Int Aquat Res (2010) 2: 167-171
(Special Issue of AquaMedit 2010 Conference, Greece)
ISSN 2008-4935
Available online at www.intelaquares.com

International Aquatic Research

A combination of selected indexes for assessing the environmental impact of marine fish farms using long term metadata analysis

Theo Mavraganis [1*], Trevor Telfer[1], Cosmas Nathanailides[2]

[1]Institute of Aquaculture, Stirling University, FK9 4LA, Scotland, UK
[2]Department of Aquaculture and Fisheries, TEI of EPIRUS, Igoumenitsa, GR 46100, Greece

Abstract

Several biological indexes can be used to assess environmental impacts of aquaculture in the aquatic ecosystem. Some biological indices are used within environmental legislative and policy frameworks which aim to monitor the impact of marine aquaculture and regulate the operation of fish farms. In Scotland, the impact of fish farms is assessed according to benthic ecosystem status compared with modeled organic loading. The purpose of this paper is to evaluate the benefits of using an optimal combination of a minimal number of selected benthic and aquatic parameters which can provide accurate and reliable information about the benthic status around the fish farm sites in Scotland. The data analyzed in this paper were obtained from the Institute of Aquaculture (IoA), of University of Stirling, and were collected from various fish farm sites across Scotland over several years. Macrofaunal and physico-chemical parameters included in the analysis were: Median Particle Size Analysis (MPSA); total sediment Carbon (C% by dw); total sediment Nitrogen (N% by dw) and Redox Potential (Eh). In this analysis a number of diversity and trophic level based indices were also used - including the Shannon Index (H'), the Infaunal Trophic Index (ITI) and the Azti's Marine Biotic Index (AMBI) - to asses the biotic status of the sites. Univariate and multivariate analysis of the data indicated that a combination of Abundance (N), H' and AMBI as biological indexes for describing the status of the ecological level along with the carbon percentage and redox potential appeared to be the give the best representation of change. This combination is even more accurate over a series of sampling stations and time points, rather than for a single site only, offering a convenient method for assessing the risk of aquaculture pollution of biotopes bellow or adjacent to floating marine fish farm cages.

Keywords: Environmental impact, Marine fish farms, Long term metadata analysis

Introduction

Many tools have been created to identify the level of pollution impacts on the marine environment due to the increase in anthropogenic activities, such as aquaculture. Aquaculture is an activity which increases nutrient enrichment in sediments beneath sea cages (Karakassis et al. 2000). Environmental changes due to this enrichment can be monitored using a range of direct physico-chemical measurements (SEPA 2005) combined with calculation of biotic indices based on invertebrate community structure (Telfer and Beveridge 2001a).

[*] Corresponding author. Email: mavraganisteo@yahoo.com. Tel: +306946941762.

A number of such indices are used including simple species richness, species/abundance diversity measures and trophic indices. These measurements are also used widely for defining environmental quality standards (EQSs) by environmental regulators and legislators. For example, the Scottish Environment Protection Agency (SEPA) has a requirement for the Infaunal Trophic Index (ITI) (Codling and Ashley 1992) to be included in annual or bi-annual monitoring assessments. AMBI is a popular numerical tool used in many industrial and research centres in order to monitor benthic ecological quality.

This is often used along with abundance (N), Shannon Index (H') and the chemical measurements, such as carbon, and nitrogen and redox potential (Lazaro et al. 2005). These indices are used to give information about the biotic community present at seabed sites and they particularly emphasise the trophic and distributions of species and their relative abundance, which can be used as an indication of environmental quality (Borja et al. 2000; Maurer et al. 1999).

This study aims to evaluate a combination of indexes and identify subsets of parameters that best describe environmental conditions and biological traits in marine salmon farming. The results are discussed in the context of improving the methodology for assessing the environmental conditions in marine aquaculture sites.

Materials and methods

The data used in the present paper were obtained from the Institute of Aquaculture (IoA), University of Stirling and were collected from 309 sampling stations around Scottish marine cage fish farms in accordance to the SEPA policy of statutory regulatory environmental monitoring studies at marine fish farms. Medium Particle Size Analysis (MPSA), carbon percentage (C%), nitrogen percentage (N%) and redoxpotential (Eh) at each sampling stations were measured using standard methods (SEPA 2005). Macrofauna were sampled using a standard size grab sampler (Van Veen 0.025 m^2) as five replicates for each stations and the species richness and abundance counts per unit area calculated after sorting by eye. Using the macrofauna data, the values of the following biological indicators was calculated:

- Number of individuals (N) in five replicates per station
- Number of species (S) in five replicates per station
- Infaunal Trophic Index (ITI)
- AZTI's MBI
- Simpsons Index (D)
- Brillouins Index (Hb)
- Shannon Index (H')
- Pielou Evenness (P)
- Heip Evenness (Eh)

ITI is a biotic index with a score between 0 and 100. In nutrient influenced conditions, such as estuaries, a value of 0 to 30 is considered highly disturbed, 30 to 60, moderately disturbed and 60 to 100, indicative of background (undisturbed) conditions (Word 1987; Codling and Ashley 1992). In the present work, in order to obtain comparable range of ITI values with the other biological indices, the ITI scores were altered by deducting 100 from all the ITI values and then multiplied by 0.07 (to approach the AMBI scaling correlation).

The AZTI Marine Biological Index (AMBI) (Borja et al. 2000; Borja and Muxika 2005) assigns a score on the basis of interactions and presence of species from different trophic levels. The score is directly related to good or poor quality environmental conditions (Borja et al. 2000; Borja and Muxika 2005). The Simpsons Index (D) is based on sample measurements that account for both richness and proportion (percent) of each species from a sample within an area. The index assumes that the proportion of individuals in an area indicate their contribution to overall diversity. If a sample has a high dominance value it is highly dominated by one species (Krebs 1992).

The Brillouin index (Hb) measures the diversity of a over a whole species population allowing for all of the data to be used rather than a statistical measure of probability of occurrence within a population (Pielou 1966; Krebs 1992). The Shannon Index (H') is based on the proportional abundance of the species present in an ecosystem. This diversity index measures the order (or disorder) observed within a particular system according to the number of individuals observed for each subspecies in a sample plot (Pielou 1966; Krebs 1992). The Pielou Evenness index (P) is based on the ratio of the Shannon Index of diversity/ species richness. Pielou Evenness index provides an estimation of the the evenness of distribution in different areas. Heip's Evenness (E^h) is a measure of how similar the abundances of different species are. When there are similar proportions of all subspecies then evenness is one, but when the abundances are very dissimilar (some rare and some common species) then the value increases (Heip 1974).

The biological indices and the water chemistry data were used for a Hierarchical cluster analysis, and the similarity between two sites was estimated according to the Euclidean distance. The Euclidean distance provides a good index of the similarity between two samples, sites with the highest similarity are characterized by the shortest distance between them (Howard 1991).

Results and discussion

Biological indices and the chemical data are presented in Tables 1 and 2, respectively. Both categories of indices (chemical and biological) exhibited wide variability between sampling stations. This variability is commonly observed in aquaculture sites and is partially a result of a variability in a range of parameters including the distance from the source of pollution (i.e. the fish cage) and a seasonal range of currents and water exchange (Borja et al. 2009).

Table 1. Average values (+/- SD) and range of the biological indexes

Index	Average (SD)	Range
ITI	4.13 (1.20)	0.91-6.99
AMBI	2.53 (1.41)	1-6
Simpsons Index (D)	0.72 (0.23)	0.03-1.00
Brillouins Index (Hb)	1.34 (0.50)	0.08-2.24
Shannon Index (H’)	10.32	2.00-24.00
Pielou Evenness (P)	0.74 (0.22)	0.06-1.00
Heip Evenness (Eh)	0.57 (0.25)	0.02-1.00

ITI was the index which exhibited the highest range of values, conversely AMBI exhibited a lower range and was therefore selected to be used for further data analysis. The correlation between the different parameters is presented in Tables 3 and 4. Carbon and Nitrogen % correlated with Redox Potential, whereas Median Partical Size Diameter did not correlated with any of the other parameters.

There was a good correlation between the biological indices, the exception being between N with Hb and H’ and between the S and P. A further analysis revealed that Hs and Hb correlated with AMBI and ITI, whereas P and Hs were highly correlated. For this reason Hs was chosen for further analysis as it can account for both Pielou evenness and equitability of the species.

Table 2. Average values (+/- SD) and range of the chemical parameters

Parameter	Average (SD)	Range
Median Particle Size	385.84 (419.92)	82 -3533
Carbon %	4.88 (2.93)	0 -10.57
Nitrogen %	0.16 (0.18)	0 - 1.17
Redox Potential	304.80 (113.10)	0 - 540

Interestingly, the results indicate that among the other biological indices, ITI, AMBI, and H’ were good indicators of benthic status, but the Shannon and AMBI indices were highlighted on the basis of how accurately they described the status of the disturbance.

The stations with clearly non-degraded environmental conditions could be easily discriminated according to the chemical and biological index analysis, nevertheless a good correlation of the biological indices with the chemical parameters was exhibited between the benthic indices and carbon and oxygen. This is due to the fact that presence of both carbon and oxygen in the benthic environment are required for high species richness, equitability and diversity. Further analysis of the data was required to evaluate the relative significance of each parameter in providing accurate information on the environmental status of aquaculture sites. These analytic methods may include multivariate analysis using ordination by non-metric multi-dimensional scaling (MDS) as Cheng et al. (2004) suggested.

Table 3. Pearson product moment correlation between chemical parameters

	C		N		Median particle size	
	Correlation	P-value	Correlation	P-value	Correlation	P-value
Redox	-0.317	<0.01	-0.322	<0.01	0.164	0.090
C			0.585	<0.01	-0.079	0.395
N					-0.094	0.312

Table 4. Pearson product moment correlation between the biological indexes of benthic status. An asterisk indicates a highly significant correlation ($P < 0.01$)

	S		D		Hb		Hs		P	
	Correlation	P-value	Correlation	P-value	Correlation	P-value	Correlation	P-value	Correlation	P-value
N	0.475	*	-0.459	*	0.026	0.077	-0.15	0.103	-0.698	*
S			0.354	*	0.751	*	0.675	*	-0.513	0.579
D					0.76	*	0.874	*	0.87	*
Hb							0.967	*	0.462	*
H									0.601	*

The use of a combination of benthic indices has the potential to reduce the error (Van Dolah et al. 1999), contrary to using a single index, and thus it can more accurately reflect the range of benthic ecological conditions.

In conclusion, the results indicate that a combination of two chemical parameters: the Redox Potential and C% with AMBI or H' would accurately predict the level of disturbance of benthic ecosystems around the aquaculture sites.

Acknowledgements

T. Mavraganis was financially supported by the State Scholarship Foundation of Greece (IKY).

References

Borja A, Franco J, Perez V. 2000. A marine Biotic Index to establish the ecological quality of soft-bottom benthos within European estuarine and coastal environments. Mar Poll Bull 40(12): 1100-1114.

Borja A, Muxika I. 2005. Guidelines for the use of AMBI (AZTI's marine biotic index) in the assessment of the benthic ecological quality. Mar Poll Bull 50: 787-789.

Borja Á, Rodríguez JG, Black K, Bodoy A, Emblow C, Fernandes TF, Forte J, Karakassis I, Muxika I, Nickell TD, Papageorgiou N, Pranovi F, Sevastou K, Tomassetti P, Angel D. 2009. Assessing the suitability of a range of benthic indices in the evaluation of environmental impact of fin and shellfish aquaculture located in sites across Europe. Aquaculture 293(3-4): 231-240.

Cheng C. 2004. Statistical approaches on discriminating spatial variation of species diversity. Botan Bull Acad Sin 45: 339-346.

Codling ID, Ashley SJ. 1992. Development of a biotic index for the assessment of pollution status of marine benthic communities, Water Research Council Report No. SR 2995, Marlow, Bucks SL7 2HD, UK.

Heip C. 1974. A new index for measuring evenness. J Mar Biolo Ass 54: 555-557.

Howard PJA. 1991. An Introduction to Environmental Pattern Analysis, Parthenon Publishing Group, Carnforth, USA, pp 254.

Karakassis I, Tsapakis M, Hatziyanni E, Papadopoulou KN, Plaiti W. 2000. Impact of cage farming of fish on the seabed in three Mediterranean coastal areas. ICES J Mar Sci 57: 1462-1471.

Krebs CJ. 1999. Ecological Methodology. 2nd ed. Prentice Hall. pp. 624.

Maurer D, Mengel M, Robertson G, Gerlinger T, Lissner A. 1999. Statistical process control in sediment pollutant analysis. Environ Poll 104(1): 21-29.

Pielou EC. 1966. The measurement of diversity in different types of biological collections. J Theor Biol 13: 131-144.

Sanz-Lázaro C, Marin A. 2006. Benthic recovery during open sea fish farming abatement in Western Mediterranean, Spain. Mar Environ Res 62: 374-387.

SEPA (Scottish Environment Protection Agency) 2005. Regulation and monitoring of marine cage fish farming in Scotland, A manual of Procedures. Standard Monitoring Survey. Version 1.6.

Telfer TC, Beveridge MCM. 2001. Monitoring environmental effects of marine fish aquaculture. In: Uriarte A, Basurco B. (Eds.), Environmental Impact Assessment of Mediterranean Aquaculture Farms. Cah Opt Mediter 55: 75-84.

Word JQ. 1978. The Infaunal Trophic Index, Annual Report 1978. Coastal Water Research Project, El Segundo, CA, USA, pp. 19-39.

Van Dolah RF, Hyland JL, Holland AF, Rosen JS, Snoots TR. 1999. A benthic index of biological integrity for assessing habitat quality in estuaries of the southeastern United States. Mar Environ Res 48: 269-283.