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Review Article

Natural Biota's Contribution to Cultured Aquatic Animals' Growth in Aquaculture Cannot Be Ignored

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The rapid expansion of the aquaculture industry is accompanied by high organic and nutrient loadings from formulated feeds. This leads to water deterioration and pathogenic microorganisms. Natural biota (e.g., bacteria, phytoplankton, zooplankton, and zoobenthos) in ponds form important parts of cultured aquatic animals' diets. They contain essential proteins, lipids, carbohydrates, amino acids, and fatty acids and are considered promising supplementary nutrition sources for cultured aquatic animals. Particularly, they are available to aquatic animals throughout the day, and an adequate supply of them as starter foods during the larvae stage ensures high survival. Since formulated feeds constitute more than 50% of aquaculture production costs, optimizing the utilization of natural biota and reducing dietary nutrient input without compromising animals' growth should be a priority to improve the economic success and sustainability of aquaculture. From this scenario, the present review offers an updated view of the natural biota category in aquaculture systems, their nutritional components, and their contributions to the growth of cultured aquatic animals. Taken together, this review emphasizes the significant roles of natural biota playing in the growth of aquatic animals and encourages maximizing utilization of natural biota to improve feed conversion efficiency and aquaculture sustainability.

1. Introduction

Aquaculture supplies more than two-thirds of fishery products consumed worldwide, contributing significantly to global food security and poverty alleviation [1]. Nevertheless, the industry faces numerous challenges regarding its sustainability, especially for nutrient pollution originating from the overuse of feeds, leading to high amounts of organic and nutrient loadings in water environments [2, 3]. The situation is particularly true for semi-intensive or intensive aquaculture production, which mainly depends on high-cost dietary inputs via "formulated artificial diets" [4–6]. The nutrient loadings result in water deterioration, which in turn causes the thriving of pathogenic microorganisms and eventually the death of cultured aquatic animals [7]. This causes more than $9.5 billion economical loss per year in aquaculture [8]. It is, therefore, of supreme importance for aquaculture management to be optimized by improving feeding strategies for aquaculture suitability [7].

Natural biota, composed of internally correlated ecological communities of biological species, are the foundation of the food chains in ecosystems and important natural food items for aquaculture targets. At the broadest level, the natural biota in the aquatic system underlies adaptive diversification of species belonging to bacteria, phytoplankton, periphyton (algae attached to stream substrates), macrophytes (visible plants that are either rooted in the substrate in the case of emergent and floating-leaved macrophytes, floating beneath the surface in the case of submerged macrophytes, or floating on the surface in the case of free-floating macrophytes), zooplankton (suspended in the water column), and zoobenthos (inhabit around the stream bed) [9]. In aquaculture ponds, the production process is based on the conversion of solar energy into chemical energy stored in glucose during photosynthesis by phytoplankton (Chrysophyceae, Cyanophyta, Bacillariophyceae (diatoms), Euglenophyceae, and Chlorophyceae (green algae)), algae, and other submerged plants, which constitute essential nutritional sources for aquatic life. Zooplankton (Protozoa, Rotifera, Copepoda, Cladocera, and Ostracoda), zoobenthos (Chironomidae, Oligochaeta, Ceratoponogonidae, and Mollusca), fish, shrimp, crayfish, and crabs dominate the consumption process, and they derive nutrition from autochthonous and added organic matters (e.g., formulated feeds) [10]. In the decomposition process, microorganisms such as bacteria (*Escherichia*, *Thermotoga*, *Cyanobacteria*, *Streptomyces*, *Methanobacterium*, *Rhodospirillum*, *Nitrobacter*, and *Azotobacter*) play significant roles in the decomposition of organic detritus and the recycling of essential nutrients, acting as a sink for carbon [11]. The decomposed detritus and inorganic nutrients are consumed by cultured aquatic animals, which finally build blocks for biomass. These natural biota (rich in proteins, lipids, amino acids, fatty acids, vitamins, trace elements, and bioactive compounds) improve the growth and nutritional values of numerous cultured aquatic animals (herbivorous/omnivorous species) [7, 12–23]. They can also replicate some of their effects with nonliving cells or components of the cell wall, particularly those involving the digestive and metabolic processes, intestinal balance, and immune system [20]. Their accessibility, palatability, reproducibility, and better nutritional levels make them valuable foods, especially for larvae. Supplying adequate natural biota during population recruitment of fish, shellfish, crayfish, shrimp, and crabs ensures maximum aquaculture production and profitability [12, 17, 24–27]. Furthermore, the utilization of these natural biota in aquaculture is cost-effective, which can hopefully reduce formulated feed inputs and increase the productivity and efficiency of aquaculture production systems [10, 28].

It is, therefore, possible to improve feeding strategies that maximize the utilization of natural biota as an alternative way to reduce formulated feed input for sustainable and environmentally friendly aquaculture. A comprehensive understanding of the categories of natural biota in aquaculture ponds, their nutritional components, and their contributions to the growth of cultured aquatic animals' is a top priority. This review detailed the category, discussed their general properties as promising candidates for aquatic animals' foods, discussed their contributions to animals' growth, and highlighted the benefits of utilizing them in aquaculture.

2. Natural Biota Category in the Aquaculture System

In freshwater aquaculture systems, natural biota are normally classified into autotrophs, heterotrophs, and detritus. Autotrophic natural biota include phytoplankton (algae, Chrysophyceae, Cyanophyta, Bacillariophyceae, Euglenophyceae, and Chlorophyceae), periphyton (attached algae), and aquatic macrophytes (very low biomass) [10, 29]. Heterotrophic natural biota comprised bacteria, zooplankton (Protozoa, Rotifera, Copepoda, Cladocera, and Ostracoda), and zoobenthos (Chironomidae, Oligochaeta, Ceratoponogonidae, and Mollusca). Detritus is characterized by organic particles from dead organisms. They interact and contribute to the formation and stability of ecosystems.

2.1. Phytoplankton. Phytoplankton is capable of oxygenic photosynthesis and normally contains chlorophyll *a*. They convert solar energy into chemical energy, which forms the base of food webs in aquatic ecosystems. In freshwater aquaculture ponds, Chrysophyceae, Cyanophyta, Bacillariophyceae (diatoms), Euglenophyceae, and Chlorophyceae (green algae) mainly constitute phytoplankton [29], with over 20 genera found (summarized in Table 1). The biomass of phytoplankton was highly variable among aquaculture ponds. For example, their biomass ranged between 7.85×10^5–10.24×10^5 cells/L, 29.39×10^5–32.90×10^5 cells/L, and 15.8×10^5–21.10×10^5 cells/L for pond bottom with sandy loam, loam, and clay loam [35]. The biomass was higher in the fish culture ponds (Subarno Agro-Based Initiative and Bismillah Agro Production), which was 36×10^5–94.92×10^5 cells/L, with *Euglena* sp., *Microcystis* sp., and *Eurolena* sp. dominant [37]. The high phytoplankton biomass was also observed in crayfish *Cherax cainii* culture ponds, which ranged from 500,000 to 14500,000 cells/L [38]. Normally, the highest phytoplankton biomass occurred in spring, followed by early autumn and summer, with the lowest abundance in winter [30]. In spring, Chlorophyceae (green algae) had the highest abundance and constituted 49%–76.6% of the total observed phytoplankton population, followed by Bacillariophyceae (diatoms, 18.9%–40.4%) [39]. In early autumn, Cyanophyceae dominated in aquaculture ponds (main genera: *Microcystis, Anabaena*, and Planktolymbya), while Chlorophyceae (*Chlorella vulgaris*, *Pediastrum* sp., and *Scenedesmus denticulatus*) were dominant in rainy seasons, and Bacillariophyceae (*Navicula angusta* and *Cyclotella meneghiniana*) were dominant in winter [30]. Overall, the biomass of Bacillariophyta, Chlorophyta, Cyanobacteria, Euglenophyta, and Pyrrophyta was 0.07–25.1×10^6 ind./L, 1.63–73.2 ind./L, 6.78–54.9×10^6 ind./L, 1.53–11.8×10^6 ind./L, and 0.09–0.72×10^6 ind./L across seasons, with the relative contributions of 12.5%, 22.5%, 12.5%, 10%, and 2.5%, respectively [33, 40].

Chrysophyceae, the golden algae, produce siliceous cysts called stomatocysts or statospores and get energy and nutrients by photosynthesis and/or heterotrophy (ingesting bacteria or complex organic molecules) [41]. Species *Hydrurus foetidus*, the genera *Mallomonas*, and *Synura* are widely distributed and are considered a valuable food source for cultured aquatic animals [31, 32, 36]. Furthermore, *Dinobryon* sp. and *Synura* sp. are also common species belonging to Chrysophyceae in aquaculture ponds.

Table 1: Phytoplankton genera recorded in aquaculture ponds.

Group	Genera
Chrysophyceae	*Synura*, *Mallomonas*, and *Dinobryon*
Chlorophyceae	*Ankistrodesmus*, *Actinastrum*, *Botryococcus*, *Chaetophora*, *Chlamydomonas*, *Chlorella*, *Chlorococcum*, *Closterium*, *Coelastrum*, *Cosmarium*, *Dictyosphaerium*, *Eudorina*, *Hyaloraphidium*, *Golenkinia*, *Monoraphidium*, *Microcystis*, *Oocystis*, *Ooedogonium*, *Pediastrum*, *Scenedesmus*, *Spirogyra*, *Tetraedron*, *Ulothrix*, and *Zygnema*
Cyanophyceae	*Anabaena*, *Anabaenopsis*, *Aphanocapsa*, *Arthrospira*, *Chroococcus*, *Coelosphaerium*, *Cylindrospermopsis*, *Gomphospaeria*, *Lyngbya*, *Merismopedia*, *Microcystis*, *Nostoc*, *Oscillatoria*, *Phormidium*, *Planktothrix*, *Planktolymbya*, and *Spirulina*
Bacillariophyceae	*Achnanthidium*, *Alexandrium*, *Amphipleura*, *Aulacoseira*, *Asterionella*, *Craticula*, *Cyclotella*, *Cymbella*, *Diatoma*, *Epithemia*, *Eunotia*, *Fragillaria*, *Gyrosigma*, *Melosira*, *Nitzschia*, *Tabellaria*, *Navicula*, *Pleurosigma*, *Pinnularia*, and *Takayama*
Euglenophyceae	*Euglena* and *Phacus*
Dinophyceae	*Ceratium* and *Peridinium*
Euglenoidea	*Euglena*, *Phacus*, *Strombomonas*, and *Trachelomonas*

Data are collected from studies of Affan et al. [30], Gusev et al. [31], Klaveness [32], Rahman et al. [33], Roy [34], Siddika et al. [35], and Taipale et al. [36].

Cyanophyceae, Gram-negative oxygenic photosynthetic prokaryotes, are ideal candidates for food supplements in aquaculture, and they also have huge potential as biofertilizers and have been applied in wastewater treatment because of their ability to produce exopolysaccharides and flocculants [42]. In ponds, *Anabaena* sp., *Aphanocapsa* sp., *Arthrospira* sp., *Chroococcus* sp., *Coelosphaerium* sp., *Cylindrospermopsis* sp., *Gomphosphaeria* sp., *Lyngbya* sp., *Merismopedia* sp., *Microcystis* sp., *Nostoc* sp., *Oscillatoria* sp., *Phormidium* sp., and *Spirulina* sp. are commonly dominate and serve as foods for numerous fish species [34].

Bacillariophyceae, the diatoms, play significant roles in the primary production of ecosystems and purifying water. They are rich in sterols, polyunsaturated fatty acids, calcium, magnesium, iron, and vitamins and are considered important natural foods for aquatic animals [34, 43]. Normally, in aquaculture ponds, *Synedra* sp. is dominant, with other genera such as *Achnanthidium*, *Amphipleura*, *Aulacoseira*, *Craticula*, *Cyclotella*, *Cymbella*, *Diatoms*, *Epithemia*, *Eunotia*, *Melosira*, *Navicula*, *Nitzschia*, *Pinnularia*, *Pleurosigma*, and *Synedra* also being frequently observed.

The dinoflagellates have normally high biomass (1,200–61,140 cells/L) and are widely used as feed additives for cultured aquatic animals. In aquaculture ponds, there are primary producers, predators, preys, and symbiotic partners. Particularly, several species such as *Heterocapsa rotundata*, *Ansanella granifera*, *Alexandrium* sp., *Takayama* sp., and *Gymnodinium smaydae* dominate, with biomass of $49.37–77.24\,\mu g\cdot C\cdot l^{-1}$, 2.16×10^{8} cells/L, 1000–1200 cells/L, and 18500 cells/L, respectively [44–49].

For Euglenophyceae (unicellular flagellates), they normally dominate in late autumn, and the most frequently occurring taxa were *Euglena* sp. and *Phacus* sp. [30, 34]. They play crucial roles in larvae surviving through the winter. The properties of efficient nutrient uptake and high biomass productivity make them a suitable source of lipids [50].

Chlorophyceae, single-celled or multicellular assemblages, are a large group of freshwater algae, which habitats from damp soil, and wetlands to the benthic zones of ponds. The common Chlorophyceae in aquaculture ponds include *Botryococcus* sp., *Chaetophora* sp., *Chlamydomonas* sp., *Chlorella* sp., *Chlorococcum* sp., *Dictyosphaerium* sp., *Scenedesmus* sp., *Pediastrum* sp., *Ankistrodesmus* sp., *Closterium* sp., *Coelastrum* sp., *Cosmarium* sp., *Spirogyra* sp., *Zygnema* sp., and *Ulothrix* sp. [29, 34]. They mainly serve in six parts: (1) nutritional supplement [51]; (2) wastewater treatment by removed nitrogen, phosphorus, chemical oxygen demand, and improving water quality [50, 52–55]; (3) disease control [56]; (4) developing and producing of biodiesel and/or bioethanol biodiesel) [57, 58]; (5) bioremoval of metals [59]; and (6) enhancing animals' health and resistance to the adverse environment [60].

2.2. Bacteria. Bacteria (mostly 1-2 μm in diameter) are unicellular, autotrophic, or mixotrophic, regulating the cycle of nutrients and energy flows in aquatic ecosystems. The biomass of bacteria in aquaculture systems can be up to 10^{10} cells·m/L, ranging from 0.5×10^{3} cells·mL^{-1} to 1.2×10^{10} mL^{-1} across seasons [61, 62], which is almost similar to phytoplankton biomass [63]. They play significant roles in aquatic animals' gut microbiota, which mediate the absorption and utilization of nutrients, physiological and immune activities, etc. The common bacteria found in aquaculture systems are (1) *Escherichia* and *Thermotoga* (intestinal microorganisms, improving digestive and immune process and protecting cultured aquatic animals from other harmful microbes); (2) *Cyanobacteria* (photosynthetic and fixing nitrogen, major contributors to carbon and nitrogen fluxes of aquaculture systems); (3) *Streptomyces* (producing bioactive secondary metabolites, such as antifungals, antivirals, immunosuppressants, and especially antibiotics, and improving metabolic and immune functions of animals); (4) *Methanobacterium* (generating methane as a metabolic by-product, and converting organic wastes into clean energy by reducing chemical and biological oxygen demand in the wastes); (5) *Rhodospirillum* (using sulfide as the electron donor for photosynthesis); (6) *Nitrobacter* (oxidizing nitrite into nitrate); and (7) *Azotobacter* (aerobic nitrogen fixation) [29, 64].

2.3. Zooplankton. Zooplankton, which transfer organic matter from phytoplankton and detritus to higher trophic levels, constitute the major part of cultured aquatic animals' nutrition and have significant implications for the recycling of nutrients and flow of energy in ecosystems [65]. Zooplankton in the aquaculture ponds mainly include Rotifera, Copepoda, and Cladocera, with more than 20 genera or species frequently observed (Table 2). Among them, rotifers (*Brachionus* sp. and *Keratella* sp.) are the most frequently observed, followed by cladocerans (*Chydorus* sp. and *Daphnia galeata*) and copepods (*Mesocyclops australiensis*) [66]. They are the most important food items in aquaculture ponds [67], which are crucial to larvae survival.

Rotifers are major foods for many cultured aquatic animals, especially juveniles and larvae [68]. Normally, *Asplanchna* sp., *Brachionus* sp., *Euchlanis* sp., *Filinia* sp., *Keratella* sp., *Lecane* sp., *Monostyla* sp., *Notholca* sp., *Polyarthra* sp., and *Rotaria* sp. are highly abundant in aquaculture ponds, which provide essential nutrition for aquatic animals' growth [34]. Although numerous research studies have focused on alternatives (e.g., improving the formulation of microdiets) [69–71] to rotifers as natural foods for cultured aquatic animals, a perfect substitute is still not found. In hatcheries of many cultured species, rotifers are suitable starter feed due to their smaller sizes (50–110 μm), constant availability, easy digestibility, and high reproductive rates, which are particularly essential for larval growth and development [26]. *Brachionus* sp. are frequently observed in aquaculture ponds, and the freshwater species *Brachionus rotundiformis* is recognized as an excellent live feed in aquaculture industries and has been widely cultured through different nutrition-enriched technologies.

Copepoda, especially their nauplii, are valuable foods for commercially important species such as *P. clarkii*. Some Copepoda genera (*Acanthocyclops* sp., *Aglaodiaptomus* sp., *Cyclops* sp., *Diacyclops* sp., and *Leptodiaptomus* sp.) are commonly found in aquaculture ponds [34]. Several Copepoda species such as *Paracyclops fimbriatus* and *Apocyclops royi* are even successfully cultured on a large scale to supply foods for cultured aquatic animals [67]. Copepods are generally considered superior to rotifers and Artemia for larval fish culture due to their high dietary profiles. Farmers normally develop its mass culture technology by adding concentrates of filtered culture to nutrient-rich water to enhance its growth during different stages such as eggs, nauplii, subadults, and adults in semiextensive ponds [26]. Cladocera such as *Daphnia* sp. and *Moina* sp., widely distributed in various water environments, are ideal live feeds in fish or crayfish larval developmental processes because of their small sizes, high nutritional values, and abundant energy storage [34, 65].

In most ponds, seasonal variations of Rotifera (from 5243 Ind/m^3 in winter to 9196 Ind/m^3 in summer), Copepoda (from 4685 Ind/m^3 in winter to 5601 Ind/m^3 in autumn), and Cladocera (from 3863 Ind/m^3 in winter to 5980 Ind/m^3 in autumn) were observed, with the total zooplankton biomass ranging from 73085 Ind/m^3 in winter to 110900 Ind/m^3 in summer [72]. The biomass of Rotifera, Copepoda, and Cladocera also ranged between 22.7×10^3–26.5×10^3 cells/L, 74.4×10^3–93.8×10^3 cells/L, and 55.9×10^3–76×10^3 cells/L for different ponds (bottom with sandy loam, loam, and clay loam) [35]. Different strategies of fertilization (simple fertilization, organic substrates, and fertilization) and the water environment also significantly influenced their biomass. For example, the concentration of zooplankton (copepods, polychaetes, protozoans, barnacles, gastropods, ciliatea, hydrozoans, and others) ranged from 124 org/L to 309 org/L, where the copepods (83%) were the most abundant organisms in ponds with organic substrates and fertilization, followed by polychaetes (5%), barnacles (5%), protozoans (3%), ciliate (2%), gastropods (1%), and others (1%) [73]. In the ponds supplied with surface water/groundwater, the biomass of Rotatoria, Cladocera, and Copepoda across the seasons was 14.1–10466 ind./L, 1.7–691 ind./L, and 369–889 ind./L, respectively [40]. Furthermore, Rotifera and Cladocera sharply declined in biomass and abundance (66% of species disappeared) when the ponds changed from surface water to groundwater [40].

2.4. Zoobenthos. Zoobenthos normally include Chironomidae (*Chironomus* sp. and *Pentaneura* sp.), Oligochaeta (*Branchiura sowerbyi*, *Peloscolex ferox*, and *Aeolosoma* sp.,), *Ceratopogonidae* (*Culiciodes* sp. and *Amphizoa* sp.), and Mollusca (*Viviparous bengalensis*) (see Table 3 for detailed information). The biomass of Chironomidae, Mollusca, Oligochaeta, and Ceratopogonidae in ecosystems was 107–376 ind./m^2, 10–85 ind./m^2, 178–1200 ind./m^2, and 44–399 ind./m^2 [40, 79]. In the settlement pond, maximum biomass of Chironomidae and Mollusca (*Cerithidea cingulata*, *Cerithium coralium*, *Thiara riqueti*, and *Stenothyra* spp.) exceeded 491 ind. $\times$ 0.02 m^{-2} and 10,000 ind./m^2 [75, 77]. It has been reported that *Branchiura sowerbyi* (21–47 ind./m^2) [80], *Peloscolex ferox* (14–36 ind./m^2), *Aeolosoma* sp. (10–27 ind./m^2), *Tubifex tubifex* (41–82 ind./m^2), *Chironomus* sp. (48–102 ind./m^2), *Pentaneura* sp. (27–62 ind./m^2), and *Viviparous bengalensis* (51–72 ind./m^2) are frequently observed and used as live foods for fish, crayfish, crabs, and others [81].

The diversity of zoobenthos varies among different ponds. For example, in grass carp culture ponds, the benthic community mainly consisted of Mollusca (*Planorbis* sp., *Lymnaea* sp., and *Napaeus* sp.) and Chironomidae [78]. In the *Hediste diversicolor* enrichment ponds, Mollusca (*Akera bullata*, *Jujubinus striatus*, *Hydrobia ulvae*, and Rissoidae) greatly increased their abundances, while in the traditional ponds, *Hydrobia ulvae* and *Abra ovata* were generally dominated [74]. Drake and Arias [76] pointed out that in the semienclosed polyculture lagoons and monoculture ponds, the abundant benthic species were Oligochaetes (1.3–18.5 ind./225 cm^2), *Abra ovata* (0.8–68.9 ind./225 cm^2), *Cerastoderma glaucum* (0.3–12.7 ind./225 cm^2), *Hydrobia minoricensis* (0.4–559.2 ind./225 cm^2), *Hydrobia ulvae* (0.1–6.7 ind./225 cm^2), *Hydrobia ventrosa* (0.1–92.1 ind./225 cm^2), and *Chironomus salinarius* (1.3–151.1 ind./225 cm^2). These benthic species benefit numerous fish species (*Sparus aurata*, *Oncorhynchus gorbuscha*, *Salmo*

Table 2: Zooplankton genera recorded in aquaculture ponds.

Group	Genera (or species)
Rotifera	*Asplanchna*, *Brachionus*, *Euchlanis*, *Filinia*, *Keratella*, *Lecane*, *Monostyla*, *Notholca*, *Polyarthra*, and *Rotaria*
Copepoda	*Acanthocyclops*, *Aglaodiaptomus*, *Cyclops*, *Diacyclops*, *Leptodiaptomus*, *Mesocyclops australiensis*, *Paracyclops fimbriatus*, and *Apocyclops royi*
Cladocera	*Chydorus*, *Daphnia*, and *Moina*

Data are collected from studies of Roy [34] and Rasdi et al. [65].

Table 3: Zoobenthos genera recorded in aquaculture ponds.

Group	Genera (or species)
Chironomidae	*Chironomus* and *Pentaneura*
Oligochaeta	*Aelosoma*, *Brachiura sowerbyi*, *Peloscolex ferox*, and *Tubifex tubifex*
Ceratoponogonidae	*Amphizoa* and *Culiciodes*
Mollusca	*Abra ovata*, *Akera bullata*, *Cerithidea cingulata*, *Cerithium coralium*, *Cerastoderma*, *Hydrobia ulvae*, *Hydrobia minoricensis*, *Hydrobia ventrose*, *Jujubinus striatus*, *Lymnaea*, *Napaeus*, *Planorbis*, *Rissoidae*, *Stenothyra*, *Thiara riqueti*, and *Viviparous bengalensis*

Data are collected from studies of Carvalho et al. [74], Carvalho et al. [75], Drake and Arias [76], Fujioka et al. [77], Kirkagac and Demir [78], and Nupur et al. [79].

salar, Tilapia, *Cobitis taenia*, *Perca fluviatilis* L., *Pelteobagrus fulvidraco*, and *Leuciscus cephalus orientalis*), shrimp (*Crangon crangon* and *Litopenaeus vannamei*), crayfish (*Austropotamobius torrentium*, *Orconectes limosus*, and *Pontastacus leptodactylus*), and crab (*Eriocheir sinensis*) [82–85].

3. General Properties of Natural Biota as Promising Candidates for Aquatic Animal Foods

Natural biota contain essential proteins, lipids, carbohydrates, vitamins, amino acids, fatty acids, sterols, organic minerals, enzymes, carotenoids, chlorophyll, and trace elements, which are directly available for larvae and adults [86].

3.1. Phytoplankton. Phytoplankton, which contain valuable phytonutrients and bioactive compounds (1909.1 mg/l of protein, 55.4 mg/L of carbohydrates, and 6.5 mg/L of lipid, and 0.064–0.234 ng/10^6 cells of retinoid-like activity of metabolites), have significant implications for hatcheries and larval development [87, 88]. The contents ((%) of total fatty acid) of main fatty acid from the classes Cyanophyceae, Chlorophyceae, Chlorodendrophyceae, Pyramimonadophyceae, Mamiellophiceae, Trebouxiophyceae, Porphyridophyceae, Cryptophyceae, Coccolithophyceae, Pavlovophyceae, Eustigmatophyceae, Raphidophyceae, Pelagophyceae, Dinophyceae, and the phylum Bacillariophyta are shown in Table 4. The fatty acids are present in different proportions in various classes, with the highest contents of 14:0, 16:0, 16:1n-7, 18:1n-9, 18:2n-6, 18:3n-3, and 18:4n-3 observed in Coccolithophyceae, Porphyridophyceae, Bacillariophyta, Chlorodendrophyceae, Trebouxiophyceae, Chlorophyceae, and Cryptophyceae. This ensures aquatic animals' optimal growth, development, and reproduction, which also improves their chemical composition, especially the fatty acid composition [89]. According to Suh et al. [90], Bacillariophyceae had the highest PUFA contents but similar C14:0, C16:0, C18:0, C20:5n-3, and C22:6n-3 contents as Dinophyceae. For Chlorophyceae, major fatty acids were 16:0, 16:1 (n-13) *t*, 16:2 (n-6), 16:3 (n-3), 18:2 (n-6), and 18:3 (n-3) [91]. Most phytoplankton species contain 7%–34% of eicosapentaenoic acid (EPA) and high docosahexaenoic acid (DHA, 0.2%–11%, in cryptomonads and prymnesiophytes such as *Pavlova* spp. and *Isochrysis* sp.), with the mean ratio of n-3 and n-6 in freshwater phytoplankton being 1.0–16.8 [86]. Eustigmatophytes (e.g., *Nannochloropsis* spp.) and diatoms often have the highest percentages of arachidonic acid (AA, up to 4%) [92]. As the important components of phytoplankton, they are the main live feed for cultured aquatic animals, providing various phytonutrients such as PUFA, saturated fatty acids (SAFA), monounsaturated fatty acids (MUFA), AA, DHA, and EPA, which are of great importance for animals' growth and development. Especially for the diatom *Cyclotella cryptica* from Bacillariophyceae, the total fatty acids and unsaturated fatty acids were 40.2–74 mg/g and 42–64.4%, with the most abundant fatty acids being palmitic acid (16:0), palmitoleic acid (16:1 n-7), stearidonic acid (18:4 n-3, SDA), EPA, and DHA [93, 94].

Besides the fatty acids, diatoms also contained recommendable contents of protein (17.81%–51.86%), carbohydrate (3.72%–17.23%), carotenoids (0.23%–0.28%), monosaccharides (1.58%–3.57%), and polysaccharides (2.25%–13.75%), with the contents of 7.29–16.91 pg/cell and 4.37–9.24 pg/cell for EPA and DHA [95–97]. Although limited studies have focused on the amino acid profiles, there is some evidence suggesting phytoplankton have excellent amino acid profiles, which makes them nutritionally cost-effective food sources for cultured aquatic animals. For

Table 4: Overview of the main fatty acid profiles of several phytoplankton species.

Classes	Fatty acids						
	14:0	16:0	16:1n-7	18:1n-9	18:2n-6	18:3n-3	18:4n-3
Cyanophyceae	3.04 ± 2.69	29.14 ± 9.70	13.33 ± 10.52	7.05 ± 3.21	10.17 ± 8.66	14.17 ± 6.95	1.13 ± 1.27
Chlorophyceae	0.75 ± 0.50	19.71 ± 3.76	1.52 ± 1.12	4.56 ± 2.94	6.16 ± 2.76	30.78 ± 8.46	1.05 ± 0.76
Chlorodendrophyceae	1.00 ± 0.85	23.01 ± 4.58	2.01 ± 1.55	10.69 ± 4.26	6.49 ± 3.32	15.31 ± 4.10	7.04 ± 3.38
Pyramimonadophyceae	1.43 ± 1.20	17.17 ± 3.81	2.92 ± 1.90	1.68 ± 1.55	2.63 ± 1.32	9.11 ± 4.57	15.67 ± 9.43
Mamiellophiceae	11.87 ± 4.66	19.80 ± 4.29	1.40 ± 0.62	1.35 ± 0.88	1.79 ± 0.51	9.11 ± 5.50	15.94 ± 5.70
Trebouxiophyceae	0.95 ± 0.64	23.50 ± 6.41	3.10 ± 2.06	4.67 ± 2.66	14.47 ± 4.17	22.48 ± 5.78	1.03 ± 1.15
Porphyridophyceae	0.80 ± 0.44	33.24 ± 6.56	2.16 ± 1.03	1.11 ± 0.88	9.36 ± 4.98		
Cryptophyceae	6.36 ± 2.71	16.68 ± 5.76	2.01 ± 1.03	3.18 ± 2.12	4.07 ± 2.93	17.86 ± 5.83	18.84 ± 6.21
Bacillariophyta	11.09 ± 4.57	18.74 ± 6.68	25.21 ± 7.35	1.31 ± 1.06	1.16 ± 0.83	0.53 ± 0.46	1.33 ± 1.07
Coccolithophyceae	17.58 ± 6.31	16.42 ± 6.94	3.17 ± 1.82	13.39 ± 5.32	4.23 ± 2.27	4.70 ± 2.09	9.59 ± 4.86
Pavlovophyceae	13.71 ± 4.50	17.44 ± 4.46	16.98 ± 5.29	2.13 ± 1.22	2.21 ± 1.60	2.07 ± 1.71	6.19 ± 2.47
Eustigmatophyceae	4.24 ± 1.68	24.14 ± 6.05	24.84 ± 3.82	5.78 ± 2.82	3.09 ± 1.77	0.70 ± 0.60	
Raphidophyceae	9.80 ± 5.35	19.46 ± 5.56	7.28 ± 3.36	3.89 ± 1.77	2.95 ± 1.39	4.02 ± 1.79	12.65 ± 5.48
Pelagophyceae	13.70 ± 3.84	20.11 ± 5.68	7.58 ± 3.91	6.60 ± 3.09	2.94 ± 1.20	5.97 ± 2.26	13.44 ± 4.91
Dinophyceae	7.08 ± 4.22	24.64 ± 8.17	2.70 ± 1.71	5.00 ± 3.76	2.34 ± 1	0.90 ± 0.83	6.28 ± 6.32

Data are collected from the study of Cañavate [89].

instance, Ahlgren and Hyenstrand [98] and Ahlgren et al. [99] stated that green alga *Scenedesmus quadricauda* (Chlorophyceae), the commonly used live foods in aquaculture, contained all amino acids (306–392 mg/g) necessary for aquatic animals' growth, which were 9.6%–10.3% aspartic acid, 4.9%–5.1% threonine, 4.6%–4.7% serine, 11.8%–13.4% glutamic acid, 4.5%–5.9% proline, 5.6%–5.9% glycine, 7.1%–7.7% alanine, 1.5%–2.7% half-cystine, 5.6%–6.0% valine, 2.2%–2.3% methionine, 3.9%–4.3% isoleucine, 7.9%–8.8% leucine, 3.8%–4.3% tyrosine, 4.9%–5.7% phenylalanine, 2.1%–2.3% histidine, 7.5%–7.8% lysine, and 5.9%–10.1% arginine. These attractive nutritional characteristics indicate that phytoplankton are high-quality foods for aquatic animals.

3.2. Bacteria. The potential of bacteria in providing nutrients for aquatic animals has been demonstrated by numerous studies. For instance, beneficial bacteria are recognized as promising candidates for aquaculture feed (dosed typically at 10^6 to 10^{10} cell·g^{-1} of feed) by Newaj-Fyzul and Austin [100] and Wang et al. [27], which provide micronutrients such as fatty acids and amino acids for *Trachinotus carolinus*, *Oncorhynchus mykiss*, *Salmo salar*, *L. vannamei*, *Paralichthys olivaceus*, *A. japonicus*, and *Ctenopharyngodon idellus*. Brown et al. [101] reported that the protein was a major constituent (25%–49% of their dry weight) of the bacteria (*Aeromonas* sp., *Derxia* sp., and *Methylophilus methylotrophus* NCIB 10515, *Pseudomonas testosterone* ACM 4768, *Pseudomonas testosterone* ACM 4768, *Pseudomonas* sp. ACM 4770). The contents of lipid, carbohydrate, nucleic acids, and ash were 2.5%–9%, 2.5%–11%, 8%–12%, and 3%–7% of their dry weight [101, 102], respectively. Besides containing 60%–82% protein on their dry matter basis, the bacteria (*Brevibacterium*, *Methylophilus* methylotrophus, *Bacillus megaterium*, *Acinetobacter calcoaceticus*, *Achromobacter delvaevate*, *Aeromonas hydrophilla*, *Cellulomonas* spp. *B. subtilis*, *Methylomonas methylotrophus*, *Thermomonospora fusca*, *Lactobacillus* spp. *Rhodopseudomonas capsulate*, *Flavobacterium* species, and *Pseudomonas fluorescens*) also consist of carbohydrates (2.5%–11% of bacterial dry weight), nucleic acids (15–18 fg·C·cell^{-1}), lipid (2.5%–9% of dry weight), minerals (Zn: 20.41–32.21 μg/g, Fe: 70.22–117.2 μg/g, Cu: 1.13–2.43 μg/g, Mn: 1.50–2.64 μg/g, Mg: 4.60–6.60 μg/g, Ca: 9.10–12.7 μg/g), and vitamins (e.g. 1.4 ng/g B_{12}), especially for rich essential amino acids (e.g. 7.72% lysine, 2.38% methionine). They (yeast, all lactic acid bacteria, *Enterococcus* sp., *Lactobacillus* sp., *Bacillus* sp., *Vibrio harveyi*, *Vagococcus fluvialis*, *Brevibacillus brevis*, and *Saccharomyces cerevisiae*) also contain trace antimicrobial peptides, acting as natural antioxidants and enhancing the immune systems of aquatic animals such as *Macrobrachium rosenbergii* and *Penaeus monodon* [103]. These ingredients are not sufficient in animal feed resources [62, 104]. As live microbial feed supplements, they help modify the gastrointestinal microbiota communities and encourage the immune responses of numerous cultured aquatic animals [105]. Furthermore, the significant roles of natural biota in stimulating digestive enzyme activities have been proven in cultured organisms such as blue shrimp, *Litopenaeus stylirostris* [106], and it also enhances the efficiency of feed utilization [107]. There is a strong indication from Salger et al. [107] that natural biota in the ponds help reduce feeding frequency (feeding Nile tilapia on formulated feed alternate days weekly), which finally enhances feed efficiency by 76% and has no deleterious effects on the growth and survival of tilapia. The excellent characteristics make beneficial bacteria promising alternatives to protein sources for feeds [27].

Recently, more and more studies have explored the possibility of partially or fully replacing fish meal with bacteria. For example, in the culture of black tiger shrimp *Penaeus monodon*, the potential for microbial bioactive to complete replacement of fishmeal and fish oil has been proved [108], with the additional benefits in growth improvement [109]. Delamare-Deboutteville et al. [110] demonstrated that the replacement of fishmeal with purple phototrophic bacteria (at 33% and 66% replacement levels) did not significantly affect the palatability of the diet, survival, or growth performance of Asian sea bass (*Lates calcarifer*). Simon et al. [22] found that tilapia fed Novacq™ (microbial biomass) at 10% replacement of fish meal in diets had significantly higher net weight gain (15.5% increase) and feed intake (33% increase). A similar finding was observed in Pacific white shrimp, *Litopenaeus vannamei*, in which 15%, 30%, and 45% of fish meal was replaced with bacterial protein meal (*Methylococcus capsulatus*), resulting in no significant differences in growth performance, mortality, or feed utilization of *L. vannamei* [111, 112].

In addition to basic nutrients provided by bacteria, they (*Vibrio* sp., *Bacillus* sp., and *Thalassobacter utilis*) also produce various kinds of enzymes such as amylase, protease, cellulase, and lipase (improving the digestion and metabolism of cultured aquatic animals and enhancing their ability of stress resistance and health) and secondary metabolites [111, 113, 114]. For example, as a probiotic bacterium, *B. subtilis* increases the digestion and assimilation of nutrients by aquatic animals and secretes antimicrobial compounds, preventing pathogens' development and improving the water environment [115, 116]. *Flexibacter* strain Inp3, which contains high polyunsaturated fatty acid (PUFA) content, not only serves as a food source for *Artemia* but also assists in the digestion of algae by *Artemia* [117, 118]. Some enzyme-producing bacteria have positive effects on improving feed efficiency, such as amylase-producing bacteria (*Aeromonas hydrophila*, *Clostridium* spp., *Pseudomonas* spp., *Flavobacterium* spp., *Citrobacter* sp., *Enterobacter* sp., *Bacillus* sp., and *Brochothrix* sp.), protease-producing bacteria (*Enterobacter* spp., *Acinetobacter* spp., and *Bacillus cereus*), cellulase-producing bacteria (*Bacillus circulans*, *Bacillus licheniformis*, *Bacillus coagulans*, *Bacillus cereus*, *Enterobacter* sp., *Aeromonas* sp., and *Citrobacter* sp. and *Brochothrix* sp.), and lipase-producing bacteria (*Aeromonas hydrophila*, *Vibrio* spp., *Acinetobacter* spp. Enterobacteriaceae, *Pseudomonas* spp., *Bacillus* sp., and *Brochothrix* sp.) [119]. The high nutritional values together with the probiotic effects make the bacteria suitable live foods for cultured aquatic animals.

3.3. Zooplankton. Zooplankton organisms constitute a major part of fish and crustaceans' larval nutrition intake, especially during the periods of hatcheries and rearing [65]. Understanding their biochemical composition will hopefully provide the scientific foundation for the development of formulated feeds, which are crucial to sustainable aquaculture [120]. Several days after hatching, the main zooplanktons consumed by fish and crustaceans' larvae are rotifers or copepod nauplii, and then they shifted to larger zooplanktonic organisms such as copepods and cladocerans [121, 122]. These zooplankton organisms have more desirable dietary nutritional characteristics as larval diets (e.g., higher protein, amino acids, saturated fatty acids, and unsaturated fatty acids [123]). In general, most zooplankton species contain a reliable protein source, which ranges over 1.9%–54.2% for protein, 79.2%–98.1% for moisture, 0.4%–11.2% for carbohydrate, 0.1%–27.9% for lipid, and 3.9%–76.4% for ash [124]. A study from Mitra et al. [125] even found that the protein could reach more than 70% (73%–79%) in zooplankton, with a high proportion of SAFA (64%–81%) as well as MUFA (10.79%–14.55%) and PUFA (3%–4.79%). Furthermore, the zooplankton also contains vitamins (e.g. vitamin A 13.61–63.95 μg/g, vitamin E 218–348 μg/g, on a dry matter basis), exogenous enzymes (protease 6.21–7.92 μg leucine/mg protein/h, lipase 25.82–39.1 μg α-naphthol/mg protein/h, and amylase 100–226.1 μg maltose/mg protein/h), minerals and trace elements such as P, Ca, Fe, Cu, Zn, and Mn, which play fundamental roles in larval development. However, these nutritional contents are highly variable among different classes. The fatty acid profile and proximate composition (protein, lipid, carbohydrate, ash, water, and fibre) and energy of zooplankton were summarized in Tables 5 and 6. For example, rotifers tend to have lower lipid contents (9.25%–11.78%) and slightly more than 50% of protein contents (52.23%–55.65%), with preferable fatty acid contents (2.9%–5.83% for EPA, 2.10%–4.52% for DHA, 23.03%–23.42% for n-3 PUFA, 12.88%–15.08% for n-6 PUFA, 8.22%–13.44% for n-3 HUFA, and 1.88%–2.47% for HUFA, Table 5). The copepods contain high protein contents (28.9%–84.9% of dry weight), lipid contents (3%–76% with the mean of 32.37% of dry weight), low carbohydrate contents (0.4%–6.1% of dry weight), and ash contents (10.3%–10.5% of dry weight), with a mean energy of 29.8 KJ/g of dry weight (Table 6). Compared to Calanoida copepod (DHA: 17.6%–20.1%, n-3 : n-6 ratio: 4.2%–5.2%) and Cyclopoid copepods (DHA: 14.8%–20.2%, n-3 : n-6 ratio: 4.7%–18.1%), cladocerans (e.g. *Moina* sp. and *Daphnia* sp.) are notable for containing higher SAFA (34.1%–34.6%), MUFA (18.7%–23.5%), ARA (5.2%–8.9%), and EPA (14.7%–22.1%) contents [130, 134]. Among cladocerans, *Moina* sp. has higher protein contents (59.95%–66.33%) but slightly lower carbohydrate contents (19.83%) than *Daphnia* sp. (39.24% and 21.87%) [24, 65, 130, 135]. *Moina* sp. also contains higher levels of most essential fatty acid components such as C14:0 (4.25%), C16:0 (10.53%), C16:1 (21.67%), and C18:1 (9.1%) [24].

The amino acid profiles of mixed zooplankton, rotifers, copepods, and cladocerans are shown in Table 7. In general, the rotifers (unenriched or enriched with multigrain, chlorella, Ori-green, or protein hydrolysate) contain higher contents of Alanine, Glycine, Valine, Aspartic acid, Glutamic acid, Proline, while Copepods have high contents of leucine, isoleucine, serine, methionine, phenylalanine, tyrosine, cystine, and Cladocerans contain higher contents of lysine, histidine, and arginine. Concerning the nutritional-richness in proteins, lipids, carbohydrates, fatty acids, and amino acids, there is no doubt that zooplankton are efficient, feasible, and economical live foods for cultured aquatic animals. More studies are encouraged to evaluate the effects of replacing fish meal with zooplankton on the growth performance, protein efficiency ratio, and feed conversion ratio of cultured aquatic animals such as European sea bass *Dicentrarchus labrax* [136].

Table 5: Overview of fatty acid profiles of several zooplankton species.

Fatty acids											
C16:0	C18:0	C18:1n-9	C18:3n-3	C18:3n-6	C20:0	C20:4n-6 (ARA)	C20:5n-3 (EPA)	C22:5n-6	C22:6n-3 (DHA)	MUFA	PUFA
Rotifers (*Brachionus plicatilis*) fed on baker's yeast *Saccharomyces cerevisiae*											
15.15	1.60	12.64	14.40	0.25	0.11	0.88	2.90		2.10		
Rotifers (Brachionus plicatilis) fed on microparticulate compound diet (CULTURE SELCO)											
16.08	1.32	13	9.43	0.28	0.15	0.84	5.83		4.52		
Rotifers (Brachionus plicatilis) un-enriched											
17–24.8	5.6–6.88	3.52–7.92	4.25–6.28		1.89	2.38	3.53–4.06	0.28	5.05–6.58		
Rotifers (Brachionus plicatilis) enriched with ori-green											
18.3	5	10.6	5.44			1.07	3.36	0.68	11		
Rotifers (Brachionus plicatilis) enriched protein hydrolysate											
17.9	5.55	8.38	5.39			1.87	4.29	0.18	7.37		
Rotifers enriched with multigain											
32.43	4.81	5.59	3.84		1.53		6.17		9.7		
Rotifers enriched with Chlorella											
21.93	5.14	3.25	5.3		1.45		6.14		9.49		
Artemia un-enriched											
5.97–10.5	2.87–6.57	18.9	0.85–1.71	5.12		0.48–1.20	2.19–2.80	0.01	0.39–0.91		
Artemia enriched with ori-green											
10.6	6.23	17.7	2.03			0.99	4.21	0.28	4.63		
Artemia enriched with protein hydrolysate											
10.6	6.48	18.4	31.2			0.56	2.71	0.02	0.72		
Mixed zooplankton											
18.6–81.2	0.1–4.12	2.60–11.9	2.05–6.34	0.14–0.74	0.24	0.24–1.54	10.9	0.11	9.20–22.7	7.03–14.75	10.1–19.78
Moina sp											
10.53		11.83	20.19			2.66	3.04		1.31		
Daphnia sp											
17.83		6.40	26.22			1.20	0.65		0.05		
*Moina micrura*un-enriched											
33.01	0.93	27.92	3.79			2.66	3.04	3.01	1.31	42.26	18.05
Moina micrura enriched with vitamin C											
34.63	6.98	17.92	5.70			7.22	3.72	2.45	1.38	25.56	24.37
Moina micrura enriched with HUFA											
24.56	14.49	8.26	3.39			4.61	8.20	1.99	10.36	17.03	35.57
Moina micrura enriched with vitamin C + HUFA											
21.11	6.51	17.43	14.94			3.99	5.05	1.63	5.17	33.37	33.98
Apocyclops dengizicus											
30.05–35.19	4.40–6.43	6.03–13.35	2.64–4.07		0.42–0.43	0.60–1.45	1.77–8.43		4.07–20.23	13.02–15.95	17.62–37.56

ARA: arachidonic acid; EPA: eicosapentaenoic acid; DHA: docosahexaenoic acid. Data are collected from studies of Chakraborty and Mallick [24], Farhadian et al. [126], Kostopoulou et al. [127], Mæhre et al. [128], Manickam et al. [123], Mitra et al. [125], Rocha et al. [21], and Singh et al. [129].

Table 6: Proximate composition and energy of several zooplankton species.

	Protein (% DW)	Lipid (% DW)	Carbohydrate (% DW)	Ash (% DW)	Water (% DW)	Fibre (% DW)	Energy content (KJ/g DW)
Amphipod	36.1	16	1.8	21.7	78.2		17.3
Copepod	32.83–55.8	11.31–32.3	1.22–1.9	10.4–21.83	80.4–87.80		14.42–29.8
Krill	49	22.2	1.9	14.1	74.6		6
Daphnia magna	39.24	4.98		14.63		4.32	
Moina micrura	52.4				89		
Diaphanosoma excisum	57.3				89.3		
Brachionus calyciflorus	50.3				91.6		
Apocyclops dengizicus	46.81–60.49	17.76–19.08	6.24–10.56				
Artemia nauplii	52.2	18.9	14.8	9.7			15.83
Artemia adult	56.4	11.8	12.1	17.4			15.83
Moina sp	66.33	10.82	19.83	3.02			
Daphnia sp	39.68	24.99	4.0	28.15			
Rotifer (*Brachionus plicatilis*) un-enriched	39.3	10.7		19.9	87.1		
Rotifers enriched with multigain	34.8	13.3		15.7	86.1		
Rotifers (*Brachionus plicatilis*) enriched with ori-green	37.3	12.1		19.9	87.3		
Rotifers enriched with chlorella	34.9	8.7		13.5	85.8		
Zooplankton	34.8	8.3		32	90.6		

Data are collected from studies of Bogut et al. [130], Chakraborty and Mallick [24], Farhadian et al. [126], Gladyshev et al. [131], Mæhre et al. [128], Ovie and Ovie [132], Rocha et al. [21], Taipale et al. [133], Wang and Jeffs [120], and Wang et al. [124].

3.4. Zoobenthos. Zoobenthos have a similar nutritional composition as zooplankton and are preferred by numerous larvae in their hatcheries and nurseries. The freshwater zoobenthos consist mostly of insect larvae, among which chironomids are common groups, and their nutritional attributes are comparable to those of fish meal. Chironomid larvae contain 49.56%–51.15% protein, 12.04%–14.22% lipid, 13.25%–14.24% ash, and 6.36%–6.66% moisture [137]. They also have satisfactory amino acids (5.45%–10.92% of methionine, 8.61%–9.44% of glutamic acid, 7.18%–7.96% of aspartic acid, 6.96%–8.25% of glycine, 4.09%–5.92% of serine, 4.67%–8.92% of alanine, and 4.66%–6.68% of cystine) and fatty acids contents (e.g. 10.68%–12.69% of C16:0, 12.52%–19.09% of C18:2n-6, 6.82%–18.04% of C18:1n-9, and 7.12%–9.25% of C18:3n-3) [137]. As a member of the chironomids, *Chironomus plumosus* has even higher protein content (57.53%) [138, 139] and contains recommendable essential amino acids and fatty acids for feeding most omnivorous and carnivorous freshwater fishery species, with 26.12% SAFA, 30.42% MUFA, and 34.03% of PUFA [138].

The red earthworm, *Eisenia fetida*, is one of the chironomid families used as feasible starter feeds for fish or crustacean larvae. It contains adequate levels of fatty acids such as 51.08%–53.04% of PUFA, 25.95%–26.90% of MUFA, and 21.16%–22% of SAFA, with the DHA content up to 15.81%–18.31% by enrichment with the bed-free technique [140]. The suitability of various earthworm species as a potential source of protein in aquatic feeds has also been proven by numerous studies. In terms of protein and lipid, the wild earthworm *Perionyx excavatus* (46.57% of protein and 8.03% of lipid) has comparable contents to that of fishmeal (54.97% of protein and 7.97% of lipid) [141]. Pucher et al. [142] investigated the effects of dried earthworms *P. excavatus* replacing fishmeal on the growth rate of carp *Cyprinus carpio* and recorded a better growth rate of carp at a level of 100% replacement. A study on shrimp *P. vannamei* found that diet containing soybean meal and earthworm meal at a ratio of 4:1 could significantly improve the growth performance and feeding efficiency [143]. It has been reported that up to 66.26% protein and 12.79% lipid in *Tubifex tubifex* have a proper profile of amino acids (13.47%–30.35% essential amino acids, 18.91%–43.44% total amino acids, 3.63% lysine, 7.25% linoleic acid, and 6.19% linolenic acid), and fatty acids (19.40%–40.13% SAFA, 24.36%–30.64% MUFA, 0.22%–2.18% EPA, 0.1%–1.17% DHA, and 8.06%–16.79% PUFA) [144]. This indicates the nutritional importance of zoobenthos in replacing conventional animal protein sources (fish meal) without compromising cultured aquatic animals' growth, with tremendous benefits from economic and sustainable aspects.

4. Nutritional Contributions of Natural Biota to Cultured Aquatic Animals' Growth

In semiintensive or intensive culture, juveniles exhibit a preference for feeding on natural biota over formulated feeds [145], and they derive a substantial part of their dietary nutrients from natural biota. They could promote better survival and growth of cultured aquatic animals compared with artificial diets alone [18, 125]. For example, the early (0.10 ± 0.05 g) and advanced juveniles (0.98 ± 0.43 g) of *Cherax quadricarinatus* fed on biofilm (Chlorophyta, xantophytas, pennate diatoms, cyanobacteria, flagellates, ciliates, rotifers, and nematodes) and formulated feed showed better survival, growth performance, and hepatopancreatic levels of total lipids when compared to the group only receiving formulated feed [146]. Natural foods such as mussels, *Perna* sp., squid, *Loligo* sp., trash fish, *Leiognathus* sp., *Oreochromis* sp., small bivalves, *Potamocorbula* sp., shrimp, and *Fenneropenaeus* sp. produce better larval quality in the mub crab genus *Scylla* than formulated feed [147]. The plankton could also improve the growth of rohu *Labeo rohita*, which was positively correlated with plankton availability [148]. Even provided with a formulated pellet, aquatic animals (e.g., *C. destructor*) consumed a high proportion of natural biota, and the dietary protein levels could be reduced from 30% to 19% without compromising their growth performance (e.g., weight, abdomen length, and abdomen width) [16]. Similar findings were also observed in channel catfish, hybrid catfish, common carp, and silver carp. Natural biota (rotifers, copepods, cladocerans, and ostracods) supported almost the same as formulated feed in their growth and survival [149], indicating farmers can benefit from improving feeding strategies by shifting towards more profitable natural food resources [150]. Overall, these studies further indicate the significant contribution natural biota make to different cultured aquatic animals' growth.

Quantifying the contributions of natural biota to the growth of cultured aquatic animals and to what extent the input of formulated feed can be reduced without compromising their growth are critical to improving feeding strategies aquaculture efficiencies. Numerous studies have been carried out to nutritionally evaluate the contributions of natural biota and formulated feeds to different cultured aquatic animals' growth. The analysis of stomach content showed that natural biota constitute main diets of many species such as juvenile *P. monodon* (only 21.7%–47.5% of formulated feed, 21.1%–42.3% of plant materials, 1.8%–31.7% of crustacean parts, and 8.6%–27% of diverse detrital matter) [151], Nile tilapia *Oreochromis niloticus* (64.2%–86.2% of detritus and phytoplankton, phytoplankton > detritus > zooplankton) [152, 153], the small freshwater fish *Amblypharyngodon mola* (50% of Chlorophyceae and nearly 30% of Cyanophyceae) [154], and *Paranephrops zealandicus* (58.3% of terrestrial detritus) [155]. This information provides an important indicator that formulated feed plays a limited role in the growth of these organisms.

Besides gut content analysis, a stable isotope mixing model is often used to quantify the contributions of natural biota to cultured aquatic animals' growth. Results found that the contributions of natural foods (e.g., detritus, diatoms, filamentous algae, macroalgae, protozoans, crustaceans, detritus, polychaetes, and rotifers) to cultured aquatic animals' growth were 44% for omnivorous crayfish *Pacifastacus leniusculus* [156], 48%–89% for juvenile shrimp *L. vannamei* [157, 158], and 43.9% for red claw *C. quadricarinatus* [159].

Table 7: Amino acid composition ((%) of total amino acids) of zooplankton, rotifers, copepods, and cladocerans.

		Rotifer *Brachionus plicatilis*			Copepod			Cladoceran	
	Total zooplankton	Unenriched	Enriched with ori-green	Enriched with protein hydrolysate	*Brachionus calyciflorus*	*Apocyclops dengizicus*	*Daphnia magna*	*Moina micrura*	*Diaphanosoma excisum*
Total amino acids	86.29–93.34	98.9	98.2	98.8					
Total essential amino acids	33.4–54.62	40.3	40.7	40.3					
Total aromatic amino acids	7.5	9.50	10.1	10.7					
Histidine	0.57–5.82	0.69–0.96	1.53	1.63	1.83		0.80	5.09	2.60
Isoleucine	1.83–4.20	2.59–5.58	5.54	5.39	4.32	6.7–7.6	0.90	4.18	2.72
Leucine	2.9–7.48	3.88–10.8	10.7	10.8	8.95	12.1–14.2	1.30	8.00	8.00
Lysine	3.26–15.31	4.12–6.83	6.42	6.90	8.64	5.0–6.9	2.20	10.73	9.95
Methionine	0.92–3.61	0.89–1.99	2.03	1.96	0.93	5.2–6.9	1.20	1.12	2.45
Phenylalanine	1.71–5.20	2.5–5.82	5.77	5.76	5.20	4.8–23.7	2.50	3.75	3.75
Threonine	1.74–4.87	2.02–2.14	2.73	2.59	3.92	4.5	1.50	2.93	3.84
Tryptophan	0.49–0.70	0.02–0.62	0.01	0.02			0.30		
Valine	2.17–9.75	2.71–7.42	7.18	7.02	4.83	4.5–7.0	1.40	4.44	6.23
Alanine	2.89–9.14	2.51–8.96	8.6	8.97	4	6.0–10.1		2.48	4.46
Allo-isoleucine	2.39	0.38	0.06	0.44					
Amino-n-butyric acid	1.27	0	0.04	0.03					
Aminoisobutyric acid	0.5	0.03	0.04	0.03					
Asparagine	1.30	0.02	0.01	0.01					
Aspartic acid	3.15–9.11	3.92–11.8	11.3	11.4	10.53	2.8–4.7		9.84	10.23
Arginine	2.95–8.13	2.94			6.37	5.6–6.6	1.60	8.17	4.78
Cystathionine	0.28	0.03	0.01	0.03					
Cystine	0.23–1.20	0.77	0.88	0.87	1.55	5.2–9.1		2.89	1.26
Glycine	3.31–15.8	2.27–8.75	8.6	9	3.37	3.3–5.1		3.90	7.80
Glycine-proline	0.48	0.05	0.02	0.10					
Glutamic acid	5.75–13.38	6.2–17.4	17.8	16.6	12.22	4.5–5.6		15.39	13.61
Glutamine	1.91	0.22	0.17	0.14					
Hydroxylysine	0.82	0.08	0.04	0.06					
Hydroxyproline	0.53	0.17	0.21	0.13					
Ornithine	0.01–1.03	0.22	0.28	0.19					
Proline	3.70	7.55	6.53	6.98	6.03	3.5–5.1		3.18	6.44
Proline-hydroxy proline	0.74	0.05	0.05	0.06					
Sarcosine	0.74	0.04	0.03	0.03					
Serine	1.63–4.98	0.42–2.19	0.55	0.73	3.45	5.3–6.4		3.42	2.65
Thioproline	1.47–2.26	0.09–1.77	0.05	0.06					
Tyrosine	3.40–5.62	3.79	3.68	3.78	2.82	4.8–7.5		3.00	3.21
α-Aminoadipic acid	0.19	0.17	0.16	0.24					
α-Aminopimelic acid	0.37	0.02	0.02	0.01					

Data is collected from Bogut et al. [130], Farhadian et al. [126], Mæhre et al. [128] , Manickam et al. [123], Mitra et al. [125], Ovie and Ovie [132], Rocha et al. [21]. Essential Amino acids are in bold.

These indicate the ineffectiveness of aquatic animals in utilizing formulated feeds. The situation is particularly true for *P. clarkii*, where the feeding levels of formulated feed could be reduced from 100% satiation to 60% satiation without compromising the growth performance (final weight, final length, gonadosomatic index, hepatosomatic index, specific growth rate, and muscle weight) and biochemical composition (crude protein, crude lipid, ash, and moisture) of *P. clarkii* due to the nutritional supplementation of natural food *Hydrilla verticillata* (60% of coverage in each pond). The stable isotope analysis revealed that the contribution of *H. verticillata* increased from 27.84% to 50.26% when feeding levels decreased from 100% satiation to 60% satiation. Another study also demonstrated that for *P. clarkii*, their main sources of energy demand are from preying on insect larvae (up to 67% by occurrence), followed by fresh macrophytes, detritus, and sediment grains [160]. Roy et al. [161] and Correia et al. [162] also reported the similar results that reducing the daily feeding ratio from 110% to 60% and from 100% to 50% (daily ration) did not significantly affect the growth of *L. vannamei* and freshwater prawn *Macrobrachium rosenbergii* due to the contribution of pond primary productivity. The study on juvenile blue shrimp *L. stylirostris* reported that juveniles' biomass (consumed natural foods in the biofloc systems) was 4.4 times as that of those grown in clear water, with natural productivity contributing to 39.6%–39.8% of its growth [106]. With certainty about reproducibility and the application of research data to real-time fish and crustacean farming, more nutritional research on the utilization of natural biota in aquaculture ponds should be conducted in situ on typical crustacean aquaculture, and the generated data from the on-farm evaluation should be evaluated from an economic perspective.

4.1. Future Perspectives. Sustainable aquaculture is a cost-effective production of fishery products, with continuous interaction with the ecosystems via natural biota. In particular, as the larvae transition to juveniles, the capacity to store food in the gastrointestinal tract is limited; hence, stage mortality occurs most frequently. There is a need at this early stage to continuously supply foods to prevent starvation and promote optimal growth and maturity [163]. However, applying natural biota to meet this demand requires robust and sustainable practices to support aquaculture management. The future of aquaculture is premised on applying natural biota in combination with other innovative techniques to improve formulated feed conversion efficiency in aquaculture. Furthermore, the future of aquaculture production also highlights maintaining the balance between natural biota biomass and formulated feed input to achieve higher fishery production with lower operational costs, which might be highly dependent on the stability of culture systems. This scenario motivates new research into intrinsic and extrinsic factors (e.g., the natural biota's functional and structural connectivity) mitigating the ecological integrity of fish and crustacean aquaculture.

Data Availability

The data used to support the findings of this study are included within the article.

Disclosure

The funding sponsors had no roles in the design of the study; in the collection, analysis, or interpretation of data; in the writing of the manuscript; nor in the decision to publish the results.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Authors' Contributions

Shiyu Jin, Qingling Kong, and Chibuike Kemdi John contributed equally to this review.

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