Best Management Practices and Environmental Management in Aquaculture – Indicators for Monitoring in Multiple Scales

RODRIGUES, G. S. [a*], QUEIROZ, J. F. de [a], FRIGHETTO, R. T. S. [a], SAMPAIO, F. G. [a], FRASCA-SCORVO, C. M. D. [b], COUTO, K. R. [c], RODRIGUES, I. A. [c]

a. Embrapa Environment, Jaguariúna (SP), Brazil

b. APTA – Pólo Regional Leste Paulista, Monte Alegre do Sul (SP)

c. Collaborating Researchers, Embrapa Environment, Jaguariúna (SP)

**Corresponding author, Geraldo.Stachetti@embrapa.br*

Abstract

The promotion of sustainable aquaculture depends on the documented adoption of Best Management Practices (BMPs), associated with the monitoring of environmental health, of the availability of natural resources (especially uncontaminated waters and sediments), and of the efficient use of inputs. In order to ensure a traceable and organized procedure to help fish farmers to comply with these requisites, a set of environmental performance indicators has been integrated into an Environmental Impact Assessment (EIA) system, under the coordination of the Brazilian Ministry of Fisheries and Aquaculture (MPA), through a research project carried out in the Furnas reservoir (Minas Gerais State, Brazil). This choice of location aims at supporting a national policy, dedicated to implement 'Aquaculture Parks' in the large reservoirs associated with hydroelectric facilities in the country. These 'Parks' have been delimitated in selected areas, following careful diagnostics of hydrodynamics, carrying capacity evaluations, multiple water uses and conflicting interests, to receive permits to install cages for fish production. One provision of said policy charges MPA to offer producers with monitoring programs related with environmental impact and social benefit assessments of these aquaculture ventures. A challenge for such monitoring programs is to encompass the multiple scales represented by (i) the individual aquaculture ventures (be these small or large numbers of fish cages for each fish farmer), (ii) the collective association of producers in an 'aquaculture park', and (iii) the community at large eventually affected by these businesses. Furthermore, the monitoring procedure should emphasize the ability to promote and recommend adoption of BMPs, while facilitating the record keeping of environmental quality and resource carrying capacity information. The primary component of this record keeping, environmental management and resource monitoring procedure has been formulated as a 'Weighted Impact Assessment System for Best Management Practices in Aquaculture' (APOIA-Aquaculture), comprised of 68 indicators integrated in a multi-attribute platform to assess the 'Spatial organization' of the enterprises (in a set of 22 indicators), the analytical conditions of 'Water quality' (14 indicators), and 'Quality of the sediments' (09 indicators), and the conditions regarding 'Management, nutrition and safety' (23 indicators). A series of case studies has been carried out at the Furnas reservoir, in order to check the flexibility of the impact assessment system towards the different enterprise typologies, and its applicability as an environmental management tool for producers. Interestingly, a subset of 'sediment quality indicators' is frequently showing sensitivity as a record of mismanagement, especially those linked with inadequate feeding management. For instance, organic matter and phosphate contents increased markedly from sediments sampled ~10m upstream (considering the local current flows) as compared to just under the cages. The main reasons for these changes seemed to be the inadequate identification of cages, with consequent poor control on feeding practices and impossible bookkeeping. Such indicator interactions, and related management tradeoffs and improved practice recommendations, are stressed in

'Environmental Management Reports' offered to producers' decision making. Further development of the methodology is now focusing the formulation of a set of 'Natural resources and environmental assets sharing' indicators, to address the joint organization of the upcoming 'aquaculture parks', in compliance with the multiple uses intended to these territories around major water bodies.

Keywords: *aquaculture, impact assessment, environmental management, water quality, Best Production Practices*

1. Introduction

As environmental conservation gains importance due to the growing impacts caused by production activities, more urgent it becomes to select, adapt and monitor the adoption of best management practices (BMPs). This is especially true for rural activities, due to their spatial scale, extent of environmental changes caused, and bulk of exploited natural resources. In order to check BMP adoption and its effectiveness, Environmental Impact Assessment (EIA) procedures facilitate the organization, analysis, and documentation of appropriate indicators, focused by local natural limitations and potentialities, as well as by the aspirations and capabilities of the involved community. Also, impact assessments promote the recommendation of practices, technologies and productive arrangements as to contribute towards the certification of environmental management and product quality, in response to the voluntary claims of producers and their organizations.

Even when impact assessments do not address any formal certification objectives, the documentation of adequate environmental management can improve product value and market insertion, as long as the indicators objectively record information on compliance with legal environmental standards, expected technical performances, and local sustainability ideals. Among the many methodologies to carry out impact assessment and environmental management of rural activities, those based on performance indicators, that include the ecological, economic and social dimensions of sustainable development, are methods of choice. Ideally, indicators are integrated in impact assessment systems, which may address several levels of complexity and degrees of compliance with environmental management goals (MONTEIRO; RODRIGUES, 2006).

Equally to the present context of environmental management compliance expected from rural activities in general, the sustainable development of aquaculture depends on the documented adoption of BMPs, associated with the monitoring of environmental health, of the availability of natural resources (especially uncontaminated waters and sediments), and of the efficient use of inputs. To satisfy these important objectives, a research project has been initiated under the coordination of the Brazilian Ministry of Fisheries and Aquaculture (MPA), to be carried out in the Furnas reservoir (Minas Gerais State, Brazil). This choice of location aims at supporting a national policy, dedicated to implement 'Aquaculture Parks' in the large reservoirs associated with hydroelectric facilities in the country.

These 'Parks' have been delimitated in selected areas, following careful diagnostics of hydrodynamics, carrying capacity evaluations, multiple water uses and conflicting interests, to receive permits to install cages for fish production. One provision of said policy charges MPA to offer producers with monitoring programs related with environmental impact and social benefit assessments of these aquaculture ventures. A challenge for such monitoring programs is to encompass the multiple scales represented by (i) the individual aquaculture ventures (be these small or large numbers of fish cages for each fish farmer), (ii) the collective association of producers in an 'aquaculture park', and (iii) the community at large eventually affected by these businesses.

So recognized the need for an appropriate method, the present research organized the main indicators, integrated them into a 'Weighted Impact Assessment System for Best Management Practices in Aquaculture' (APOIA-Aquaculture), and carried out field studies to check the applicability of this management tool, as well as its adequacy towards attending the demands of aquaculture entrepreneurs and promoting their engagement in the adoption and appraisal of best aquaculture practices.

2. Method

A proven alternative to assess impacts, gauge technical adequacy, and promote environmental management is the 'Weighted System for Environmental Impact Assessment of Rural Activities' (RODRIGUES; CAMPANHOLA, 2003). This sustainability indicators system aims at analyzing the environmental quality and the productive performance contexts at the rural establishment scale and its immediate vicinity, complying with the quantitative fundamentals of EIA science; while providing farmers with a decision support instrument under the following principles:

- allow the assessment of the most diverse rural activities, in varied environmental settings and contrasting socioeconomic contexts;
- include indicators relative to the ecological, economic, socio-cultural and management aspects pertaining to local sustainable development;
- facilitate the detection of critical control points for management correction;
- express results in a simple and direct manner, to farmers, rural entrepreneurs, decision-makers, and the general public alike;
- be constructed in a user-friendly interface, capable of automatically offering an integrated impact (or sustainability, or performance…) index, contributing toward environmental management and eco-certification, according to the demands of farmers and their organizations.

This procedure has been implemented and perfected through numerous studies in the most varied environmental and productive contexts (RODRIGUES ET AL., 2010), before being complemented with specific aquaculture indicators, benchmarks and coefficients as a 'Weighted Impact Assessment System for Best Management Practices in Aquaculture' (APOIA-Aquaculture)', introduced here.

Once implemented as an environmental management tool at the aquaculture venture scale, the set of Management Reports provided to producers are aligned and complemented with territorial geographic information, as to compose an environmental monitoring program and productive management report to the Aquaculture Park and associated producers.

2.1 Formulation and features of the 'APOIA-Aquaculture' environmental management system

Trusting in the knowledge of groups of aquaculture experts and producers, a set of 10 organizational criteria, under the managerial dimensions of 'Spatial organization', 'Water quality', 'Sediment quality', and 'Management, nutrition and safety', and 68 multi-criteria indicators (Tabela 1), were integrated as APOIA-Aquaculture.

Table 1. Set of dimensions, criteria and indicators observed in APOIA-Aquicultura

Weighted Impact Assessment System for Best Management Practices in Aquaculture (APOIA-Aquaculture)	
Dimensions and criteria	**Indicators**
SPATIAL ORGANIZATION General conditions of implementation	**1.** Distance to markets / transportation infrastructure **2.** Access to water / to cages **3.** Proximity of pollution sources **4.** Existence of conflicting water uses **5.** Local hydrodynamics **6.** Conditions of shelter and protection
Characteristics of cage placement	**7.** Type of reservoir **8.** Dilution area / Cage cramming **9.** Cage layout **10.** Distance to docking **11.** Minimal annual depth
Format and dimensions of the cages	**12.** Cage format **13.** Area / side surface ratio **14.** Type and dimensions of the net

	15. Sistema de fixação
Operational infrastructure and equipments	**16.** Laboratories / analytical instrumentation **17.** Fuel storage **18.** Feed and supplement storage **19.** Medicine and therapeutic product storage **20.** Docking facility **21.** Platforms and barges **22.** Boats, machinery and implements
WATER QUALITY	**23.** Transparency **24.** Dissolved oxygen **25.** Coliforms **26.** BOD_5 **27.** pH **28.** Nitrate **29.** Nitrite **30.** Total ammonium N **31.** Phosphate **32.** Turbidity **33.** Chlorophyll a **34.** Conductivity **35.** Visual water pollution **36.** Potential pesticide impact
SEDIMENT QUALITY	**37.** Organic content **38.** pH **39.** Phosphate **40.** Exchangeable K **41.** Exchangeable Mg (and Ca) **42.** H + Al (potential acidity) **43.** Total bases **44.** CEC **45.** Bases saturation
MANAGEMENT, NUTRITION AND SAFETY Management and operations	**46.** Productive cycle formal planning **47.** Procedures of fish reception and release **48.** Procedures of vaccination and prophylaxis **49.** Procedures of fish classification and distribution **50.** Frequency and timing of cleaning and reparations **51.** Procedures of disinfections **52.** Disposal of incrusting materials
Feeding practices	**53.** Population densities **54.** Frequency and timing of feeding **55.** Periodicity of biometric check **56.** Control of feed quantities and consumption **57.** Adjustment of feed type (by age) **58.** Control of predators and competitors
Safety	**59.** Control and record of fingerlings origin **60.** Control and record of apparent symptoms **61.** Control and record of behavioral symptoms **62.** Bookkeeping of prophylactic / therapeutic products **63.** Control and Record of fish losses **64.** Procedure for disposal of dead fish
Fish harvest and product quality	**65.** Weighting and controls of termination **66.** Procedure of harvest from cages **67.** Procedures of fasting and off-flavor control **68.** Aspect of the final product

These indicators are constructed in scaling checklists in which quantitative data obtained in field surveys / field and laboratory analyses are translated into impact indices, according to multi-attribute utility functions (scale normalized from 0 to 1, with the baseline of environmental compliance modeled at 0.7 – Figure 1). BMP indicators are checked with producers and managers, following observation of degree of adoption and compliance with technical recommendations and benchmarks (AYROZA, 2011).

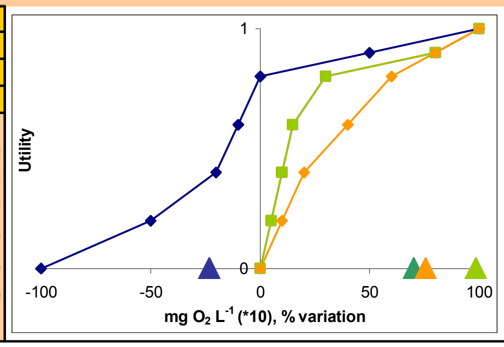
Indicators of environmental quality and natural resources adequacy are formulated to allow verification of multiple performance indices, relative to (1) environmental impact caused, i.e., the variation in the state of the environment due to aquaculture implementation; (2) adequacy of the used natural resources for aquaculture, i.e., the sources of water and type of substrate; (3) managerial capability and effectiveness of production practices, i.e., productive performance; up to those (4) indicative of compliance with applicable legal environmental standards, that is, generation and destination of residues or effluents. All indices are evaluated, gauged and expressed according to technical recommendations, scientific literature and legal regulations.

Table of mg O_2 L^{-1}		
Dissolved oxygen		
Before	Cages	After
9,85	7,02	7,55

Index of dissolved O_2 1= Percent DO variation

IOD1 - Variation % =	-23
IOD2 - Quality before =	9,85
IOD3 - Quality in cages =	7,02
IOD4 - Quality after =	7,55

IOD1	IOD2 e 3 (*10)	IOD4 (*10)	Utility
-100	0	0	0
-50	5	10	0,2
-20	10	20	0,4
-10	15	40	0,6
0	30	60	0,8
50	80	80	0,9
100	100	100	1



Best fit equation for Utility transformation

1. Logistic model: y=a/(1+b*exp(-cx))
2. Exponential model: y=a(1-exp(-bx))

Coefficients:

1. Variation %		2. IOD4	
a =	0,97	a =	1,16
b =	0,39	b =	0,02
c =	0,06	2. IOD 2 e 3	
		a=	0,962
		b=	0,058

U-IOD-1=	0,40
U-IOD-2=	0,96
U-IOD-3=	0,95
U-IOD-4=	0,90

Fig. 1. Typical multi-attribute scaling checklist for indicator assessment and Utility valuation in the APOIA-Aquaculture module, presenting the Dissolved Oxygen indicator, measured upstream (before), in the cages, and downstream (after) the main flow of water; and the four resulting performance indices, related to the environmental impact (% variation between before and after); the resource quality (before); the quality of productive management (cages); and the conformity with legal standards (after).

The APOIA-Aquaculture module is then comprised of 30 such scaling checklists, formulated as to appropriately accommodate the 68 indicators. Data for the assessments are obtained in field surveys, followed by the producers / managers, and water and sediment sampling, whose analytical results are fed directly into the scaling checklists, formulated as to weight the data and graphically express synthesis indices of BMP adoption and productive performance. Based on the integrated evaluation of these indicators and indices, technical recommendations become more effective and consistent, favoring decision making towards management adjustments.

2.2 Field studies and system validation

An applicability validation and method testing step for the APOIA-Aquicultura module has been carried out in two aquaculture ventures, selected to become some of the Project´s Environmental Management Demonstration Units, in the Aquaculture Park Guapé 1, located at coordinates 20°43'05.3'' latitude south and 45°56'02.3'' longitude west, on the margins of the Furnas Reservoir, in Guapé municipality (MG). Each producer manages approximate 80 cages (2x2x2 m), distributed in rows 20 m apart, right beside the delimited Aquaculture Park, to be eventually licensed by the Ministry of Fisheries (MPA). Field surveys were carried out in August 2012 (end of dry season), and the individual 'Environmental Management Reports' were presented to producers, who offered their critical view and suggestions for multiplication of the studies among other entrepreneurs.

3. Results

3.1 Case study 1

Aquaculture Venture 01 showed adequate environmental and productive performance indices, with especial reference to excellent water quality indices (to all 13 indicators) at the time of sampling. As defined in the APOIA-Aquaculture module, the integrated performance index reached 0.69 (in the utility scale of 0 to 1.0 with BPM compliance baseline set at 0.70 – Figure 2).

A mean performance index equal to 0.89 resulted for the Spatial Organization dimension, attesting to adequate General conditions of implementation, but with a small deficiency in the Operational infrastructure and equipments (lack of even simple water quality measurements, e.g., DO, transparency and temperature).

The Water quality dimension reached performance 0.95, as determined by the constancy of excellent chemical and biological characteristics, except for Dissolved oxygen levels, which even lowered within the cages (-23%) remained above 7 mg/L, perfectly adequate for the fish, and in compliance with environmental quality standards defined in applicable legislation.

Indicators of Quality of sediments, however, pointed out expressive buildup of organic matter and nutrients (notably phosphate, but also potassium) in the samples immediately at the bottom of the cages location, comparatively to the position upstream the preferential water flow. With a mean performance index equal to 0.54 these indicators register the cumulative effects of other deficiencies, observed in the feeding practices.

In this sense, absence of biometric check and, more importantly, lack of adequate control of the offered feed and calculation of consumption, individually for each cage, associated with inappropriate procedures for disposal of residues, resulted in a 0.74 index for the 'Management, nutrition and safety' dimension (see Figure 2). Correction of these few deficiencies, improving the procedures for control and record keeping, can foster the BMP adoption status of Aquaculture Venture 01, improving its production quality and the viability of the enterprise.

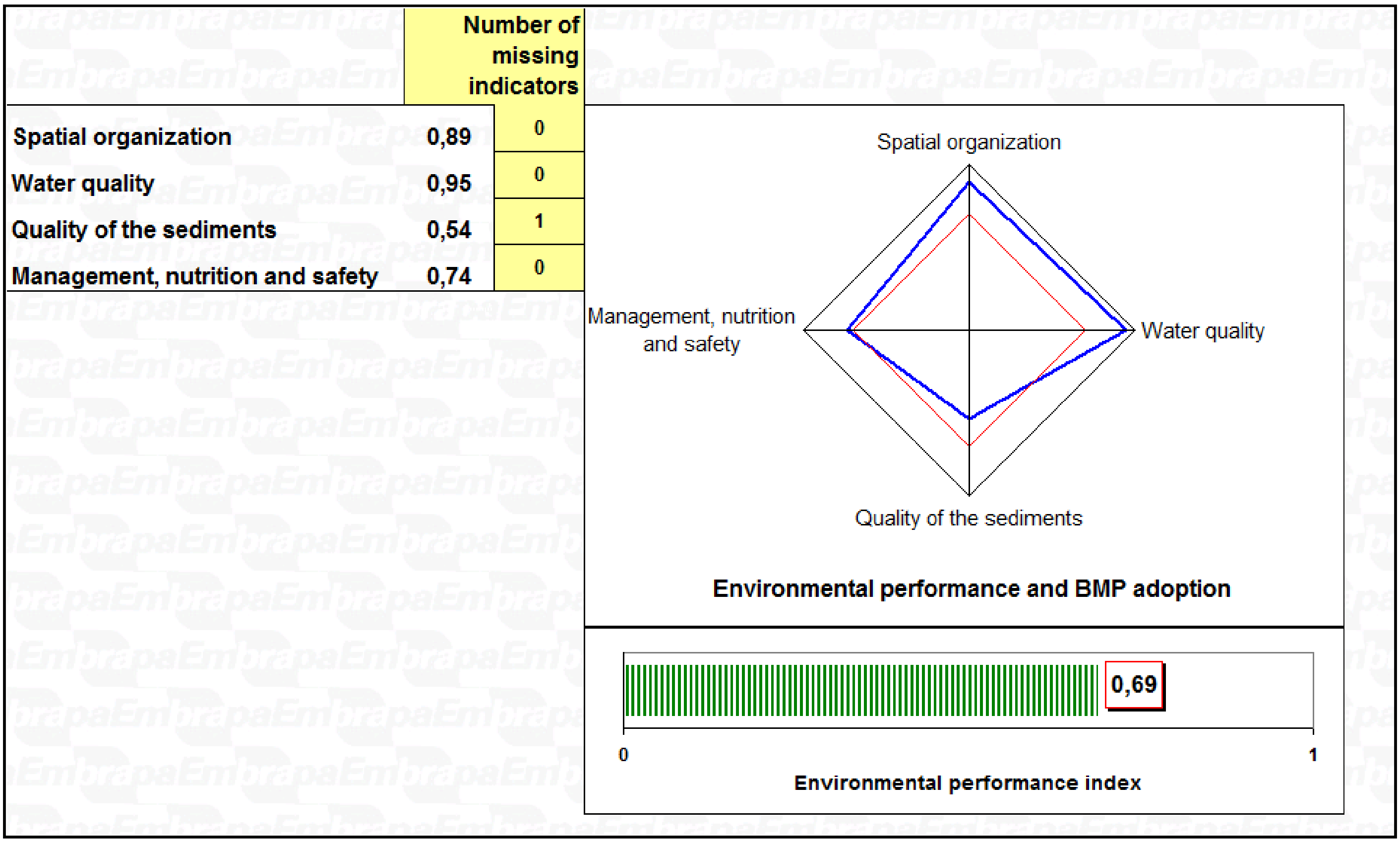


Fig. 2. Environmental performance indices obtained for Aquaculture Venture 01, located at the Furnas Reservoir (Minas Gerais State, Brazil). Results of the APOIA-Aquaculture environmental management system, August 2012.

3.2 Case study 2

Aquaculture Venture 02 reached a mean integrated performance index equal to 0.66 (Figure 3). Specifically, a mean 0.77 index resulted for the set of indicators of the Spatial organization dimension, also showing deficiencies in the availability of monitoring instrumentation, and poor conditions for storage of feed and supplements. Water quality parameters were also excellent (performance index 0.93), although larger increases in organic content and nutrients were observed in the sediments, causing a mean performance index equal to 0.52.

Such results point out a risk to water quality, since excess nutrients, especially P, may cause damaging algae blooms and, in the eventuality of a water thermal inversion, common in these colder days of August, deeper nutrient rich waters can ascend and impose a high oxygen demand, exposing the cages to hypoxia, fish to asphyxiation and death, with consequent important economic losses.

These deficiencies result form inadequate feeding practices, as shown by a 0.65 performance index for the Management, nutrition and safety dimension (Figure 3).

		Number of missing indicators
Spatial organization	0,77	0
Water quality	0,96	0
Quality of the sediments	0,52	1
Management, nutrition and safety	0,65	0

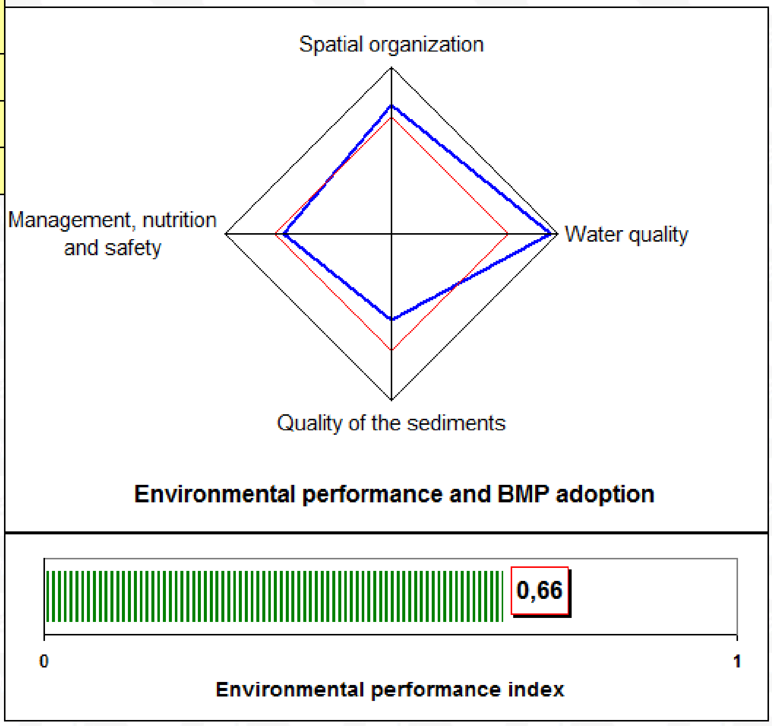


Fig. 3. Environmental performance indices obtained for Aquaculture Venture 02, located at the Furnas Reservoir (Minas Gerais State, Brazil). Results of the APOIA-Aquaculture environmental management system, August 2012.

The performance indices summarized in Figures 2 and 3 for the different case studies are instrumental to facilitating understanding of indicator tradeoffs and communicating management options and recommendations to producers. Furthermore, as a means of documenting environmental monitoring results, the APOIA-Aquaculture module provides an objective bookkeeping tool, registering in its indicator scaling checklists, the original data upon which performance indices are drawn. For example, Table 2 shows the array of analytical data, and related performance indices, for the set of indicators of environmental quality, for Aquaculture Venture 01.

Table 2. Set of original analytical data and related performance indices, APOIA-Aquaculture environmental management system

Water quality			***Mean index = 0.95***		Quality of the sediment			Mean index = 0.54	
Indicator	***Value before***	***Value after***	***Impact index***	***Performance index***	***Indicator***	***Value before***	***Value after***	***Impact index***	***Performance index***
Dissolved oxygen	9.85	7.02	0.40	0.95	*Organic matter*	2.2	3.9	0.41	0.64
Coliforms	0	0	0.70	1.00	*PH*	5	5.2	0.99	0.58
BOD_5	0.3	0.2	1.00	1.00	*Phosphate*	29	370	0.0	0.10
pH	6.8	6.7	0.91	0.94	*Exchangeable K*	0.6	1.2	0.03	0.34
Nitrate	2	2	0.70	1.00	*Exchangeable Mg (and Ca)*	33 + 3	47 + 4	0.89	0.67
Nitrite	0.03	0.03	0.70	0.97	*H + Al (Potential acidity)*	42	42	0.70	0.38
Total ammonium N	0.23	0.26	0.55	0.89	*Total bases*	36.6	52.2	0.97	0.90
Phosphate	0.33	0.27	0.90	0.68	*CEC*	78.6	94.2	0.89	0.98
Turbidity	1	1	0.70	1.00	*Bases saturation*	46.6	55.4	0.88	0.48
Chlorophyll a	0	0	0.70	1.00					
Conductivity	0.031	0.032	0.67	0.95					
Visual water pollution	100% absent	100% absent	0.70	1.00					
Potential pesticide impact	100% absent	100% absent	0.70	1.00					

4. Discussion

With these characteristics of the APOIA-Aquaculture environmental management system producers can ascertain which attributes may be in disaccord with his/hers BMP adoption choices and natural resources use objectives. To technical assistants the indicator system facilitates communication of the interaction between productive and management factors, promoting an integrated view for technical recommendation. To public agents and decision makers, the indicator system represents a documented and analytical base of the operational conditions of aquaculture ventures, favoring monitoring and consequent adoption of promotion and control measures, aiming at the integrated environmental management of the productive sector.

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