Uncertainty of methodologies assessing ecological status in transitional water systems

Incertezza delle metodologie di valutazione dello stato ecologico negli ecosistemi acquatici di transizione

Ilaria Rosati, Alessio Pollice, Serena Arima, Giovanna Jona Lasinio, Alberto Basset

Abstract Assessments of ecological status according to the principles devised by the Water Framework Directive (WFD) are always associated with some degree of uncertainty. This uncertainty stems from the inevitable imperfection of the assessment criteria (i.e. development of indicators of ecological status, refinement of reference conditions and class boundaries, and routines for integrated assessment) and from the uncertainty of measurements. Here, we address the ecological status classification issue in transitional water ecosystems, using benthic macroinvertebrates and four proposed multimetric indices (BAT, BITS, M-AMBI and ISS), likely to respond differently to different sources of stress and natural variability adding uncertainty to resulting classifications. In order to investigate the possible contrasting behavior of the four multimetric indices, we propose two multivariate Bayesan hierarchical models in which the multimetric indices are jointly modeled as function of abiotic covariates and indicators of anthropogenic pressures.

Abstract *La valutazione dello stato ecologico secondo i principi espressi nella Direttiva Quadro sulle acque 2000/60 è sempre caratterizzata da un certo grado di*

Ilaria Rosati, Alberto Basset
Dipartimento di Scienze e Tecnologie Biologiche ed Ambientali, Università del Salento, Prov.le Lecce-Monteroni, 73100 Lecce, e-mail: ilaria.rosati@unisalento.it; alberto.basset@unisalento.it

Alessio Pollice
Dipartimento di Scienze Economiche e Metodi Matematci, Università degli Studi di Bari "Aldo Moro", Largo Abbazia Santa scolastica 53, 70124 Bari, e-mail: alessio.pollice@uniba.it

Serena Arima
Dipartimento di Metodi e Modelli per l'Economia, il Territorio e la Finanza, Sapienza Università di Roma, via del Castro Laurenziano 9, 00161 Roma, e-mail: serena.arima@uniroma1.it

Giovanna Jona Lasinio
Dipartimento di Scienze Statistiche, Sapienza Università di Roma, via del Castro Laurenziano 9, 00161 Roma, e-mail: giovanna.jonalasinio@uniroma1.it

incertezza. Questa incertezza deriva dall'inevitabile imperfezione dei criteri di valutazione (i.e. sviluppo di indicatori dello stato ecologico, perfezionamento delle condizioni di riferimento e dei limiti delle classi, sviluppo di metodi per la valutazione integrata) e dalla variabilità intrinseca delle misurazioni. Questo contributo riguarda la classificazione dello stato ecologico di ecosistemi acquatici di transizione tramite macroinvertebrati bentonici ed utilizza quattro indici multimetrici già noti (BAT, BITS, M-AMBI ed ISS) che rispondono in modo differente a varie fonti di stress e di variabilità naturale, aggiungendo incertezza alle classificazioni che ne derivano. Allo scopo di analizzare i possibili comportamenti difformi dei quattro indici multimetrici vengono proposti due modelli gerarchici bayesiani in cui gli indici dipendono congiuntamente da funzioni di covariate abiotiche ed indicatori di pressione antropogenica.

Key words: lagoons, classification, multimetric indices, Bayesan inference

1 Introduction

Lagoons are important ecological systems, which also have considerable historical and socio-economic value. In recent years, there has been increasing recognition of the economic importance of lagoons through their provision of ecosystem services such as nutrient cycling, flood control, shoreline stabilization, water quality improvement by reducing the pollution load transported by freshwaters, fisheries resources, habitat and food for migratory and resident animals and recreational areas for humans (Levin, 2001; Basset et al. 2013). However, these services are increasingly threatened as lagoons are among the most vulnerable coastal systems to both natural and human pressure (Viaroli et al., 2005).
The need to act has also been acknowledged by politicians and legislation (e.g. Water Frame Work Directive 2000/60) has been adopted to stop further deterioration and restore lagoons healthy state. The Water Framework Directive (WFD, 2000/60/EC) requires EU Member States to assess the ecological status of each water body in Europe and to ensure a sustainable management such that good ecological quality of all water bodies will be obtained by 2015. The ecological status of aquatic ecosystems is defined in terms of the quality of the biological community, as well as the systems' hyrological and chemical chareteristics. Lagoons can be clustered in types (Basset et al., 2013), which display several different internal gradients of physical conditions and hence of the biota associated with them. Therefore, disentangling the anthropogenic negative pressures on guilds or biological quality elements (sensu WFD, 2000/60/EC) and ecosystem ecological status from the occurring natural pressures is particularly challenging in lagoons and it represents a major source of uncertainty in the process of ecological status assessment. (Elliott and Quintino, 2007; Basset et al., 2013). Several multimetric indices have been proposed particularly focusing on benthic macroinvertebrates (Borja et al., 2011), which are known to be sensitive to both natural and

anthropogenic pressures. Here, we will focus on four multimetric indices: BAT (Texeira et al., 2009), BITS (Mistri and Munari, 2008), M-AMBI (Borja et al., 2004; Muxika et al., 2007) and ISS (Basset et al., 2012). However the proposed indices are likely to respond differently to different sources of stress and natural variability components, adding uncertainty to resulting classifications. To properly understand what drives multimetric indices disagree in classifying lagoons' ecological status, we propose two multivariate Bayesan hierarchical models (Arima et al., 2013; Pollice et al., 2014). In the first model only three of four multimetric indices are considered jointly with abiotic covariates and indicators of anthropogenic pressures and in the other one the four multimetric indices are jointly modelled through a multivariate normal mixture accounting for the dependence on relevant abiotic covariates.

2 Materials and methods

Data on benthic macroinvertebrates were originally collected from 13 transitional water ecosystems located in different countries (Italy, Albania, Greece and Romania) and from three lagoons in Apulian region, all caraterized by a high heterogeneity of environmental conditions. Abiotic parameters and experts' opinion evaluations of external anthropogenic pressures were also made available. The macrobenthic community was examined using four multimetric indices BAT, BITS, M-AMBI and ISS.

In Pollice et al., 2014 we adopt a multivariate statistical model within a Bayesian hierarchical approach, allowing for the inclusion of multiple sources of information and external prior knowledge to quantify the effects of input variables as abiotic covariates and indicators of anthropogenic pressures on the different performance of multimetric ecological quality indices. Model parameters are estimated by Markov chain Monte Carlo posterior simulations implemented using the JAGS software. Model assessment and sensitivity analysis are performed by influence measures, posterior predictive summaries and residual analysis.

In Arima et al., 2013 we propose a Bayesian hierarchical model where the multimetric indices are jointly modelled through a multivariate normal mixture. Each mixture component is estimated as a function of covariates of interest and corresponds to an ecological status. The proposed approach overcomes misclassification issues of existing methods and explores the potential of an alternative classification procedure as multimetric indices are modeled jointly and the ecological status is uniquely defined according to all of them. Model specification includes the use of weakly informative prior distributions and the adoption of the Maximum a Posteriori decision rule to assign the lagoons to ecological status classes. Model parameters are estimated by Markov chain Monte Carlo posterior simulations implemented using the WinBUGS software.

3 Results

The main results achieved analysing the two different data sets are listed below:

1. Multimetric indices can be in disagreement and lead to contrasting assessments of the ecological status of the same ecosystem. The figure 1 showes that M-AMBI and ISS have a stronger linear correlation ($R \simeq 0.84$) while both pairs M-AMBI/BITS and BITS/ISS show a weaker dependence ($R \simeq 0.25$);
2. Multimetric indices have differentiated responses to abiotic parameters and anthropogenic pressures (Table 1). Particularly BITS differs with respect to M-AMBI and ISS.
3. The Bayesan classification model obtained by integrating the four indices (M-AMBI, BAT, BITS and ISS) showed a higher accuracy in the ecological status evaluation with respect to a priori approach (Table 2).
4. The key role of selected abiotic drivers and external pressures on lagoon ecological status have been highlighted by the pattern of variation of multimetric indices through Bayesan analytical approach.

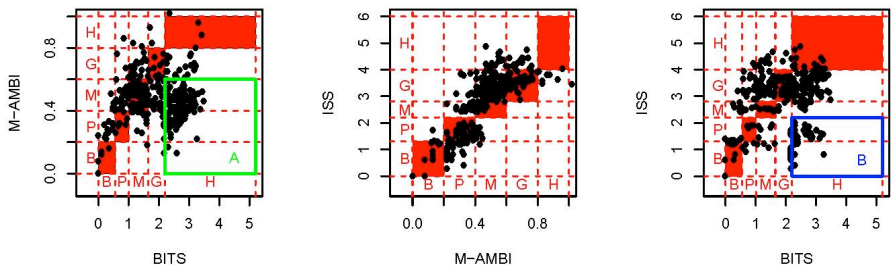

Figure 1: Joint distribution of pairs of multimetric indices with standard classification boundaries. Area A and B contain clusters of observation with contrasting behavior of two indices.

Table 1: Posterior estimates of index-specific regression coefficient and 95% credibility intervals for model. Estimates corresponding to strictly positive or negative credibility intervals are highlighted in red.

	M-AMBI	***BITS***	***ISS***
Water temperature	-0.042 (-0.211, 0.136)	-0.229 (-0.410, -0.049)	-0.052 (-0.223, 0.121)
Dissolved oxygen	0.151 (0.020, 0.282)	-0.217 (-0.354, -0.080)	0.169 (0.039, 0.298)
Salinity	0.014 (-0.206, 0.229)	0.177 (-0.045, 0.401)	0.007 (-0.206, 0.219)
pH	0.232 (0.133, 0.333)	0.154 (0.049, 0.258)	0.212 (0.112, 0.313)
Chlorophyll	-0.206 (-0.302, -0.109)	-0.260 (-0.365, -0.156)	-0.210 (-0.306, -0.114)
Agricultural inputs	-0.006 (-0.138, 0.127)	-0.033 (-0.173, 0.117)	0.063 (-0.069, 0.196)
Domestic discharges	0.262 (0.137, 0.385)	0.230 (0.097, 0.361)	0.257 (0.132, 0.379)
Industrial discharges	-0.325 (-0.470, -0.175)	-0.265 (-0.417, -0.113)	-0.227 (-0.372, -0.080)
Fisheries	-0.447 (-0.651, -0.243)	-0.101 (-0.311, 0.103)	-0.442 (-0.647, 0.244)

Table 2: Lagoon classification according to the proposed bayesan model and classification according to a priori approach as in Basset et al. (2013).

Lagoon	***Proposed model***	***A priori approach***			
		BAT	***BITS***	***M-AMBI***	***ISS***
Agiasma	Good	High	Good	High	Moderate
Alimini	High	Good	High	Good	Good
Cesine	Good	Good	Moderate	Good	High
Grado Marano	Good	High	Moderate	High	Good
Grado Valle Cavanata	Moderate	Moderate	Poor	Moderate	Good
Grado Valle da Pesca	Good	High	Good	High	Good
Karavasta	Good	High	High	High	High
Lehaova	Good	Good	Poor	Good	Good
Logarou	High	High	High	High	Good
Narta	Good	Moderate	High	Good	High
Patok	High	High	Good	High	High
Sinoe	Poor	Moderate	Poor	Moderate	Good
Torre Guaceto	Good	Good	Moderate	Good	Good

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