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WATER PRODUCTIVITY EVALUATION THROUGH MICROBIAL INDICES IN AQUATIC ECOSYSTEM

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ABSTRACT

It is becoming more widely acknowledged that microbial indices are essential instruments for assessing water production in fisheries and aquaculture. These indicators represent the composition, dynamics, and role of microbial communities, which are critical to organic matter breakdown, nutrient cycling, and ecosystem health. Since the growth and health of aquatic creatures in aquaculture systems are directly impacted by the quality of the water, knowledge of microbiological factors is crucial for sustainable production.

Heterotrophic Bacterial Count (HBC) and Total Bacterial Count (TBC) are important microbiological indices that provide information on the availability of organic materials and microbial biomass. Aquaculture waters' microbiological safety is evaluated by counting coliforms, especially total and faecal coliforms, which act as indicators of pollution. Microbial activity and nutrient turnover, which are essential for primary productivity and food web maintenance, are reflected in bacterial production rates and Microbial Biomass Carbon (MBC). Other significant indicators of microbial metabolic activity and ecosystem stress include the Biochemical Oxygen Demand (BOD), microbial respiration rate, and enzyme activities (such as urease and dehydrogenase). While nitrifying and denitrifying bacterial counts are used to evaluate nitrogen cycling efficiency, sophisticated indexes such as the Shannon-Weaver diversity index and Simpson's index offer a quantitative measure of microbial biodiversity. The energy efficiency of microbial communities is further revealed by the microbial quotient (qCO). When taken as a whole, these indicators help evaluate the ecological balance, nutrient condition, and water quality of fishery habitats, wetlands, reservoirs, and aquaculture ponds.

Aquaculture professionals can identify early indicators of eutrophication, pollution, or disease outbreaks and take prompt action by using microbiological indices. Furthermore, as compared to traditional physicochemical evaluations, these biological indicators are more economical and environmentally friendly instruments. This study provides a scientific basis for better aquaculture management and increased aquatic food security by highlighting the importance of microbial indices as essential elements of water productivity assessment.

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Keywords: Evaluation, water productivity, Microbial indices, Bacterial biomass, DO, BOD, Phosphate, Direct count.

INTRODUCTION

Water productivity (WP) refers to the benefits obtained per unit volume of water used, which includes microbial dynamics, nutrient cycling, ecosystem health, and biomass yield in aquatic ecosystems and aquaculture (Boyd & Tucker, 1998). Microbial indices include microbial biomass carbon and nitrogen, total number of heterotrophic bacteria, community diversity and composition indexes, enzyme activity, and chlorophyll-a and periphyton

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microbe biomass. These indicators are strongly related to aquatic productivity and carrying capacity, representing microbial abundance, metabolic activity, and ecosystem function, as per studies by Azim et al., 2005 and Ray et al., 2010. Microbial indices, such as microbial biomass, diversity, and activity, are increasingly recognized as sensitive markers for assessing water productivity and ecological integrity (Van der Heijden et al., 2008). As Molden et al (2010) stated that traditional water productivity assessment focuses on input-output biomass connections, but recent methods incorporate microbial indicators that directly impact primary production, organic matter breakdown, nutrient recycling, bacterial biomass, heterotrophic activity, enzymatic indices, and microbial community structure as reported by Azim et al., 2005. Ray et al (2010) stated that microbial communities are crucial for increasing water production in aquaculture systems, influencing biogeochemical processes, improving nutrient availability, and controlling pond and wetland/lakes water quality.

Azim et al. (2005) found that periphyton and microbial biofilms improve fish production in Bangladeshi aquaculture ponds by retaining nutrients and increasing primary productivity. Van Dam et al. (2002) found that enzymatic activity and microbial biomass are reliable indicators of ecosystem productivity and nutrient cycling efficiency. Ray et al. (2010) used biofloc technology to improve water productivity and nutrient recycling in prawn cultivation systems. Rydin et al. (2011) found that bacterial populations control phosphorus bioavailability, affecting eutrophication dynamics and water productivity. Paerl & Otten (2013) proposed that increasing beneficial microorganisms enhances productivity and water quality in both freshwater and marine environments.

Saha et al. (2002) stated that microbial biomass carbon and nitrogen are crucial indicators of pond soil and water productivity in carp polyculture systems while, higher microbial indices are linked to improved fish yield and nutrient recycling. Studies by Mandal et al (2010) revealed that that high bacterial biomass indicates effective organic matter breakdown, enhancing fish productivity and nutrient availability. Probiotic application has been shown to increase microbial biomass and diversity in Indian aquaculture ponds, improving water productivity and nutrient utilization efficiency (Ghosh et al, 2004). Microbial biofilm indices, including bacterial density, enzymatic activity, and chlorophyll-a, are reliable indicators of ecosystem health and water production as reported by Jana & Chakraborty (2013). Routine monitoring of microbial indices, such as total heterotrophic bacterial count and nitrifying bacteria count, is recommended for freshwater aquaculture health (ICAR-CIFA, 2018). Microbial indices are crucial for improving primary productivity, regulating water quality, enhancing biosecurity and disease control, and evaluating sustainability (Azim et al., 2005; Saha et al., 2002). They provide information on nutrient mineralization and organic matter decomposition, ensuring balanced nutrient dynamics and reducing nitrate and ammonia toxicity (Ray et al., 2010). Healthy microbial communities suppress harmful bacteria, enhancing fish health and production (Ghosh et al, 2004). Microbial indices are sensitive markers of productive and sustainable water usage, combining ecological, chemical, and biological aspects (Van van Heijden et al., 2008). Microbial indices are becoming increasingly effective tools for assessing water productivity in aquatic systems worldwide. However, issues include limited integration into regular monitoring systems, environmental variability, and standardization of microbial index protocols (ICAR-CIFA, 2018). Future research should focus on creating real-time microbiological indices and combining molecular methods with traditional indices for ecosystem-level assessment (Paerl & Otten, 2013). Microbial indices can be used in biofloc and integrated multitrophic aquaculture systems to sustainably maximize water productivity (Ray et al., 2010).

Microbial indices are biological indicators used to evaluate aquaculture and fisheries systems' water quality and productivity. These indices cover a range of microbial characteristics that affect organic matter breakdown, nutrient cycling, and ecological stability, including abundance, activity, diversity, and function. Early identification of eutrophication, disease outbreaks, and deterioration in water quality is made possible by incorporating microbiological data into aquaculture monitoring systems.

The following is an overview of typical micro-biological indices.

- **Total Bacterial Count (Boyd, 1990)**
  Total bacterial count (TBC) is the most basic microbial index used in aquaculture to estimate the overall bacterial population. High TBC may suggest organic pollution or nutrient enrichment.
- **Heterotrophic Plate Count (APHA, 2017)**
  One of the most basic microbiological indices for determining the microbial load in aquatic

environments is the total heterotrophic bacterial count. Usually, spread or pour plate methods using nutritional agar are used to determine it. However, it reflects the abundance of heterotrophic bacteria using carbon sources and is used as a surrogate measure of organic matter levels.
Formula: HPC = Number of colonies × dilution factor

- **Coliform Count and Fecal Coliform Count (WHO, 2004)**
  Coliforms, especially fecal coliforms like *E. coli*, serve as indicators of water contamination and nutrient influx from sewage or animal waste. The Most Probable Number (MPN) method estimates bacterial density in water samples. Coliforms are fecal indicator organisms. Their presence reflects contamination from sewage or livestock waste, impairing water quality.
- **Fecal Streptococci Count (Cabelli et al., 1983)**
  Streptococci counts serve as indicators of fecal pollution of animal origin, often used alongside coliforms.
- Microbial Biomass Carbon (Vance et al., 1987)
  Microbial Biomass Carbon (MBC) represents the active microbial component and is key in nutrient cycling. Measured using fumigation-extraction.
- **Microbial Biomass Nitrogen (Brookes et al. 1985)**
  Like MBC, Microbial Biomass Nitrogen (MBN) reflects the nitrogen within microbial cells and supports nitrogen cycling evaluation.
- **Biochemical Oxygen Demand (BOD) (APHA, 2017)**
  BOD represents the amount of oxygen required by microbes to decompose organic matter over 5 days, a proxy for microbial metabolic activity. High BOD indicates high organic matter and microbial activity, which could either enhance productivity or lead to hypoxia.
- **Microbial Respiration Rate (CO Evolution)**
  This index measures the rate of CO release from microbial metabolism and is a direct indicator of microbial activity. It helps assess carbon turnover and aerobic microbial dynamics in aquaculture pond sediments.
- **Microbial Growth Efficiency (MGE), (del Giorgio & Cole, 1998)**
  It measures the efficiency of microbial biomass production from substrate.
- **Bacterial Biomass Production (BBP) (Kirchman, 2001)**
  BBP estimates microbial productivity based on incorporation of labelled substrates. It is vital for estimating microbial contribution to carbon flow.
- **Bacterial Production (Fuhrman & Azam, 1980)**
  Thymidine method estimates the bacterial growth rate via DNA synthesis using ^{3}H-thymidine.
- **Bacterial Production (Leucine Incorporation) (Kirchman, 2001)**
  It uses ^{3}H-leucine to quantify protein synthesis, particularly in heterotrophic bacteria.
- **Bacterial Respiration Index (BRI) or Respiration Rate (Tiedje, 1982; Robinson & Tiedje, 1984)**
  It measures microbial oxygen demand, an indicator of biological activity and decomposition.
- **Microbial Diversity Index, Shannon-Weaver Diversity Index (H') (Shannon & Weaver, 1949)**
  It reflects microbial community diversity, related to ecosystem stability.
- **Shannon-Wiener Diversity Index (H') (Lozupone & Knight, 2008; Wang et al., 2018)**
  Microbial diversity is assessed using indices like Shannon-Wiener Index, which accounts for species richness and evenness.
- **Simpson's Diversity Index (Simpson, 1949)**
  Another diversity measure that emphasizes species dominance. It is used to measure the dominance or evenness of bacterial species in aquatic ecosystems.
- **Evenness Index (E) (Pielou, 1966)**
  It shows how evenly microbial species are distributed. Evenness measures how evenly individual microbes are distributed among species.
- **Chao1 Richness Index (Chao, 1984)**
  It estimates species richness considering rare microbes (singletons, doubletons).
- **Dehydrogenase Activity or Microbial Enzyme Activity (Casida et al., 1964)**
  It is an indicator of microbial oxidative metabolism in aquatic sediments. Dehydrogenase is an intracellular enzyme that reflects overall microbial metabolic activity. It measures reduction of triphenyl tetrazolium chloride (TTC) to triphenyl formazan (TPF) spectrophotometrically.
- **Alkaline Phosphatase Activity (Tabatabai, 1994)**
  It assesses phosphorus mineralization by microbes. It is essential for assessing microbial contribution to phosphorus cycling.
- qPCR Index (Functional Gene Abundance) or Quantitative PCR (qPCR) Index (Smith & Osborn, 2009).

It quantifies functional genes related to nitrogen, carbon, and phosphorus cycling. Quantification of genes like *nifH*, *amoA*, and *nirS* via qPCR gives insight into microbial nutrient cycling roles.

- **16S rRNA Gene Sequencing Diversity (Caporaso et al., 2010)**
  It illuminates bacterial composition and abundance via amplicon sequencing.

Analysis: Alpha and beta diversity via QIIME2 pipelines

- **Fluorescent *In Situ* Hybridization (FISH) Index (Amann et al., 1995)**

  It is used to visualize and quantify specific microbial groups via rRNA probes.

- Fatty Acid Methyl Ester (FAME) Profiling (Zelles, 1999)

  It identifies microbial community structure based on phospholipid profiles.

- **Community-Level Physiological Profiles (CLPP) (Garland & Mills, 1991)**

  Assesses microbial metabolic diversity via Biolog EcoPlates.

- **Denaturing Gradient Gel Electrophoresis (DGGE) or Microbial Community Fingerprinting (Muyzer et al., 1993)**
  It is used for microbial fingerprinting to evaluate shifts in diversity. Denaturing Gradient Gel Electrophoresis evaluates community shifts under stress. Index: Band richness and Shannon index

- **Total Microbial Activity Index (TMAI)**
  TMAI is a composite index of respiration, enzymatic activity, and biomass. This provides a single, standardized metric to assess productivity-supporting microbial activity.

- **Sulfate Reducing Bacteria (SRB) Index**
  Sulfate reducing bacteria reduce sulfate to hydrogen sulfide—a key anaerobic process. Their abundance indicates organic loading and sediment redox condition.

- **Monitoring:** qPCR for *dsrA* gene or black precipitate test in media. Excessive SRB presence may indicate overfeeding or pollution.

- **Pathogenic Bacterial Load Index**
  This index assesses potentially harmful bacterial populations, such as *Vibrio* or *Aeromonas* spp., using CFU counts or PCR. It is critical for fish health and management in intensive systems.

- **Biofloc Microbial Density**
  In biofloc technology (BFT), microbial aggregates recycle nutrients and serve as food. Their density and quality are linked to water productivity.

- **Bacterial Production Rate**
  It measures how fast bacteria reproduce and accumulate biomass, typically using leucine or thymidine incorporation.

- **Redox Potential and Microbial Index**
  Sediment redox potential is an indirect microbial index. Anaerobic microbial activity (e.g., methanogenesis, SRB) lowers redox values.

  Typical scale:

  +300 mV: Aerobic

  0 to –100 mV: Facultative anaerobic

  < –200 mV: Strictly anaerobic

Lower redox values are associated with microbial nutrient regeneration but may indicate excessive organic load.

- **Specific Oxygen Uptake Rate (SOUR) (Grady Jr. et al., 1999)**
  It indicates microbial respiration and metabolism.
  Formula: SOUR = (mg O^2 consumed/h) / (mg biomass)

- **Oxygen Uptake Rate (OUR)**
  OUR measures how quickly microbes consume oxygen, indicating organic load processing capacity. Used in evaluating pond aeration requirements and microbial metabolism.

- **Community-Level Physiological Profiling (CLPP)**
  Assesses microbial functional diversity via carbon utilization profiles (e.g., BIOLOG EcoPlates).

- **Microbial Water Productivity Index (MWPI)**
  A synthetic metric integrating microbial load, enzymatic activity, and functional diversity to reflect water's biological productivity. This index supports decision-making in aquaculture management for maximizing yield sustainably.

- **Nitrifying Bacteria Abundance (Belser, 1979)**
  Nitrifiers convert ammonia to nitrite and nitrate, crucial for nitrogen cycling.

  Ammonia-oxidizing bacteria are key for nitrogen cycling in aquaculture.

- Potential Nitrification Rate (PNR) (Belser & Mays, 1980)
  It measures microbial conversion of ammonia to nitrate, vital in nutrient removal.

- **Actinomycetes Count (Williams & Davies, 1965)**
  It is involved in decomposition of organic matter and antibiotic production.
- **Fungal Count (Gulis et al., 2009)**
  Aquatic fungi decompose complex organic compounds. Their abundance is useful in assessing detrital processing.
- **Microbial Quotient (qCO_2) (Anderson & Domsch, 1990)**
  It evaluates microbial efficiency under stress or disturbance. It also reflects the metabolic efficiency of microbial communities.
- **Carbon Use Efficiency (CUE) (Manzoni et al., 2012)**
  It is the ratio of biomass production to substrate assimilation. CUE defines how microbes convert substrate into biomass.
- **Potential Denitrification Rate (PDR) (Groffman et al., 1999)**
  It quantifies the capacity of microbial communities to reduce nitrate.
- Biofilm Bacterial Load (Hall-Stoodley et al., 2004)
  It quantifies bacteria attached to surfaces in aquaculture systems.
- Bioindicator Species Index (Suresh Kumar et al., 2020)

Selection of microbial species which indicate specific environmental conditions or pollution.

- Total Plate Count (TPC) in Biofilm (Austin & Austin, 2016)
  It evaluates bacterial colonization in aquaculture tanks or cages.
- Bacterioplankton Abundance Index (Porter & Feig, 1980)

  It is used as a proxy for microbial productivity and organic loading.
- Microbial Index of Biological Integrity (MIBI) (Harris, 2009)

An integrative index combining multiple microbial metrics to evaluate ecosystem health.

Role of dissolved oxygen

Dissolved oxygen is crucial for aquatic life and water quality, as it allows fish and animals to breathe, ensuring the body of water's livability. According to Odum (1956) diurnal dissolved oxygen (DO) tests are essential for determining the water productivity in aquatic environments because they shed light on the equilibrium between respiration and photosynthesis. Aquatic plants and phytoplankton generate oxygen during the day, but respiration takes over at night and uses oxygen. Wetzel (2001) emphasized that analyzing DO curves over a 24-hour period allows for an estimation of biological oxygen demand (BOD) and potential stress levels on aquatic fauna. Researchers can estimate net primary productivity (NPP), community respiration (R), and gross primary productivity (GPP) by monitoring changes in DO concentrations. Higher productivity is indicated by larger diurnal fluctuation, particularly high daytime DO and low nocturnal DO. These metrics are helpful in determining whether lakes and wetlands are eutrophic or oligotrophic, as well as in analysing aquaculture pond systems (Odum, 1956). Fish health and feed efficiency depend on maintaining adequate DO levels, and monitoring is advised to identify overfertilization or algae overgrowth (Boyd & Tucker, 1998).

Dissolved oxygen concentrations are known to play a significant role in aquatic production in any given body of water, but these concentrations do not stay constant throughout the day; rather, they decrease after sunset and reach a minimum just before dawn, before cycling back up again. Deuterium (DO) rises relatively slowly on overcast days and falls more noticeably after sunset. When there is a high concentration of planktonic bloom, and the secchi disc transparency is less than 15 cm at noon, the depletion of dissolved oxygen (DO) after sunset is rapid, and fish suffer at night because of the low DO in the surrounding water. Since a DO level below 5.0 mg/l for more than 8 hours is detrimental to fish growth and reproduction, it is crucial for farmers to be aware of the DO position at night and to take the necessary precautions in advance to ensure that the DO value does not drop below 3.0 mg/l during the night or before dawn (Boyd, 1982).

Diurnal experiments in various bodies of water have shown that the night time DO position may be explained by calculating the microbial DO consumption per hour using Winkler's approach. For four hours, from 10:00 AM to 2:00 PM, after determining the initial DO in ppm in a separate white bottle (I), this approach calls for two water filled black bottles suspended in water, one containing one drop of formaldehyde (A) and the other bottle devoid of formaldehyde (B). Now, after being suspended in water for 4 hours, the DO values in the two black bottles should also be assessed. The following can be deduced from the three DO values given above the microbial consumption of DO per hour (K) in mg/l:

K= I (A-B)/4 in mg/l per hour

Data revealed that DO does not stress out fish and prawn in bodies of water when K is less than 0.5 mg/l/hr. However, when K is greater than or equal to 1.0 mg/l/hr, DO during the night or just before dawn becomes a major stressor for these species, leading to a significant drop in production owing to mortality or disease outbreaks. In this way, we can monitor the rate of DO consumption by microbes throughout the day and respond appropriately to any drop in output.

Determination of water body's productivity through direct count of its bacteria and plankton

Bacteria and plankton are crucial for ecosystem productivity and nutrient cycling, and their diversity and abundance can be used to assess the health and trophic status of a water body, in addition to other variables. In most aquatic food webs, fish are the third most common species. Because of this, it must rely on both primary and secondary organisms to provide its nutritional needs. One way to quantify the water body's productivity is by counting the bacterio-plankton directly under a microscope. The total number of microbial cells in a sample of water can be determined using this technique (Razumov, 1947; Kuznetsov, 1959). Azam et al. (1983) highlighted the importance of the microbial loop in aquatic environments where as APHA (2017) highlighted the correlation between ecosystem productivity and bacterial and planktonic counts using direct enumeration techniques like epifluorescence microscopy, flow cytometry, and standard plate counts for bacteria, and Sedgwick-Rafter cell for plankton. Higher phytoplankton density and viable bacterial counts indicate higher primary productivity and microbial activity, supporting efficient feed conversion, better fish growth, and healthier pond conditions, as highlighted by Wetzel (2001) and Boyd & Tucker (1998). After a specific volume of water has been filtered through the membrane filters, the number of microbes in the water is to be recorded. The maximum allowable pore size of the membrane is 0.3 mm. The filters must have a clean, smooth surface for operation.

A glass funnel of the Millipore type is used for the filtration process, with the working surface diameter being precisely determined. Using a pencil, membrane filters are assigned numbers. The amount of water that has to be filtered is proportional to the body of water's productivity. A volume of 10–25 ml is needed for waters with low productivity, 5–10 ml for eutrophic waters with moderate productivity, and 0.5–1.0 ml for waters with high contamination levels. If you want your microbes to be evenly distributed, add 2-3 cc of distilled water that has already been filtered through filteration process. Stained filters are the next step. Put two or three sheets of regular filter paper into a petri dish and fill it with a solution of 3% erythrocin in 5% phenol. After soaking the filter paper in erythrocin overnight, dry it in a desiccator for 20 minutes. It is also required to add Millipore membrane filter paper with small square grids on top of the wet filter paper.

Placing the stained membrane filter over surface filter paper that has been soaked with distilled water will decolorize it. The tint of the membrane filters has changed to a faint pink. The filters are set up on a drop of immersion oil that is placed on top of a glass slide for microscopic observation. Extra oil is added to the membrane filter by dropping it onto its surface. In doing so, the filter becomes nearly see-through, revealing the microbes' varying hues. To facilitate counting, the filter is placed under the microscope with a cover glass in place. A tiny square of the filter is used to count the amount of microorganisms. Each stained membrane has ten of these squares, and an average is calculated for each of them. For every water sample, you need to count ten squares of ten of these membranes before you can get an average. Now that we know the filtered water volume, average microbial load per small square of the membrane filter, and working surface diameter and microbial load per millilitre of water, we can compare these values to those of other productive bodies of water.

$$N = \frac{n}{a} \times \frac{s}{v} \text{ cells/ml.}$$

N = no. of microorganisms per ml
n = no of microorganism per small square
a = area of the small square
s = area of the filtering surface
v = volume of water filtered

The average rate of carbon fixation by photosynthesis throughout the growing season was 2.55 g/m^2 per day, according to Boyd (1973). Assuming that the carbon content of dry phytoplankton is 48% (Boyd & Lawrence,1966), photosynthesis results in the daily production of 5.32 g/m^2 of dry matter. Assuming that half of the overall output occurs between 10:00 and 14:00 hours, photosynthesis produced 2.66 g/m^2 of dry matter each day.

Productivity evaluation based on phosphate-phosphorus intake

Phosphorus consumption significantly impacts productivity in various biological systems, including

plant growth, human health, and animal output. Phosphorus availability in aquatic environments influences algae development rates and can cause eutrophication if concentrations exceed biological thresholds (Wetzel, 2001). Nutrient loading models, introduced by Vollenweider in 1968, link phosphorus inputs to algal biomass creation and water quality deterioration, making phosphate intake crucial for ecosystem health. Studies by Boyd and Tucker (1998) highlight the importance of phosphorus budgeting in aquaculture ponds. Excessive phosphate loading decreases nutrient usage efficiency, encourages sediment accumulation, and destroys algal blooms. Phosphorus usage efficiency (PUE), the ratio of biomass yield to phosphorus applied, is a useful metric for water productivity (Boyd, 2015). FAO technical recommendations emphasize phosphorus monitoring is necessary to maintain optimal productivity levels for sustainable aquaculture methods.

Deficits or excesses can negatively affect health and performance. When the quantities of other vital nutrients are optimal, the primary production of a body of water is determined by water soluble inorganic phosphorus (Das & Dehadrai, 1986). According to Rodhe (1965), in order to fix 500 mg of C/m^2, it is necessary to absorb 10 mg of P/m^2. This lays the groundwork for estimating the rate of carbon fixation from phosphate-phosphorus consumption by microbes. As a result, 50 milligram of carbon fixation will take place for every milligram of phosphate-phosphorus consumed. By measuring the concentration of phosphate from phosphorus at the beginning and end of an incubation period of four hours, from 10:00 to 14:00 hrs, we can determine the primary productivity or carbon fixation rate of a body of water and compare it to values obtained from other bodies of water.

During the 10.00–14.00 hour time frame, the average gross primary productivity in fertilised ponds was 1.76 mg/l of carbon per hour, while in unfertilized ponds it was 0.18 mg/l of carbon per hour (Boyd, 1973). Fertilized ponds had primary productivity that was ten to fifteen times higher than control ponds, according to research by Hall et al. (1970). As a result, the carbon fixation rate and, by extension, the water body's productivity, may be easily calculated by comparing the initial phosphate-phosphorus concentration with that after four hours of incubation under ambient conditions, from 10:00 to 14:00 hrs.

Evaluation of productivity by calculating the quantity of bacteria present

Azam et al. (1983) emphasized that heterotrophic bacteria increase production by breaking down organic materials and releasing nutrients like phosphate and nitrogen that primary producers can use. Wetzel (2001) asserts that, particularly in settings with limited nutrients, bacterial productivity and biomass are essential markers of microbial loop effectiveness. Boyd and Tucker (1998) found that high bacterial numbers indicate strong microbial activities and active nutrient recycling, promoting increased biomass output per unit of water. Subramanian et al. (2013) underscored the importance of bacterial indicators in assessing water quality and feeding efficiency in ponds.

Bacterial number calculation evaluates productivity by assessing growth and activity in industrial or environmental settings. Methods include direct microscopic counts, viable cell counts, and indirect measurements like turbidity or biomass determination. Since the bacterial load is directly proportional to the availability of nutrients and, by extension, fish food organisms, measuring a body of water at 35°C in nutrient agar medium provides a decent estimate of its productivity and water quality. As a result of bacterial sickness, germs infiltrate fish organs and eventually reach muscle when this load above the essential concentration (10^5/ml of water) (Buras et al., 1985). Bacterial loads of 10^4/ml and higher have been detected in polluted waterbody, while productive waters had bacterial loads of 10^2–10^3/ml or slightly higher. A low productivity is indicated by a bacterial load below 10/ml.

Conclusion

Microbiological indices are sensitive, efficient, comprehensive tools and crucial for understanding aquatic ecosystem dynamics, particularly in fisheries and aquaculture. These indices provide insights into ecological status, productivity potential, and water quality, enabling proactive management and early warning systems for pollution, eutrophication, and disease outbreaks. Integrating microbiological indices into routine monitoring frameworks ensures more productive and sustainable aquaculture methods, promoting environmentally friendly fish culture practices. It can improve environmental health, production, and sustainable management. The accuracy of productivity estimates and ecosystem-based management can be significantly improved by combining microbiological data with traditional water quality evaluations, especially as global demand for

aquatic food increases. It is becoming increasingly effective tools in assessing water productivity in aquatic systems worldwide. Future studies should focus on standardizing these indices, creating specific baselines, and using contemporary molecular tools. Ultimately, microbiological indices are essential for directing aquaculture growth and sustainable fisheries in a time of environmental uncertainty.

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