural part of the salt pond ecology though there are some concerns that these areas have too high salinity and not enough freshwater to manage levels.
- **Aquaculture and feed:** Tunisia has a well-established **marine aquaculture** sector. In 2022, it produced ~20,926 tons of fish, predominantly Mediterranean species (sea bass, sea bream) grown in offshore cages. These species require hatcheries, and Tunisia operates fish hatcheries that *depend on Artemia cysts* for larval rearing. Tunisia also cultivates some inland tilapia and has recently explored shrimp farming on a pilot scale. The aquafeed industry is present but small; specialized feeds for sea bream/bass are often imported from Europe. A domestic Artemia supply would benefit Tunisian hatcheries by reducing reliance on imported cysts and potentially lowering costs. **Terrestrial feed market:** Tunisia's poultry and livestock sectors produce feeds, but given Tunisia's moderate size, this market is not huge in global terms. Still, any Artemia biomass by-product could be tested in high-end animal feed or pet food manufacturing (Tunisia has an export-oriented agri-food processing sector).
- **Consumption and market:** Tunisians consume a moderate amount of seafood (being a Mediterranean country). Per capita fish consumption ~11 kg. Seafood (fish, octopus, and so on) forms ~16 percent of protein intake for coastal populations. Tunisia also exports high-value seafood. Shrimp consumption is met by a mix of domestic wild catch and some imports—not a staple but part of the cuisine. The country's aquaculture aims to reduce seafood trade deficits and supply the domestic market. Artemia cysts are currently 100 percent imported for hatcheries—a local source could find an immediate market in Tunisia's ~10+ marine hatcheries and could be exported to nearby countries (for example, Egypt or Algeria). Malnutrition is low relative to sub-Saharan Africa, so human food application of Artemia is not a priority here and could be met with hesitation for cultural reasons. Government research bodies (such as the National Institute of Marine Sciences) have experience in aquaculture and likely support innovation such as Artemia farming.
- **Regulatory and research support:** Tunisia has *never inoculated* its salt ponds with foreign Artemia strains. This reflects a biosecurity-conscious approach—the country has been careful to preserve its native brine shrimp genetic resources. Researchers note that Tunisia instead focuses on maximizing what the local Artemia can produce (cysts and biomass) rather than introducing *A. franciscana* or others. This policy has avoided potential invasive impacts; for instance, neighboring Algeria and Libya also share similar Artemia species, maintaining regional biodiversity. Tunisia's aquaculture sector is relatively advanced (notably in marine fish culture), and it relies on Artemia for hatcheries. The regulatory framework (administered by the General Directorate of Fisheries) ensures that any use of natural Artemia does not compromise the environment.

- **Opportunities:** Tunisia's combination of *large saltworks*, *active hatchery-based aquaculture*, and *export channels* makes it very attractive for a commercial Artemia operation. A venture could partner with existing salt companies (for instance, using part of Chott El Djerid salt ponds during off-peak salt season to produce Artemia cysts). The product could serve local hatcheries and be exported to Europe/Middle East (leveraging Tunisia's trade links and proximity).
- **Constraints:** Potential competition with established Artemia exporters (for example, the Artemia from neighboring Algeria's salt lakes or imported cheaper cysts) means Tunisian Artemia must compete on quality (hatchability) or price. Also, some regulatory clarity would be needed if introducing non-native Artemia strains to boost yields (though local Artemia exist, strains like San Francisco brine shrimp might yield more—their introduction would need environmental vetting). Lastly, processing capacity (for cleaning and packing cysts) would need to be developed locally to meet international standards.

Uganda

Inland Salt Lake and Major Fish Producer

- **Appropriate model for scaling:** Bangladesh + Thailand + Viet Nam models - Utilizing artisanal Artemia farming in seasonal salt pans and biomass production to meet local hatchery demand.
- **Saline geography:** Despite being landlocked, Uganda has notable hypersaline crater lakes in the western Rift Valley. Lake Katwe and nearby Lake Bunyampaka are saline lakes where traditional salt mining occurs. Lake Katwe's brine is extremely salty (up to ~30 percent salinity) and has long sustained artisanal salt extraction. These lakes present an ideal environment for Artemia—studies indicate brine shrimp can survive in dilutions of Lake Bunyampaka water, and trials have been done to culture Artemia using Lake Katwe brine (Enock and Nyamweha 2016). There is an estimated 20+ million tons of salt reserves in Katwe (Kirabira et al. 2013), and if managed properly, the lake could support ~40,000 tons of salt production per year alongside Artemia. Currently, a few hundred local salt miners work there in the dry season.
- **Salt industry:** Small-scale and traditional. Annual production from Lake Katwe varies (commonly a few thousand tons of crude salt). There was a failed salt factory project, now largely artisanal output. Salt from Uganda covers only a fraction of domestic need, so the country imports up to 100,000 tons of salt yearly. Number of salt miners ~700–1,000 (seasonal workers at Katwe). Market valuation is low due to unrefined products (salt sells cheaply to traders). However, the salt lakes are an underutilized asset that could generate additional revenue via Artemia cysts in the dry season when salinity peaks and salt crystallizes.
- **Aquaculture and feed:** Uganda is one of Africa's top aquaculture producers. Official figures report ~101,000 tons in 2022 (though some estimates put current output nearer 45,000–60,000 due to data variability). It ranks third in Africa after Egypt and Nigeria. Key species are Nile tilapia (in cages on Lake Victoria and ponds countrywide) and African catfish (particularly for tank/pond culture). The aquafeed market is growing; several feed mills operate (some Ugandan and some feed imported from Kenya). There are thousands of fish farmers, including a few large companies with cage farms and many smallholders. Importantly, Uganda has many hatcheries for tilapia and catfish fry—these often use Artemia nauplii to feed delicate larval stages, as local studies emphasize the need for affordable live food (Sserwada et al. 2018).. The terrestrial feed industry is moderate (poultry and pig feed on a smaller scale than neighbors).
- **Consumption and market:** Fish is a major part of Ugandans' diet historically (especially around the Great Lakes). Per capita fish consumption was ~12 kg in 2018 but may have dipped with wild catch decline. Still, fish provides critical animal protein. Uganda imports some fish to meet demand and exports some (particularly dried silverfish). Shrimp/crustacean consumption is negligible (no coast and freshwater prawns not common in local diet). Artemia cysts are currently imported for use in local hatcheries and research—any local production would directly replace these imports and perhaps be exported to other inland African markets. Malnutrition remains a challenge in Uganda's north and parts of the west; interestingly, the salt-rich Katwe region has communities with limited protein sources aside from fish from nearby Lake Edward. A successful Artemia farm there could explore turning part of the biomass into a supplemental food ingredient (after proper processing) for malnourished populations or, more realistically, use additional income from Artemia to improve food access.
- **Regulatory and research support:** Following laboratory success, researchers have suggested proceeding to controlled field trials. As part of an international collaboration, Uganda's National Fisheries Resources Research Institute (NaFIRRI) and Belgium's Artemia Reference Center have worked together on this topic. A webinar in 2022 reported that *Artemia* cysts were being hatched in tanks and ponds as intermediate steps, and eventual wild inoculation in Ugandan lakes "will follow" once enough data and capacity are in place. This indicates active research support, backed by foreign expertise, to establish *Artemia* for R&D and local aquaculture use. Uganda has no native *Artemia*—surveys in 2010 confirmed that lakes such as Katwe, Bunyampaka, and others had no existing brine shrimp populations. Thus, any introduction is carefully considered.
- **Opportunities:** Lakes Katwe and Bunyampaka offer a contained environment to pilot Artemia farming. These lakes could produce Artemia cysts for Uganda's expanding hatchery sector and even export to neighboring countries with aquaculture (Rwanda, Kenya, the Democratic Republic of Congo). The infrastructure needed (harvesting nets, dryers) is minimal and could be managed by existing salt cooperatives, adding an income stream in the off-season for salt miners.
- **Constraints:** Quality control and processing of cysts would need training; also, the remote location (far from Uganda's aquaculture centers in central/eastern regions) means transport logistics for heavy wet biomass or delicate cysts. Additionally, Lake Katwe lies adjacent to Queen Elizabeth National Park—any development must consider environmental impacts and not disrupt wild bird (flamingo) feeding or the natural ecosystem balance.

Zambia

Landlocked, No artemia farming, but Emerging Aquaculture Hub

- **Appropriate model for scaling:** No artemia farming possible but a major aquaculture producer and potential consumer of Artemia production in regional countries—Zambia could benefit from imports for its hatchery and aquafeed industry (one of the biggest in Africa).
- **Saline geography:** Minimal natural salt lakes; most salt is imported or produced in small pans. No large hypersaline ecosystem identified—Zambia's focus is freshwater aquaculture rather than salt production. (The country relies on imported salt for consumption.)
- **Salt industry:** Insignificant - no major solar saltworks or coastal salterns. Any local salt comes from small-scale evaporation of salty springs. (Zambia does not appear in Africa's top salt producers.)
- **Aquaculture and feed:** Among Africa's top aquaculture producers, with ~75,600 tons farmed fish in 2022 (primarily Nile tilapia and some catfish). Aquaculture has grown ~6.7 percent annually and may soon rival wild catch. Fish contributes over 50 percent of animal protein in Zambian diets, underlining strong local demand. The aquafeed industry is developing—Zambia now even exports fish feed regionally. Terrestrial feed market: ~79,000 tons animal feed produced (as of the mid-2000s) dominated by poultry and livestock, so Artemia meal could find a niche as specialty feed additive.
- **Consumption and market:** Per capita fish consumption ~12 kg/year (important protein source). Malnutrition in some rural provinces is high; an Artemia project could partner with NGOs to use excess biomass for nutrition programs, though the primary market would be aquaculture feed.
- **Regulatory and research support:** Zambia's government has prioritized aquaculture development. It launched a National Fisheries and Aquaculture Policy (2023) to boost sustainable fish production, making Zambia one of the top aquaculture producers in Africa.
- **Opportunities:** Use existing aquaculture infrastructure: If hypersaline ponds are created (for example, repurposing abandoned mines or salt springs), Artemia could supply the vibrant fish farming sector. But the biggest opportunities would be for neighboring countries such as Namibia and Botswana where there is limited aquaculture but great potential for artemia farming to supply artemia to Zambia.
- **Constraints:** Lack of natural saltwater bodies means high initial setup cost (pumping brine inland). Also, without a shrimp hatchery industry, demand for Artemia cysts is limited to fish hatcheries, which mostly breed species (tilapia and catfish) that can use cheaper feeds. Regulatory support for aquaculture is strong, but Artemia-specific knowledge is limited in-country.

Annex 3. Investment Cases in Latin America

Bolivia

High-Altitude Salt Flats, Artemia Export Potential

- **Appropriate model for scaling:** Bangladesh and Viet Nam and Thailand model - Artemia cyst production in hypersaline lakes for export markets rather than domestic use. Given Bolivia's lack of a strong aquaculture sector, local demand for Artemia is minimal, making commercial cyst harvesting the most viable option.
- **Saline geography:** Bolivia's Altiplano region features numerous hypersaline lakes, such as Laguna Colorada, Laguna Hedionda, and Lake Poopó, which naturally support Artemia. These high-altitude ecosystems (3,500–4,500 m) are key habitats for flamingos, indicating the presence of abundant cyst-producing Artemia populations. However, the extreme climate (cold temperatures, high ultraviolet radiation) affects seasonal Artemia productivity, requiring careful harvesting strategies.
- **Salt industry:** Bolivia has extensive salt flats, notably Salar de Uyuni, the world's largest salt flat, primarily used for lithium extraction rather than salt production. Traditional salt mining occurs in smaller saline lakes and flats, often through community-based operations. While some of these salt environments may support Artemia, large-scale salt-Artemia integration is not currently practiced.
- **Aquaculture industry:** Bolivia's aquaculture is small and focused on freshwater species, mainly Amazonian fish (tambaqui, pacú) in lowland ponds and trout in high-altitude lakes. Hatcheries rely on formulated starter feeds rather than Artemia, and there are no large-scale shrimp farms or marine fish hatcheries that would use Artemia cysts. This means Bolivia's Artemia farming would be entirely export-driven rather than supporting local hatcheries.
- **Aquafeed and livestock feed markets:** There is no established aquafeed industry that would use Artemia, and Bolivia's livestock sector relies on soy and fishmeal as protein sources. Artemia biomass is unlikely to compete with existing feed ingredients in Bolivia, making cyst exports the primary commercial opportunity. Some small domestic markets could exist for ornamental fish breeding or research use, but these would be niche.
- **Consumption and markets:** Bolivians do not consume Artemia, and there is no cultural precedent for eating small crustaceans. Fish consumption is relatively low (~3–5 kg per capita) and concentrated in lowland regions. Dried river shrimp are sometimes used in traditional dishes, but Artemia would require significant processing and marketing to be accepted as food. Instead, Artemia's contribution to human nutrition would be indirect—generating income for highland communities and supporting global aquaculture production.
- **Regulatory and research support:** Bolivia's hypersaline lakes are mostly within protected areas, such as Eduardo Avaroa National Park, where conservation policies focus on flamingos and lake ecology. Any Artemia harvesting would require careful regulation to avoid disrupting bird populations. Bolivia has no existing Artemia-specific policies, but environmental agencies could establish sustainable harvest quotas. Research on Bolivian Artemia is limited, though universities and conservation groups have studied lake ecology.
- **Opportunities:** Bolivia could develop community-led Artemia cyst harvesting to provide alternative livelihoods in the Altiplano. With proper branding, Andean Artemia could be positioned as a premium, eco-friendly product for global aquaculture. Integration with lithium mining projects could also be explored.
- **Constraints:** Strict conservation regulations may limit large-scale Artemia harvesting to protect flamingo populations. High-altitude logistics, lack of infrastructure for cyst processing, and Bolivia's distance from major ports could raise export costs. Market entry may also be challenging, as buyers prefer reliable, large-volume suppliers.

Brazil

Large-Scale Salt Industry, Expanding Aquaculture, Artemia Integration

- **Appropriate model for scaling:** Thailand + Viet Nam models - Biomass production can be scaled in large salt farms, and cysts processed for both domestic use and potential exports.
- **Saline geography:** Brazil's vast coastline (8,500 km) includes numerous solar saltworks and lagoons ideal for Artemia. The Northeast region—especially Rio Grande do Norte (RN)—is Brazil's salt hub, with coastal evaporative salinas around Macau, Mossoró, and Areia Branca. These saltworks, often >500 ha each, produce ~95 percent of Brazil's salt (Rocha et al. 2012). Brines are held for months, allowing stable hypersaline ecosystems to form; *Artemia franciscana* has been recorded in RN and Ceará salt ponds (Camara 2012). Further south, hypersaline lagoons such as Araruama (Rio de Janeiro state) also host Artemia after introductions.
- **Salt industry:** Brazil's salt production is about 6.3 million tons/year, one of the world's top 10 producers. This industry provides extensive saline infrastructure—large ponds that could be co-cultured with Artemia. Given Brazil's warm climate and suitable salinities, mass Artemia cyst production in northeastern saltworks has been studied and deemed feasible.
- **Aquaculture industry:** Brazil is Latin America's largest aquaculture producer by volume (excluding algae), with ~860,000 tons in 2022. The industry is dominated by freshwater fish—especially tilapia (~550,000 MT) and native species such as tambaqui—which generally do not require Artemia at scale. However, Brazil also farms marine shrimp (*Litopenaeus vannamei*) along its northeast coast, with production rebounding to 113,000 MT in 2022 after previous disease setbacks. Dozens of shrimp hatcheries operate in Ceará, RN, and Bahia, all of which rely on imported Artemia cysts for larval rearing. Marine fish aquaculture is still nascent (some cobia, snapper, and pompano projects), but if it grows, those hatcheries would likewise need Artemia. Brazil's aquaculture is valued around ~US$1–2 billion (tilapia being a major agribusiness). With both shrimp and a push into high-value marine fish, Brazil's demand for Artemia cysts and biomass is significant and growing—yet all cysts are imported currently. Establishing domestic Artemia farming (for example, harvesting cysts from saltworks) could lower hatchery input costs and improve self-sufficiency.
- **Aquafeed and livestock feed markets:** As a major grains producer, Brazil's aquafeed formulations often use soy protein, but fishmeal is still important for carnivorous species and shrimp. Brazil produces some fishmeal (from sardine bycatch, and so on) but not enough; it imports fishmeal for aquafeeds and livestock feed (globalseafood.org). Artemia biomass could be explored as a local alternative protein. In shrimp maturation facilities in Brazil, adult Artemia (often imported frozen) are sometimes fed to broodstock, indicating a niche market for Artemia biomass exists. Additionally, Brazil's vast poultry industry might utilize Artemia meal if it were cost-effective (for pigments or protein). While this is speculative, any large-scale Artemia production could find multiple uses. The constraint is cost—Artemia must compete with other protein sources. Nonetheless, rising Artemia cyst prices globally make a case for local production in Brazil to serve its own aquaculture sector and possibly export to nearby countries.
- **Consumption and market:** Brazil's per capita fish/seafood consumption is only ~8 kg/year, relatively low—beef and poultry dominate diets. Seafood is more popular in coastal communities and the Amazon basin, but small shrimp are not a staple nationally. Dried salted shrimp (often small river shrimp) are used regionally (for example, in northeast Brazilian cuisine) as a flavoring, suggesting some cultural familiarity with tiny shrimps as food. However, Artemia for direct human consumption is virtually unheard of in Brazil. Instead, Artemia contributes indirectly by supporting aquaculture of species Brazilians do eat (tilapia, shrimp). If needed, Artemia could possibly be processed into a fish sauce or dried snack given precedent in Asian markets, but it would require creating a taste preference for it. More realistically, boosting aquaculture (via Artemia feed) will increase the availability of fish and shrimp in local diets, aiding nutrition.

- **Regulatory and research support:** Brazil has a robust framework for aquaculture development. EMBRAPA (the federal agricultural research agency) operates an aquaculture and fisheries center that investigates new culture species and feeds. Brazilian researchers have reviewed Artemia cyst production in the northeast (Camara 2020) and identified saltworks as multiuse systems (salt, beta-carotene algae, Artemia, and so on). The government encourages integrated salt-fish initiatives; for example, some saltworks already allow *artisanal fishing* of fish and Artemia that enter ponds. Biosecurity regulations exist for shrimp hatcheries (Specific pathogen Free broodstock import rules, and so on), which would extend to on-site Artemia culture (to avoid introducing pathogens). Brazil is generally open to aquaculture innovation—if Artemia farming can improve hatchery production or create exportable products, it aligns with Brazil's push to become an aquaculture giant (globalseafood.org). Overall, Brazil's combination of natural resources, industry scale, and scientific support bodes well for Artemia farming investments.
- **Opportunities:** Extensive solar saltworks in RN provide ideal conditions for Artemia co-culture. Brazil's expanding shrimp farming industry could drive demand. Fishmeal shortages may encourage alternative protein sources.
- **Constraints:** There is limited awareness of Artemia farming as an industry, and saltworks owners may be reluctant to integrate Artemia production. Domestic fishmeal availability competes with Artemia biomass applications.

Chile

High-Value Aquaculture, Hypersaline Salares, Export Potential

- **Appropriate model for scaling:** Viet Nam model - Utilizing hypersaline salares (salt flats) for cyst production, with potential export to Artemia-dependent hatcheries in Latin America.
- **Saline geography:** Chile's unique geography includes the **Atacama Desert** in the north, home to numerous *salares* (salt flats) and hypersaline lakes. The Salar de Atacama (around **3,000 km^2** total area) and other Andean salt lakes (Chaxa, Cejar, and so on) have brines that host halophilic life including **Artemia** (Gajardo et al. 2006). While these high-altitude lakes are remote, they present large potential habitats.
- **Salt industry:** Chile also has coastal saltworks (though salt production is smaller, ~8 million tons/year, mainly as a by-product of mining). The extreme salinity and sunlight in the salares create vibrant microbial and Artemia communities. For instance, certain Chilean Artemia populations (possibly *A. persimilis*) are adapted to these environments. Though not currently exploited for aquaculture, these saline ecosystems could support cyst harvesting or Artemia cultivation if access were granted (many are in protected areas for flamingos). In summary, Chile has extensive saline resources but mostly in isolated areas; leveraging them for Artemia farming would require infrastructure in the desert or expansion of coastal saltern ponds.
- **Aquaculture industry:** Chile is a world leader in aquaculture by value, primarily due to salmon farming. It produces about 1 million tons of salmonids annually, valued around US$5 billion, second only to Norway. Salmon hatcheries, however, do not rely on Artemia—salmon fry are started on formulated feeds. Thus, Chile's massive aquaculture output does not translate to Artemia demand in the way shrimp hatcheries do. That said, Chile also cultivates other species: mussels (~350,000 MT) and some shrimp (limited) and is experimenting with marine fish such as seriola and turbot, which *would* need live feeds at larval stages. For now, Artemia use in Chile is mostly in research and perhaps ornamental fish breeding. The salmon industry's scale means Chile uses a lot of aquafeed (and fishmeal) but not Artemia. If Artemia farming were developed in Chile, the likely market could be export of cysts/biomass to other countries, that is, Ecuador (leveraging Chile's Artemia strains adapted to unique conditions) or future diversification into species that need live feed. Chile's aquaculture economy is huge, but Artemia's role is currently minor; future opportunities may grow if the country diversifies beyond salmon.
- **Aquafeed and feed markets:** Chile is one of the world's top fishmeal producers, owing to its sizable pelagic fisheries (Guzamán-Pincheira et al. 2024). Much of this fishmeal and fish oil goes to domestic salmon feed manufacturing. Salmon feeds use high-quality fishmeal, but the industry is actively reducing fishmeal inclusion for sustainability. There may be interest in alternative proteins—though Artemia meal is unlikely to be used for grow-out feed given its cost. Instead, Chile could use Artemia in hatchery and nursery phases for non-salmon species. For example, if Chile develops hatcheries for new marine finfish or crustaceans, Artemia cysts will be needed. Chile's scientific community is aware of the global Artemia supply bottleneck, so producing Artemia in-country (perhaps in tandem with salt or lithium extraction in salares) could be an innovative venture. Excess Artemia biomass might also be processed for nutraceuticals (brine shrimp are rich in carotenoids and omega-3 fatty acids). Overall, Chile's feed market is large but focused on formulated feeds; Artemia could find a place in early-stage feeds or specialty applications.
- **Consumption and market:** Chileans consume about 14.6 kg of seafood per capita, including a variety of fish (salmon, jack mackerel) and shellfish. Small crustaceans are not common in the diet, though *krill* from Antarctic waters has been harvested by Chile for fishmeal and oil. Direct human use of krill (in supplements) exists, but Artemia for direct human food is not utilized in Chile. The idea could be explored (for example, as a protein-rich powder or in famine relief foods), but culturally, there is no demand. However, Chile places a strong emphasis on seafood as a healthy food source and is concerned with food security in remote coastal communities. Indirectly, Artemia could enhance food security by enabling the culture of species that diversify local diets (for instance, if Artemia helps spawn native fish for restocking or aquaculture). In summary, Artemia's human nutritional impact in Chile would be indirect and relatively minor in the short term.

- **Regulatory and research support:** Chile has a well-developed aquaculture regulatory framework (especially for salmon biosecurity and environmental monitoring). While Artemia farming is not specifically addressed in regulation, any collection from natural saline lakes would require environmental permits (most northern salares are protected). The Chilean government, through agencies such as CORFO, funds innovation in aquaculture—for example, there have been grants for developing new hatchery technologies and live feeds. Chilean researchers (for example, at Universidad de Antofagasta and Universidad de Los Lagos) have studied Artemia biodiversity and ecology in Chile's salt lakes (Gajardo et al. 2006). This knowledge base could support applied R&D for cultivation. Additionally, Chile's interest in the blue biotech sector means an Artemia venture (for cysts or bioactive compounds) might receive support if it shows export potential. While Chile's current aquaculture does not lean on Artemia, the country's strong research institutions and innovation climate would be supportive if Artemia farming is proposed, especially as a means to diversify aquaculture or add value to salt flat resources.
- **Opportunities:** Chile's hypersaline Atacama salares offer a unique niche for Artemia cyst harvesting. There is potential for export to Peru and Ecuador. Strong research capacity supports Artemia trials.
- **Constraints:** Most of Chile's aquaculture (salmon) does not rely on Artemia, limiting local demand. The harsh desert environment requires specific adaptations for Artemia farming.

Ecuador

Shrimp Powerhouse, Thriving Saltworks, Artemia Potential

- **Appropriate model for scaling:** Thailand + Viet Nam + China models - Small-scale cyst and biomass production can be integrated into existing solar salt ponds to support the thriving shrimp hatchery sector.
- **Saline geography:** Ecuador has extensive hypersaline environments along its coast. Coastal salt flats in Salinas (Santa Elena Peninsula), Ecuador—evaporation ponds operated by ECUASAL (*Ecuatoriana de Sal y Productos Químicos*) cover 1,300 ha and produce ~70 percent of Ecuador's salt. *The high salinities and abundant nutrients (bird guano) in such ponds create ideal conditions for Artemia populations* The Santa Elena Peninsula hosts large solar saltworks (for example, ECUASAL in Salinas, 1,300 ha) where brine reaches >180 psu and sustains dense Artemia populations (globalseafood.org).
- **Salt industry:** These artificial salt ponds—the largest wetlands in Ecuador—are seasonally pink from halophiles and brine shrimp. Smaller salt flats and evaporation ponds elsewhere in Manabí and Esmeraldas Provinces could also support Artemia. Annual salt production is modest (75,000 tons) but concentrated in these high-salinity sites that double as potential Artemia farms.
- **Aquaculture industry:** Ecuador is a global shrimp farming powerhouse, recently becoming the world's largest producer/exporter of farmed shrimp. Shrimp production exceeded 1.2 million tons in 2023, valued around US$6.3 billion in exports. Dozens of commercial hatcheries along the coast rear *Litopenaeus vannamei* (white-leg shrimp) larvae, relying on Artemia cysts as a crucial live feed. Besides shrimp, aquaculture of marine finfish is minor, and tilapia farming is relatively small-scale. The booming shrimp sector drives high demand for Artemia cysts to fuel its hatcheries but mostly being imported. Ecuadorian companies have pioneered local Artemia biomass production—since 2000, Bioartemia Cía. has cultured Artemia in Salinas to supply shrimp broodstock feed. This indicates strong scalability potential if more salt ponds are dedicated to Artemia farming.
- **Aquafeed and feed markets:** Ecuador's aquafeed industry is geared toward shrimp—shrimp feed production uses fishmeal and other proteins. While Ecuador does not produce much fishmeal domestically, it can import fishmeal relatively easily (neighboring Peru and Chile are top fishmeal exporters). Artemia biomass could be a novel feed ingredient or supplement. For instance, frozen Artemia biomass is already used in shrimp broodstock diets. If Artemia farming expands, excess biomass (beyond hatchery and nursery feeds) could be processed into meal for high-protein aquafeeds or even livestock feed. Reducing dependency on imported feed inputs is attractive for Ecuador's aquaculture sector.
- **Consumption and market:** Despite its fishing and shrimp industries, Ecuador's per capita seafood consumption is about 8.3 kg/year, relatively low. Seafood is part of the diet (for example, tuna, shrimp, tilapia domestically), but much of the high-value catch is exported. There is little cultural precedent for eating very small crustaceans in Ecuador—shrimp are popular but typically the larger penaeids. Artemia itself is not presently viewed as food. However, indirectly, Artemia contributes to food security by supporting shrimp farming (an export earner and job creator). Should protein needs rise, it is conceivable Artemia biomass could be used in fish sauce or as a fortifier, but culturally, this would be new.
- **Regulatory and research support:** The Ecuadorian government recognizes aquaculture as a strategic sector. In 2017, a dedicated Ministry of Aquaculture and Fisheries was briefly established, and today, aquaculture falls under the Ministry of Production. Biosecurity regulations for shrimp farms (to prevent disease) extend to live feeds—cyst imports are monitored and quality controlled. Ecuador has local expertise in Artemia: Private sector initiatives (Bioartemia) and collaboration with research institutions (for example, ESPOL University's aquaculture programs and research station CENAIM) support innovation. There are no specific Artemia farming subsidies, but general incentives (tax breaks, simplified licensing) for aquaculture projects could apply. Overall, Ecuador's strong shrimp industry and existing saltworks make it one of the most promising Latin American candidates for scaling up Artemia farming.
- **Opportunities:** Large-scale shrimp aquaculture industry provides a strong market for locally produced Artemia cysts and biomass. Existing saltworks in Santa Elena and Manabí could be adapted for Artemia farming. High demand for hatchery feed supports investment.
- **Constraints:** Most Artemia cysts are imported, and transitioning saltworks to Artemia farming requires infrastructure adaptation. Human food applications are currently limited.

Peru

Expanding Shrimp Sector, Seasonal Salt Ponds, Cyst Feasibility

- **Appropriate model for scaling:** Bangladesh + Viet Nam models - Leveraging seasonal salt ponds for artisanal Artemia production and cyst harvesting to supply local hatcheries.
- **Saline geography:** Peru's arid coast features several hypersaline lagoons and estuaries suitable for Artemia. A notable site is the Virrilá Lagoon (Sechura Bay) in Piura—a hypersaline estuary where salinity can exceed 150–180 g/L (globalseafood.org). In the 1990s, this area hosted pilot Artemia production (Project *Artemia del Pacífico*), confirming the natural Artemia population's viability. Other potential zones include coastal salt pans in southern Peru and highland salt flats (for example, Maras in Cusco, though small-scale).
- **Salt industry:** Peru's salt production is around **1.24 million tons/year**, mainly from coastal evaporation ponds. These saltworks and brine pools could be leveraged for Artemia farming, as done experimentally in Sechura.
- **Aquaculture industry:** Peru's aquaculture sector is smaller but growing. Shrimp farming is concentrated in the northwest (Tumbes and Piura regions), with production around 40,000–45,000 tons in 2022. White-leg shrimp are the main species, cultivated by a handful of companies that operate hatcheries and rely on Artemia for larval rearing. Peru also farms scallops and trout (each tens of thousands of tons) and some tilapia in the Amazon basin, but those do not currently use Artemia. The aquaculture industry value is in the order of a few hundred million US dollars (shrimp exports, trout for local markets). Hatchery capacity for shrimp is limited compared to Ecuador, but if the sector expands (there is interest in reviving shrimp farms and diversifying species), Artemia demand will rise. The Sechura Artemia project demonstrated that commercial Artemia biomass production is feasible to supply local hatcheries, potentially reducing reliance on imported cysts.
- **Aquafeed and feed markets:** Peru is paradoxically a top **fishmeal producer** (from wild anchoveta fisheries thefishsite.com) yet its aquaculture sector is modest. Fishmeal is a major export commodity; domestic aquafeed manufacturers have ample access to inexpensive fishmeal and fish oil. This reduces urgency to find alternative protein such as Artemia for grow-out feed, since fishmeal is plentiful locally. However, Artemia biomass could find a niche in specialty feeds—for example, enrichment diets for shrimp broodstock or larval feeds for any future marine finfish hatcheries. If Artemia cysts were produced in Peru, they could be exported or form the basis of a local Artemia-based feed industry. The existence of large fishmeal plants also means infrastructure for feed processing is available (if Artemia biomass were to be processed into a meal or paste).
- **Consumption and market:** Peruvians traditionally eat a lot of seafood (ceviches and so on)—about 27 kg per capita, one of Latin America's highest. They consume mainly fish (for example, hake, anchoveta products) and larger crustaceans (shrimp, crab) when available. Small crustaceans are not common in the cuisine, though *camarones* (river prawns) are used in dishes such as chupe de camarones. Artemia are not used for human food but indirectly contribute to it by enabling aquaculture. Given Peru's rich seafood culture, introducing Artemia as a direct food might not be necessary, but in a food security context, Artemia could be processed into protein/fat-rich supplements or fed to poultry/fish that Peruvians ultimately eat. Culturally, there is no inherent aversion—dried tiny shrimp could be used similarly to how Asian cultures use them, but it would require creating a market.
- **Regulatory and research support:** Peru's government (through the Ministry of Production, PRODUCE) has an aquaculture promotion plan aiming to increase farm output. There are national aquaculture innovation projects and some academic research (Universidad Nacional de Tumbes, IMARPE) investigating new species and feeds. Artemia farming aligns with these goals as it can boost hatchery self-sufficiency. Peru enforces biosecurity protocols for aquaculture—for example, controlling import of live shrimp postlarvae and Artemia cyst quality to prevent disease introduction. The country's prior Artemia project provided local know-how, though it was a private initiative. If investors propose Artemia farming (especially in conjunction with expanding shrimp farms), they would likely find a supportive regulatory environment. Overall, Peru has good natural sites and a need for Artemia as it looks to scale aquaculture, though current production is limited.
- **Opportunities:** Shrimp farming in Piura and Tumbes creates a demand for Artemia cysts. Virrilá Lagoon and other seasonal hypersaline areas can support cyst harvesting. Peru's fishmeal industry provides infrastructure for Artemia processing.
- **Constraints:** Artemia is not currently a priority in Peru's aquaculture strategy, and cyst production would need strong investment. Dependence on seasonal ponds may limit year-round production.

Annex 4. Investment Cases in Asia

India

Massive Salt Pans, Leading Shrimp Producer, Artemia Expansion Zone

- **Appropriate model for scaling:** Viet Nam + Thailand models - Utilizing vast salt pans for cyst production and biomass cultivation, especially for shrimp hatchery use.
- **Saline geography:** India possesses extensive saltpan areas and salt lakes that could support Artemia. The Rann of Kutch in Gujarat is one of the world's largest salt flats (~7,500 km^2) and yields millions of tons of salt annually; during seasonal flooding, parts of it form hypersaline pools that can harbor Artemia. Similarly, the Sambhar Salt Lake in Rajasthan (230 km^2) is a perennial hypersaline lake where *Artemia* have been reported. Along India's coastline, major saltworks in Gujarat (Little Rann) and Tamil Nadu (Tuticorin region) create thousands of hectares of evaporation ponds. These warm, shallow ponds are typically ideal for brine shrimp—in fact, *Artemia franciscana* was introduced into some Indian saltworks in the past for water quality management. In recent years, the Rajiv Ghandi Aquaculture Centre is involved in several small Artemia production projects along the west coast.
- **Salt industry:** India's salt production is about 24–30 million tons/year (third largest globally), so the sheer area under high salinity is enormous. Not all salt ponds currently have Artemia, but they could be seeded. Moreover, many shrimp farms in India, especially in Andhra Pradesh and Odisha, become very saline after harvest and could be repurposed seasonally for Artemia cultivation. With its tropical climate and vast salterns, India has high geographical potential for Artemia farming, especially in Gujarat's salt flats and coastal Tamil Nadu.
- **Aquaculture industry:** India is a global aquaculture leader by volume (ranked second or third). In 2022, farmed shrimp production was around 900,000 MT (mostly exported), and freshwater fish (mainly carp) production exceeded 5 million MT. However, carp and other freshwater finfish are usually raised in ponds with natural feed or formulated feed—they do not depend on Artemia. The big Artemia consumer in India is the shrimp hatchery sector, which is substantial. Along the east coast (Andhra Pradesh, Tamil Nadu, Odisha) and west coast (Gujarat), there are hundreds of shrimp hatcheries producing billions of postlarvae to supply India's shrimp farms. These hatcheries rely almost exclusively on imported Artemia cysts to feed shrimp larvae. India also has emerging marine finfish hatcheries (for Asian seabass, cobia, pompano, and so on) run by government and private players, all of which use Artemia at the larval stage. Tilapia farming in India is growing (especially with the introduced GIFT tilapia strain), but hatcheries mostly use artificial feeds; still, some high-quality tilapia hatcheries do use Artemia nauplii to boost fry growth. In monetary terms, Indian aquaculture is valued at several billion US dollars (shrimp exports ~US$5.5 billion, domestic fish market large as well). The need for Artemia in India is acute—with the world's second-largest shrimp aquaculture, India likely consumes a very large share of the global Artemia cyst supply. Any local Artemia production would thus directly support one of India's most valuable export industries and could scale with it.

- **Aquafeed and feed markets:** India has a booming aquafeed manufacturing sector (for carp, shrimp, and tilapia) but still relies on fishmeal imports to supplement domestic fishmeal. Artemia here is chiefly a **hatchery input**. The cost of cysts is a significant part of hatchery operating expenses. If India could produce Artemia cysts or biomass domestically, it would save foreign exchange and reduce hatchery costs. Indian feed companies and research institutes (such as CIBA [Central Institute of Brackishwater Aquaculture]) have been experimenting with **Artemia biomass as an ingredient** in larval feeds and broodstock diets. Artemia are rich in HUFA essential for larval fish/shrimp, so incorporating them can improve seed quality. Beyond aquaculture, there is exploratory interest in using Artemia or other brine organisms as chicken/fish feed additives (for pigments or protein). However, given the scale of India's aquafeed needs, Artemia would only ever comprise a small, specialized segment. The more impactful scenario is developing **Artemia cyst production hubs in Indian saltworks**, enabling India to possibly become an Artemia exporter (or at least self-reliant). With global Artemia demand around ~3,500 MT, even capturing a fraction of that market by leveraging India's vast salt pans could be economically attractive.
- **Consumption and market:** India's average per capita fish consumption is relatively low at 7.9 kg/year, but this masks great regional variation—coastal communities in Kerala, West Bengal, Goa, and so on eat much more seafood, whereas many inland or vegetarian populations eat little to none. Eating habits in India do include small dried fish and shrimp in some areas; for example, dried prawns and shrimp are used in curries and chutneys in the northeast and coastal regions. While Artemia are not known in Indian cuisine, using them as food would not be conceptually alien in regions that already consume small river shrimp or crayfish. Still, any direct human use of Artemia in India would likely be minimal—the greater benefit is indirect: bolstering aquaculture so more fish and shrimp reach the Indian consumer. Fish is seen as a nutritious food in India's food security planning, and increasing aquaculture production (with stable seed supply) is crucial to meet the protein demand for a growing population. In addition, India has a history of using unconventional foods in rural diets during lean times (for example, wild greens and insects in some tribal areas). If needed, Artemia (dried and ground) could possibly be used in fortified foods for malnutrition, given its protein and micronutrient content, though this is speculative. In short, Artemia's role in Indian human nutrition will be indirect but important by supporting a reliable supply of fish and shrimp.
- **Regulatory and research support:** The Indian government is actively encouraging aquaculture expansion through schemes such as the Pradhan Mantri Matsya Sampada Yojana (PMMSY). Part of this push includes improving hatchery technology and domesticating critical inputs. There is recognition that dependence on imports (such as Artemia cysts) can be a vulnerability. Indian Council of Agricultural Research (ICAR) institutes such as -Central Institute of Brackishwater Aquaculture CIBA) and Central Institute of Fisheries Education (CIFE) have conducted research on Artemia culture in salt pans and even on encapsulating Artemia in feeds. Biosecurity regulations in India's shrimp farming (which include mandatory testing of broodstock and SPF seed) implicitly value quality live feed—only reputable cyst brands are allowed. If Artemia were farmed locally, it would fall under the purview of the Coastal Aquaculture Authority or state fisheries departments for licensing. Given India's large salt industry, there are also regulations for saltpan land use—any integrated Artemia production might need coordination between fisheries and salt departments. On the research front, India has pioneered low-cost techniques such as lab-scale Artemia hatching and enrichment for farmers. Transitioning to large-scale Artemia farming will require demonstration projects, which the government or PPPs could fund. Notably, India's National Fisheries Development Board (NFDB) could consider Artemia hatcheries as a priority. Overall, policy support in India is favorable for anything that reduces import dependence and boosts aquaculture output, so Artemia farming ventures would likely receive encouragement, technical expertise, and possibly financial incentives in the form of subsidies or soft loans for innovative aquaculture projects.
- **Opportunities:** Large-scale salt pans in Gujarat and Tamil Nadu provide ample area for Artemia farming. The huge shrimp hatchery sector ensures consistent demand. Government aquaculture policies encourage localized hatchery feed production.
- **Constraints:** Heavy reliance on imported Artemia cysts. High competition from other aquafeed ingredients. Potential biosecurity concerns in integrating Artemia farming.

Indonesia

Shrimp Giant, Vast Brackish Ponds, Artemia Demand Hub

- **Appropriate model for scaling:** Bangladesh + Thailand + Viet Nam models - Enabling smallholder Artemia production alongside aquaculture and using cysts to reduce dependency on imported Artemia for hatcheries.
- **Saline geography:** Indonesia, with its extensive coastline and salt-making tradition, has many suitable sites for Artemia. The country's largest salt production area is on Madura Island (East Java), where vast evaporative ponds exist. Other significant saltworks operate in Central Java, East Nusa Tenggara (NTT), and South Sulawesi.
- **Salt production:** These tropical salterns can reach hypersalinity, and historically, some were inoculated with Artemia (Indonesian salt farms have at times cultured Artemia to improve salt quality and yield cyst by-products.). Indonesia's salt production (~650,000 tons/year) does not meet its huge domestic demand, leading to imports—but the existing salt ponds (thousands of hectares) are prime candidates for dual salt-Artemia production. Additionally, Indonesia's countless brackish shrimp ponds (tambaks) often become hypersaline during dry seasons and could potentially be converted or fallowed as Artemia ponds between cropping cycles. The geographic spread (from Java to Eastern Islands) means a variety of strains could be farmed. In summary, Indonesia has ample warm hypersaline environments (both natural lagoons and man-made ponds) that could be tapped for Artemia farming, especially in Java and NTT where salt ponds are underused part of the year.
- **Aquaculture industry:** Indonesia is one of the world's top aquaculture producers, with output (excluding seaweed) of 5.5 million tons in 2021. Key sectors include shrimp farming—Indonesia produces nearly 900,000 MT of farmed shrimp annually (vannamei and some tiger shrimp), much of it exported—and finfish culture (tilapia, catfish, carp for domestic markets, plus milkfish and groupers). The sheer scale of hatchery operations is massive: There are hundreds of shrimp hatcheries (notably in Java, Sumatra, and Sulawesi), as well as milkfish fry producers and grouper hatcheries in Bali and elsewhere. All these hatcheries are heavy Artemia users. In fact, with the expansion of shrimp and marine fish hatcheries, Indonesia likely ranks among the largest Artemia cyst consumers globally after Ecuador. The aquaculture industry is valued at several billion US dollars (shrimp exports alone ~US$2.2 billion). Despite high production, the sector's growth is held back partly by feed/hatchery input costs—meaning a local Artemia supply could be transformative. There have been pilot projects in Indonesia to locally produce Artemia cysts (for example, inoculating salt ponds in Bali and Madura with *Artemia franciscana*). If scaled, Indonesia could reduce reliance on imported cysts and use Artemia biomass to support its fast-growing aquaculture, which has government targets to more than double production in coming years (was.org).
- **Aquafeed and feed markets:** Indonesia's aquafeed industry is enormous, supplying feed for shrimp, fish, and poultry. The country does produce some fishmeal (from trawl bycatch and seasonal fisheries) but still imports a large volume of fishmeal to meet feed mill demand. Artemia, in this context, is mostly a *live feed* for hatcheries rather than a processed feed ingredient. Large integrators (for example, shrimp hatchery companies) import cysts and also sometimes use nurse ponds to grow Artemia biomass as supplementary feed for broodstock. If Artemia biomass were produced cheaply (for instance, as a secondary crop in salt farms), it might be incorporated into formulated larval feeds or enrichment diets. Indonesia is also a center of tropical aquaculture innovation—there is exploration of *biofloc* and other technologies to reduce feed costs. Artemia fits well as a natural feed to boost larval survival rates. Additionally, surplus Artemia could potentially be marketed for ornamental fish breeders, a niche but sizable market in Indonesia (for example, raising arowana or marine ornamentals). Given that global Artemia cyst prices have risen and can be a bottleneck, the ability to produce Artemia within Indonesia would strengthen its aquaculture value chain.

- **Consumption and market:** Indonesians are notable seafood consumers at ~44.7 kg per capita—one of the highest in the world. Fish is a staple protein especially in coastal and island communities. Small shrimp and krill are part of local diets in some areas; for example, *ebi* (dried small shrimp) is used in Javanese and Sundanese cuisine, and fermented shrimp paste (*terasi*) is ubiquitous in Indonesian cooking. Thus, the concept of eating tiny shrimp is culturally normal in Indonesia. Artemia from salt ponds could theoretically be harvested for food (dried or made into *terasi*), although currently, they are not utilized this way. More realistically, improving hatchery output via Artemia will increase production of fish and shrimp for Indonesians to eat, indirectly benefiting nutrition. Also, Indonesia has pockets of malnutrition—protein-rich foods such as fish are crucial—and aquaculture expansion is seen as a solution. One could even imagine Artemia biomass being used in supplemental foods (high-protein biscuits or powders) for human consumption if processed properly, as Indonesia has been innovative in developing products such as tempeh from unconventional protein sources. In summary, while direct human consumption of Artemia is not practiced, the cultural acceptance of small shrimp as food is high, and the indirect benefits of Artemia to seafood supply are very significant in Indonesia.
- **Regulatory and research support:** The Indonesian government (Ministry of Marine Affairs and Fisheries) strongly promotes aquaculture—it has set ambitious production goals and provides support for hatchery improvements and feed development. Indonesia is a member of the regional NACA (Network of Aquaculture Centres in Asia-Pacific), which has conducted training on Artemia resource management enaca.org. Past collaborations with the Artemia Reference Center (Ghent University) introduced *Artemia franciscana* to Indonesian salt ponds, indicating government openness to such initiatives. Policies such as localized feed production incentives and technology transfer grants could support Artemia farming ventures. Biosecurity is also key—Indonesia battles shrimp diseases, so producing Artemia domestically under controlled conditions could reduce the risk of introducing pathogens via imported cysts. Indonesian research institutes (for example, BRPBAP in Jepara) have live feed experts, and universities conduct studies on Artemia usage. The climate is ripe for innovation: Indeed, climate-smart Artemia production guidelines have been considered as part of sustainable aquaculture practices. In essence, Indonesia has policy, research, and economic motivation to invest in Artemia farming—it aligns with national goals of self-sufficiency and sustainable aquaculture growth.
- **Opportunities:** One of the world's largest shrimp producers, with hatcheries relying on imported Artemia. Large brackish shrimp ponds could be adapted for Artemia cultivation. Strong government push for aquaculture self-sufficiency.
- **Constraints:** High competition from imported cysts. Lack of awareness about integrating Artemia farming in existing brackish ponds. Infrastructure investment needed to scale cyst production.

The Philippines

Milkfish Stronghold, Small Salt Farms, Hatchery Dependency

- **Appropriate model for scaling:** Bangladesh + Thailand models - A few big and many small salt farms can be repurposed for Artemia production, focusing on biomass for the country's extensive milkfish hatchery sector.
- **Saline geography:** The Philippines, an archipelago, has many coastal salt-making areas and lagoons that could host Artemia.
- **Salt industry:** Traditional solar salt farms exist in Pangasinan, Cebu, and Mindanao—typically small ponds using seawater evaporation. Though the country produces only ~725,000 tons of salt annually (and even imports salt to meet demand), these saline ponds present an opportunity for Artemia co-culture. Additionally, some inland areas such as Laguna de Bustos (a seasonal lake) turn hypersaline in dry months and could sustain Artemia. The Philippines being tropical, temperatures are ideal for year-round Artemia growth. The key is ensuring sufficiently high salinity (>60 ppt); many ponds reach that at peak dry season. One notable site is Las Piñas–Parañaque wetland near Manila, which has brackish to hypersaline sections attracting birds—an indicator Artemia could thrive. Overall, while the Philippines lacks large salt flats, it has myriad small salt ponds and aquaculture evaporation basins that are geographically suitable for Artemia farming.
- **Aquaculture industry:** The Philippines has a sizable and diverse aquaculture sector (~over 0.5 million tons of fish/seafood annually). The backbone is bangus (milkfish) farming, which produces around 400,000 MT per year and depends on hatcheries that feed rotifers and Artemia to larvae. The country also produces ~10,000–15,000 MT of shrimp (*P. vannamei* and some black tiger shrimp)—much lower than its 1980s peak—but there is interest in reviving shrimp farms. Tilapia (~300,000 MT) are mostly raised in lakes and use fry from hatcheries (tilapia fry can eat formulated feed early, so Artemia use is minimal for tilapia.). There is also significant production of seaweed (not relevant to Artemia) and ornamentals (which do use Artemia in rearing fry). Major hatcheries for milkfish and shrimp are located in Iloilo, Cebu, and Luzon, all of which rely on imported Artemia cysts. Given the scale of milkfish alone, the Philippines consumes a large quantity of Artemia—typically importing cysts from the GSL and elsewhere. The aquaculture industry is valued at roughly ~US$1 billion and is growing to meet domestic fish demand. Scaling local Artemia farming would greatly benefit the milkfish hatchery segment (one of the world's largest) and reduce foreign dependency for critical feed.
- **Aquafeed and feed markets:** The Philippines imports a substantial amount of fishmeal for aquafeeds, as local fishmeal production (from sardines) is not enough. Aquafeed demand is driven by tilapia, milkfish, and shrimp feeds. Artemia biomass could be utilized in specialized feeds—for example, some shrimp broodstock diets in the Philippines include fresh feeds such as worms or Artemia if available. More practically, live Artemia nauplii are fed directly in hatcheries, so the focus is on cyst supply. If Artemia farming yields excess cysts or adults, these could potentially be processed into poultry or pig feed supplements (Filipino farmers do use fermented fish/shrimp paste to feed pigs in some areas). This indicates that turning Artemia into a similar product is conceivable if there is a surplus—it would be an acquired taste but not far-fetched given the existing use of small crustaceans in food. For now, the main target of Artemia production would be reducing the cost of hatchery feeds and possibly selling cysts regionally if oversupplied.
- **Consumption and market:** Filipinos are heavy seafood consumers—about 28.4 kg per capita—and seafood (fish, shellfish, seaweed) is integral to diets. Small crustaceans are part of this food culture: Filipinos commonly use tiny shrimp or krill in sauces and dishes (for example, bagoong alamang, a salty fermented shrimp paste made from minute shrimp/krill) (shopwestcovina.seafoodcity.com). Thus, from a cultural perspective, there is no barrier to using small shrimps such as Artemia as food, though currently, Artemia are not harvested for that purpose. In times of need or as a novelty, Artemia could be dried or processed as human food—for example, as savory snacks or flavoring—and people might accept it similarly to other dried shrimp products. More importantly, increasing Artemia availability will help hatcheries produce more fish and shrimp, thereby improving overall seafood supply for local consumption. Given the Philippines' high reliance on seafood for protein, any enhancement to aquaculture productivity (via reliable Artemia feed) is a boost to human nutrition and food security.
- **Regulatory and research support:** The Philippines has strong institutional support for aquaculture. The Bureau of Fisheries and Aquatic Resources (BFAR) oversees hatchery programs and biosecurity. The country is also home to the SEAFDEC Aquaculture Department, a leading research center that developed commercial milkfish hatchery technology decades ago—including the

use of Artemia. Researchers in the Philippines have experimented with Artemia pond culture on a small scale, and ongoing training programs exist on live food production for hatcheries. Government policy encourages reducing input costs for fish farmers, so producing Artemia locally (thus cutting expensive imports) would be welcomed. There may be incentives such as soft loans or technical assistance for ventures that localize aquafeed inputs. Additionally, any Artemia farming would fit into the Philippines' national aquatic agenda of self-sufficiency and bio-secure hatchery practices. Overall, the climate for Artemia farming in the Philippines is favorable: There is technical know-how, pressing demand, and government interest in improving hatchery outputs.

- **Opportunities:** Large-scale milkfish hatchery sector requires Artemia cysts. Numerous small salt farms across the country could integrate Artemia farming. Government incentives support aquaculture expansion.
- **Constraints:** High reliance on imports for cysts and small salt farm sizes may limit large-scale Artemia production. Artemia as human food is not yet established.

Annex 5. Investment Cases in the Middle East

The Islamic Republic of Iran

Artemia Present, Growing Aquaculture, Cyst Market Potential

- **Appropriate model for scaling:** Viet Nam model - Focusing on cyst harvesting from natural Artemia stocks in Lake Urmia while also developing controlled Artemia farming in salt ponds.
- **Saline geography:** The Islamic Republic of Iran boasts some of the most significant hypersaline habitats in the Middle East. The crown jewel is Lake Urmia in northwestern Iran—once one of the largest salt lakes in the world (surface area historically 4,750–6,100 km^2) (Eimanifar and Mohebbi 2007). Lake Urmia's salinity can exceed 300 g/L in dry periods, and it is famed for its endemic brine shrimp *Artemia urmiana* population. Although Lake Urmia has shrunk drastically due to drought and water diversion, efforts are under way to restore it, which would revive its Artemia habitat. Beyond Urmia, the Islamic Republic of Iran has numerous salt lakes/deserts: the Maharloo Lake near Shiraz (seasonally pink with Artemia and Dunaliella), the Dasht-e Kavir and Dasht-e Lut salt deserts (with some wet salt flats), and coastal salt marshes along the Persian Gulf.
- **Salt industry:** The Islamic Republic of Iran's total salt production is ~2.8 million tons/year, indicating substantial evaporative facilities that could support Artemia. Notably, in southern provinces such as Fars and Bushehr, there are solar salterns and shrimp farm effluent ponds that turn hypersaline. The Islamic Republic of Iran's varied climate (temperate north, arid central, tropical south) means Artemia could potentially be farmed year-round by choosing the right region. In summary, the Islamic Republic of Iran has rich natural Artemia sites (such as Urmia) and man-made salterns, providing an excellent geographic base for Artemia cultivation.
- **Aquaculture industry:** The Islamic Republic of Iran has a growing aquaculture industry with about 478,000 MT produced in 2021. A large portion of this is freshwater carp and trout farming in inland waters (which do not use Artemia), but the Islamic Republic of Iran also has a notable shrimp farming sector. Shrimp farms (mostly on the Persian Gulf coast in Bushehr, Hormozgan, and Khuzestan) produce tens of thousands of tons of *P. vannamei* annually—exact figures vary, but roughly 30–40,000 MT in recent years. These shrimp hatcheries require Artemia for larval rearing and have sometimes faced cyst supply issues. Additionally, the Islamic Republic of Iran is investing in sturgeon aquaculture (for caviar and meat) and marine finfish culture (grouper, seabass in cages and ponds). Sturgeon hatcheries might use little or no Artemia (sturgeon larvae often fed tubifex worms or formulated feed), but marine fish hatcheries definitely require Artemia. The Islamic Republic of Iran's aquaculture output is valued in hundreds of millions of US dollars (especially caviar contributing high value). The Islamic Republic of Iran's unique position is that it has both modern aquaculture and a natural Artemia resource (Lake Urmia). Indeed, there have been attempts to harvest Artemia cysts from Lake Urmia for use in local hatcheries. As the Islamic Republic of Iran aims to expand aquaculture (it was ranked seventeenth globally in aquaculture production), securing a local Artemia supply is strategically important. Should Lake Urmia recover, the Islamic Republic of Iran could potentially harvest significant volumes of *Artemia urmiana* cysts; alternatively, Artemia could be farmed in evaporation ponds in the south. The Islamic Republic of Iran's aquaculture expansion plans would directly benefit from domestic Artemia farming, reducing the need for imports and possibly allowing the country to export cysts in the region.

- **Aquafeed and feed markets:** The Islamic Republic of Iran produces some fishmeal (from Caspian Sea Kilka and Gulf fisheries by-products) but also imports feed ingredients. Aquafeeds for trout and carp are produced locally, whereas shrimp feed often relies on high-quality imported additives. Artemia cysts for hatcheries have largely been imported (or sourced from Urmia in small quantities). The Iranian Artemia Research Center has worked on culturing Artemia as a live feed to ensure hatcheries have a stable supply. One concept in the Islamic Republic of Iran has been to use *Artemia biomass from Urmia Lake* as a protein source for poultry or aquafeed; millions of Artemia died during lake desiccation, and there were studies on using that biomass. While this is not yet a commercial reality, it shows the thinking toward using Artemia beyond just live feed. If Artemia farming is scaled, the Islamic Republic of Iran could incorporate Artemia biomass into the diets of farmed shrimp (for example, replacing some fishmeal with processed Artemia meal) or use it for broodstock conditioning. Artemia nauplii will remain irreplaceable for larviculture, so the primary goal is meeting that demand. Given that global Artemia cyst demand outstrips supply, any surplus the Islamic Republic of Iran could produce (for instance, from a revived Lake Urmia) could find buyers in other aquaculture-heavy countries. The Islamic Republic of Iran could emerge as a regional supplier of Artemia cysts and derived feed products if its programs succeed, leveraging both natural lakes and man-made saltworks for production.
- **Consumption and markets:** The Islamic Republic of Iran's per capita seafood consumption is around 12.1 kg/year, moderate by global standards. Fish (both fresh and marine) is part of the diet, especially in coastal regions and the Caspian area, but red meat and poultry are more dominant nationally. Eating brine shrimp or small crustaceans is not part of traditional Iranian cuisine. However, there is one indirect human connection: Lake Urmia's Artemia supported huge flocks of flamingos, whose beauty and eventual decline became a public symbol of the lake's ecological importance. Thus, Iranians recognize Artemia as a key part of a natural food web, if not as food for themselves. From a food security perspective, the Islamic Republic of Iran is interested in increasing seafood in diets for health benefits. By boosting aquaculture with Artemia feed, more affordable fish can be offered to consumers, improving nutrition. In remote areas near hypersaline lakes, some locals historically harvested wild brine shrimp cysts (not to eat but to sell as fish bait or feed). It is conceivable that if pressed, people could consume Artemia, but culturally it would be unusual. Instead, the concept of Artemia as 'mini-livestock' to feed fish that people eat is the accepted narrative. If Artemia production mitigates the protein gap via aquaculture, it indirectly supports the Islamic Republic of Iran's food security objectives.
- **Regulatory and research support:** The Islamic Republic of Iran is a regional leader in Artemia research with two main players. The Iranian Fisheries Science Research Institute established a dedicated Artemia Research Center in Urmia in 2000, focusing on Artemia ecology, culturing, and its use in aquaculture. The Artemia center at Urmia University has been involved in several projects to produce Artemia cysts and biomass for local use in aquaculture farms. This center (now part of the Urmia Lake Restoration Program) has been pivotal in studying how to mass-culture Artemia and even bank cysts for aquaculture use. The government has strong interest in saving Lake Urmia, and part of that involves managing Artemia populations as the lake refills. On the policy side, the Islamic Republic of Iran supports aquaculture through subsidies on feed and broodstock imports; if Artemia farming projects arise, they could fit into these support schemes. The Artemia & Aquaculture Research Institute at Urmia University has a long tradition in studying Artemia production and use in local aquaculture. The country's science-driven approach (for example, hosting international Artemia symposiums in the past) and government backing mean that research and policy alignment is high for Artemia. In short, the Islamic Republic of Iran not only has the natural resources but also the political will and scientific capacity to develop Artemia farming, both to aid its aquaculture sector and possibly to export cysts, all under a regulated and studied framework.
- **Opportunities:** Lake Urmia historically supported wild Artemia cyst production, which could be revived. The growing shrimp and marine fish farming sectors increase demand. The Islamic Republic of Iran has strong research institutions specializing in Artemia.
- **Constraints:** Lake Urmia's fluctuating water levels make cyst harvesting inconsistent. Political and economic barriers may limit foreign investment.

Saudi Arabia

Aquaculture Ambitions, Solar Saltworks, Artemia for Biosecurity

- **Appropriate model for scaling:** China + Viet Nam models - Integrating Artemia into large solar saltworks and harvesting cysts for growing shrimp and marine fish hatcheries.
- **Saline geography:** Saudi Arabia's environment is dominated by deserts, but there are substantial coastal sabkha (salt flats) and high-salinity brine pools that could nurture Artemia. Along the Red Sea coast, near Jeddah and Jizan, there are saltworks and hypersaline lagoons. Along the Persian Gulf coast, vast sabkhas (such as the Sabkhat Matti spanning Saudi Arabia/United Arab Emirates [UAE]) and man-made evaporation ponds from desalination plants create extreme salinities.
- **Salt industry:** Saudi Arabia produces about 2 million tons of salt per year, mostly through solar evaporation in eastern provinces. These salt farms are potential Artemia sites. Importantly, Saudi Arabia's largest aquaculture complex (NAQUA in the Red Sea coast) has integrated facilities that include effluent ponds which can get hypersaline. For some time, NAQUA cultivated Artemia in its operations using Red Sea water. This suggests that at least in localized areas, conditions are suitable and already being used. Additionally, Saudi Arabia's climate (hot and dry) means evaporation is intense—a challenge for water supply but ideal for concentrating brines. Even brine discharge from desalination plants (of which Saudi has many) could be redirected to Artemia production ponds, turning waste into a resource. Overall, while Saudi Arabia lacks natural perennial salt lakes, it has ample artificial and coastal hypersaline environments, from which Artemia farming could be developed, especially in tandem with existing aquaculture or salt industries.
- **Aquaculture industry:** Saudi Arabia's aquaculture sector is rapidly emerging. Current production is modest (~55,000 MT in recent years) (enaca.org), mostly shrimp and some fish, but the government's Vision 2030 plan targets hundreds of thousands of tons. Shrimp farming is the cornerstone—farms in the Red Sea (such as NAQUA and others) produce *P. vannamei* shrimp for export. These farms operate modern hatcheries that depend on Artemia for larval rearing. Saudi Arabia also farms some marine fish (for example, barramundi, seabream, and hamour/grouper) in cages and ponds; their hatcheries likewise need live feeds. With expansion, the number of hatcheries will grow, driving Artemia demand up. The total value of aquaculture in Saudi Arabia is climbing (shrimp exports and high-value fish for local markets). NAQUA, for instance, is one of the largest integrated aquaculture companies in the Middle East and has been proactive in securing Artemia—it even partnered to ensure a supply of Artemia nauplii on-site (iandv-bio.com). Currently, Saudi Arabia imports all Artemia cysts from abroad. But given the small volumes of aquaculture at present, the country could feasibly aim for self-sufficiency in Artemia as it scales.
- **Aquafeed and feed markets:** Saudi Arabia imports the bulk of its aquafeeds and feed ingredients (it has no domestic fishmeal production of note, for example). The country is investing in feed mills for aquaculture, but ingredients such as soybean meal and fishmeal are brought in. Artemia cysts are also imported and are a high-cost component for hatcheries. Saudi Arabia's large shrimp integrators are exploring ways to reduce hatchery feed costs and improve biosecurity—cultivating Artemia on-site is one such measure. Saudi Arabia's substantial poultry industry could use novel protein sources too, but using Artemia for that would likely be cost-prohibitive unless done at a very large scale. More realistically, any Artemia farming in Saudi Arabia will directly service aquaculture: live nauplii for larvae, and perhaps frozen adults for broodstock or juvenile feed. As Saudi aquaculture is aiming to be state-of-the-art, integrating Artemia bioreactors or pond culture as part of a hatchery's design could become standard. Also, if Saudi Arabia overshoots in Artemia production, it could export cysts to other Gulf countries or Southeast Asia. Considering global supply tightness, this could even become a small export earner in the future. Right now, the focus is meeting domestic demand; but with government-backed expansion, Saudi Arabia could become a regional hub for Artemia-based feed solutions as part of its quest for aquaculture self-reliance.

- **Consumption and markets:** Saudi Arabians consume about 11.3 kg of seafood per capita. Traditionally, diets in Saudi Arabia leaned on meat and dates, with seafood more common in coastal communities. However, fish consumption is rising with changing lifestyles and a push for healthy eating. Small crustaceans (such as krill or tiny shrimp) are not part of the cuisine—Saudis prefer larger fish and shrimp. It is unlikely Artemia would be used directly as food in Saudi Arabia; there is no precedent like the shrimp pastes of Asia. The more relevant aspect is how Artemia farming can contribute to food security by enabling more aquaculture. Saudi Arabia, as a desert nation, sees aquaculture as a way to produce protein without stressing limited freshwater resources. Artemia is a key piece in making aquaculture sustainable and independent (since relying on imported cysts could be a vulnerability). In the long run, if aquaculture meets its targets, Saudi citizens will have more locally farmed fish/shrimp to eat, reducing reliance on seafood imports. Artemia thus plays a supporting role in the Kingdom's food security strategy. As for any direct human health uses, perhaps in exotic gourmet circles, brine shrimp could be a novelty (for example, as a quirky cocktail ingredient or garnish), but that is a stretch—there is no current indication of Artemia entering diets. Indirectly, by helping produce omega-3-rich fish domestically, Artemia contributes to healthier diets in Saudi Arabia.
- **Regulatory and research support:** Saudi Arabia's government is strongly committed to expanding aquaculture and has set up regulatory frameworks and incentives to do so. The Ministry of Environment, Water and Agriculture oversees aquaculture, and there are national strategies emphasizing sustainability and biosecurity. Biosecurity is a top priority—a national biosecurity manual for aquaculture is in place (sas.org.sa), and it covers live feed handling to avoid disease. This means any Artemia culture would be done under strict protocols (for example, preventing introduction of foreign strains without approval and sanitary monitoring of cultures). On the research side, Saudi institutions (often in collaboration with international partners) are getting involved in aquaculture R&D. KAUST (King Abdullah University of Science and Technology) has marine research that could extend to live feeds. NAQUA itself, being a large company, conducts trials and innovations—their success with in-house Artemia shows private sector R&D capacity. Additionally, Saudi Arabia often works with global experts (for instance, Belgium's INVE Aquaculture has been active in the region) to implement new technologies. If an investor or research body proposed a dedicated Artemia farm (for example, using desalination plant brine), it would likely get government backing as it aligns with the self-sufficiency narrative. The regulatory environment would treat Artemia farming as part of the aquaculture value chain—requiring licensing but also eligible for government support and potentially public funding. Given the clear statements in plans that live feeds are critical for hatchery success, Saudi regulators and policy makers are very much in favor of local Artemia production to de-risk the ambitious aquaculture expansion.
- **Opportunities:** Large-scale aquaculture expansion in the Red Sea increases Artemia demand. Solar saltworks could be leveraged for Artemia farming. Government policies promote food security through aquaculture investments.
- **Constraints:** Harsh desert climate may limit year-round production. High reliance on desalinated water for aquaculture may complicate Artemia farming.

United Arab Emirates

Desalination Brine, Solar Saltworks, and High-Tech Aquaculture

- **Appropriate model for scaling:** China model - Leveraging desalination brine ponds for controlled Artemia production, ensuring cyst supply for hatcheries and high-tech aquaculture.
- **Saline geography:** The UAE, including Dubai and other emirates, has an arid climate with extensive coastal salt flats. While the UAE's salt production is not globally large (see Sama Salt Production Co.), it does have notable hypersaline areas. For example, the sabkha plains of Abu Dhabi (spreading thousands of hectares) are salt-encrusted flats that periodically flood with seawater and evaporate. These could be engineered into Artemia cultivation ponds if water supply is managed. Dubai itself has the Ras Al Khor wildlife sanctuary—a coastal wetland with fluctuating salinity that supports flamingos (indicating presence of brine shrimp or similar prey). Additionally, the UAE has many desalination plants, especially in Abu Dhabi and Dubai, which discharge brine. This discharge could be diverted to artificial salt ponds for Artemia farming, turning an environmental liability into an aquaculture asset. Temperatures in the Gulf are high, meaning fast Artemia growth cycles but requiring careful water management to prevent salinity overshoot. In summary, the UAE lacks natural large salt lakes, but it compensates with man-made environments (salt pans, evaporation basins, brine effluent ponds) that can be optimized for Artemia. The relatively small geographic scope (compared to giants such as the Islamic Republic of Iran or India) means Artemia farms would be more controlled, possibly high-tech operations, but certainly feasible.
- **Aquaculture industry:** The UAE's aquaculture industry is still in early stages but expanding. Dubai and the other emirates have invested in fish farming (hamour/grouper, seabream, tilapia in Recirculating Aquaculture Systemsi, and so on) and shrimp farming (there are only a couple of shrimp farms in the UAE). Total production is modest (a few thousand tons per year), but plans are in place to increase this as part of food security initiatives. For instance, the Ministry of Climate Change and Environment has established the Sheikh Khalifa Marine Research Center in Umm Al Quwain, which includes a large hatchery for species such as grouper, pomfret, and shrimp. All those hatchery operations rely on live feed including Artemia. Currently, the UAE likely imports Artemia cysts for these uses. As the industry is small, the volume is not huge, but the cost of cysts per unit product is high for hatcheries. If Dubai or the UAE scales up aquaculture (they have high-tech projects such as offshore fish cages, aquaponics, and so on), the reliance on Artemia will grow correspondingly for any species that is bred locally. The UAE's aquaculture is largely high value, targeting local premium seafood markets. Ensuring a steady supply of Artemia nauplii will be important to maintain quality fry output. In summary, while the present aquaculture output is low, the UAE has a clear trajectory toward expansion, and establishing Artemia farming could both support that growth and even position the UAE as a supplier of Artemia to its Gulf neighbors (who are also ramping up aquaculture).
- **Aquafeed and feed markets:** The UAE imports most of its animal feed, including aquafeeds and feed ingredients, given limited local raw materials. Artemia cysts are part of those imports for aquaculture. One potential advantage the UAE has is capital and technology—it could explore controlled Artemia cultivation systems (for example, indoor bioreactors or fenced ponds using desalination brine) more readily than other countries. Such systems can produce clean Artemia nauplii at a premium quality, which aligns with the UAE's preference for high-tech solutions. If Dubai invests in an Artemia hatchery facility, it could supply local hatcheries year-round without concerns of global price fluctuations. The demand for Artemia biomass beyond hatcheries is not currently significant (no large-scale livestock to feed with Artemia), so any production would be channeled to aquaculture. One interesting possibility: Artemia as live feed in the ornamental fish industry—Dubai is a trade hub for ornamental fish in the Middle East, and locally bred ornamentals could use Artemia (many hobbyists hatch Artemia for fish). A commercial Artemia operation could also cater to this niche (selling cysts or live nauplii to aquarium shops). The feed market in the UAE will likely remain dependent on imports for bulk feeds, but for the specialized segment of hatchery feed, domestic Artemia farming can carve a reliable niche.

- **Consumption and market:** The UAE has relatively high seafood consumption (due to its coastal population and expatriate communities); the per capita seafood intake is about 27 kg/year, which is higher than the global average. Local diets include a lot of fish (grilled, fried, and so on) and shrimp/lobster in luxury cuisines. However, direct consumption of tiny shrimp or Artemia is not part of the food culture. People are accustomed to larger shrimp and fish. It is unlikely that Artemia would be marketed for human food in Dubai—the city leans toward gourmet and luxury, and brine shrimp do not obviously fit that, except perhaps as a novelty molecular gastronomy ingredient. Therefore, Artemia's contribution to human nutrition in the UAE is indirect: By making local aquaculture viable, it ensures a supply of fresh, locally farmed seafood for the population. The UAE is concerned with food security (as a desert nation importing most of its food), and boosting aquaculture is a pillar of their strategy. Artemia farming would strengthen that pillar, helping ensure that hatchery production of fingerlings and postlarvae is not a limiting factor in seafood production. In emergency scenarios, could Artemia be a protein source? Possibly, but given the UAE's wealth, it is more practical that Artemia remains part of the hidden supply chain that guarantees fish on the table.
- **Regulatory and research support:** The UAE government actively supports aquaculture development through policies and funding. For example, it provides land and financing for new aquaculture farms, and it has updated regulations to streamline aquaculture licensing. If Artemia farming is proposed, it would likely be facilitated under these aquaculture regulations. There are also environmental regulations—any large-scale use of coastal flats or desalination brine would need environmental impact assessments, as the UAE is careful to protect its coastal ecosystems (for example, mangroves and wildlife sanctuaries). On the research front, the UAE collaborates internationally; it might draw on expertise from countries such as Belgium (Artemia Reference Center) or the US for Artemia projects. We can expect a high degree of technological adoption—for instance, using renewable energy to pump brine or sensor networks to monitor Artemia culture conditions—consistent with Dubai's smart city ethos. Government agencies would oversee biosecurity, ensuring that any Artemia introduced (if not already present in local salt waters) poses no risk. Given that Dubai successfully maintains flamingo populations in Ras Al Khor presumably feeding on natural Artemia or similar, there is evidence the organism can thrive there. Turning that natural presence into a managed farming operation would have regulatory support as it dovetails with the UAE's vision of innovation in food production. In conclusion, Dubai/the UAE has favorable conditions and support for Artemia farming on a pilot-to-commercial scale, as part of its broader agenda to secure and localize aquaculture inputs.
- **Opportunities:** Desalination plants produce brine waste that can be repurposed for Artemia farming. High-tech aquaculture projects are expanding in Dubai and Abu Dhabi, increasing the need for local hatchery inputs.
- **Constraints:** Small-scale aquaculture industry means limited immediate demand. Need for specialized infrastructure to cultivate Artemia in controlled environments.

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