A First Biopollution Index Approach and Its Relationship on Biological Quality in Catalan Rivers

Beatriz Rodríguez-Labajos, Carolina Solà, and Antoni Munné

Abstract The purpose of this chapter is to present results of the applicability of the most well-known biopollution (BP) and biocontamination (BC) indices available in the literature by using information from the standard monitoring programme for fish carried out in Catalonia. As a part of this exercise, the pertinence of the results is evaluated by answering two questions: (1) are the BP&BC indices actually indicators for quality status, i.e. do their results respond to indicators of pressures on water bodies? And if so, (2) are the indices redundant with the existing indices of quality status for a given biological element? This discussion will be done in relation to the use of information on alien species (AS) for the purpose of future management and the ensuing role of uncertainty in the ecological assessment on water bodies according to the Water Framework Directive (2000/60/EC).

Keywords Alien species, Biocontamination, Biological indices, Biopollution, Catalan basins, Water Framework Directive

Contents

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Abbreviations

AS Alien species
BC Biocontamination
BP Biopollution
BPL Biopollution level index
IBPR Integrated biopollution risk index
SBC Site-specific biological contamination
WFD Water Framework Directive

1 Framing the Discussion: Alien Species and the Water Framework Directive

Same than in other regions of its European context, in the Catalan River Basin District, the recognition of alien species (AS) as a pressure to good ecological status has led authorities in charge of implementing the Water Framework Directive (WFD) to develop ad hoc programmes of measures. However, one of the challenges of integrating AS in the management of the ecological status of water bodies is that AS are at the same time a pressure to ecological status and a component of a the biological elements assessed to evaluate ecological status [1]. An enquiry to review how EU Member States deal with AS in their national status assessments unveiled a wide range of practices [2, 3]. This issue was a matter of concern of the WFD Ecological Status Working Group (ECOSTAT) that organised two different technical workshops in 2008 and 2009–with the participation of the lead author–to discuss this topic. In search of a harmonised European approach, ECOSTAT pondered whether AS should be taken into account in the WFD assessment. The starting point was that the Annex V of the WFD states that "water bodies should be 'totally or near totally undisturbed'" in the reference condition. An interpretation of this, for instance, is that WFD precludes the presence of AS at high-quality status. From there, it follows a deliberation about how the impacts of AS are captured in the assessment tools for ecological status classification. The use of supplementary biopollution and biocontamination (BP&BC) indices is one among several options that seem to be favoured by the national authorities in charge of implementing the WFD [2].

Table 1 Biopollution and biocontamination indices from the literature

Index	General description	Data requirements
SBC – site-specific biological contamination index [11]	Based on AS richness and abundance	AS richness and relative abundance per assessment unit
IBPR – integrated biopollution risk index [8]	Risk-based approach with reference to the proportion of AS with potential to spread, establish and cause impact	AS richness and relative abundance per assessment unit
		Evidence of AI impact (either on native biodiversity, ecosystem functions, trophic production, human access to natural resources, human, domestic animal and plant health, recreational and aesthetic activities, infrastructure or control costs)
BPL – biopollution level index [10]	Based on the abundance and distribution of the species and their impact on communities, habitats and ecosystem functions	AS relative abundance and distribution within each assessment unit
		Evidence of AS's impact on native species of communities, on habitats and on ecosystem functioning per assessment unit

The use of the term biopollution to discuss the issue of AS is relatively recent, and it has been basically applied to the aquatic environments [4, 5]. Biological pollution is related to the adverse impacts of invasive alien species due to effects on one or more levels of biological organisation: individual (such as internal biological pollution by parasites or pathogens), population (by genetic change, e.g., hybridisation), community (by a structural shift), habitat (by modification of physical-chemical conditions) or/and ecosystem (by alteration of energy and organic material flow) [6]. It conveys the idea that AS disrupt the ecosystem's health and thus impair the ecological quality of the environment [6, 7]. The adverse effects of biopollution may encompass social and economic costs. The most well-known methodologies to assess biopollution are the integrated biopollution risk index (IBPR) [8, 9] and biopollution level index (BPL) [10]. Another related term, also useful for guiding the management response to AS, is biological contamination or biocontamination (BC) that avoids any reference to potential impacts of the species and therefore is not considered equivalent to biopollution (BP). Biocontamination can be estimated through the site-specific biological contamination (SBC) index [11]. It is worth saying that the normal status classification usually relies on the match between the quality classes and differentiated effects of stressors, which would be a good property to maintain in the integration of AS to the assessment [1, 3]. In the final recommendations of the workshops organised by ECOSTAT, the critical importance of methods for identifying risk and the need to test biopollution indices across all types of surface waters is pointed out, including their application to the procedures of the WFD [12].

Given the relevance of this discussion, the purpose of this chapter is to present results of the applicability of the most well-known BP&BC indices available in the literature (Table 1) using information from the standard monitoring programme in Catalonia (NE Spain). As a part of this exercise, the pertinence of the results is evaluated by answering two questions: (1) Are the BP&BC indices actually indicators of quality status, i.e. do their results respond to indicators of pressures on water bodies? And if so, (2) are the indices redundant with the existing indicators of state for a given biological element? Note that this discussion will be done in relation to the possible use of information on AS for future management and the ensuing role of uncertainty in the assessment on water bodies according to the Water Framework Directive.

2 Applicability of Biopollution and Biocontamination Indices in Catalan Rivers, a Test Using Fish Species

The study area for the test includes 23 watersheds bounded by the administrative limits of Catalonia, with a total area around 32,000 km^2 (NE Spain). As the region features Mediterranean climate, half of the watersheds comprise ephemeral streams. The dataset includes information from sampling sites along the different river typologies present in the study area, occasionally some of the water bodies containing more than one site (Table 2). Environmental and fish community data were available from sites sampled in 2002–2003 ($n_{s2003} = 333$) and 2007–2008 ($n_{s2008} = 311$) as a part of the routine monitoring programme run by the watershed authority, the Catalan Water Agency [13, 14]. In the case of fish, the BIORI protocol secures obtaining the parameters needed for the estimation of the indices SBC and IBPR, namely, AS richness and relative abundance per assessment unit. In particular, abundance is registered both in terms of density (individuals/ha) and in terms of biomass (kg/ha) [13]. It is worth noting that there is absence of fish in 19.5% (in 2002–2003) and 24% (in 2007–2008) of the monitored sites due to diverse circumstances. Examining the data for the period 2002–2003, whereas 2% were sites with a dry river bed – i.e. ephemeral streams without fish according to historical data – or offered bad conditions for fishing (2%), there is a remarkable 15% of sites were the absence of catches indicates adverse conditions for the survival of the fish fauna, clearly in relation to ecological quality issues.

Focussing on the sites with available information about the fish community, and once contrasted the datasets of both monitoring periods, this section analyses BP&BC indices in water bodies in 2002–2003 ($n_{WB2003} = 182$) and 2007–2008 ($n_{WB2008} = 235$). Comparisons are done intersecting available information in coincident water bodies. The assessment of biopollution requires the characterisation of the species according to their native or alien status. This information was obtained from ACA [13] and Sostoa et al. [14] and adapted through expert assessment for the case of *Salmo trutta*, *Anguilla anguilla* and *Phoxinus phoxinus*.

Table 2 Number of sampling sites across different conditions for the two different analysed periods (2002–2003 and 2007–2008)

Number of items	2002–2003	2007–2008
Total sites (n_S)	333	311
Sites without catches (i.e. no fish, dry river bed or bad conditions for fishing)	65	76
Sites with fish catches	268	235
Water bodies with fish catches (n_{WB})	182	235

2.1 Site-Specific Biological Contamination Index (SBC), a Reasonable Quick Assessment of State

The site-specific biological contamination index (SBC) enables the comparison of different aquatic ecosystems according to their level of pollution from new taxa, taking into consideration their relative abundance in the ecosystem [11]. Accounting for the proportion of alien taxonomic orders in the community and the relative abundance of alien individuals, the biocontamination can be classified in five levels from 'no' biocontamination (SBC = 0) to 'severe' biocontamination (SBC = 5) and can be inversely interpreted as a contribution from the 'very good' status to the 'very bad' status of the aquatic ecosystem. The levels are determined through different thresholds in the proportion of species richness and/or the alien species abundance (see Fig. 1).

The initial testing done by the developers of this methodology for rivers of Central Europe used macroinvertebrate data compiled from different sources. After that, the SBC index was applied for the case of the Isle of Man, for macroinvertebrate data [15]. In this case, the data consistently relied on the UK Environment Agency guidelines for monitoring sampling, similar to a well-known assessment system for ecological quality of rivers using macroinvertebrates. A similar exercise was undertaken by Šidagyte et al. [16] for the case of invertebrates in Lithuanian lakes. The two latter studies have the explicit objective of analysing the biocontamination results in relation to metrics of ecological status and/or to environmental stressors parameters. While in the first one there was a significant negative relationship between biological quality indices and the SBC indices, in the second case SBC indices were unrelated either to biological quality indices or to stressor variables.

The SBC is not a risk index, since it does not point to possible negative outcomes but to actual adverse ecological consequences that percolate from the presence and abundance of AS. Once the data for the selected taxa is available, the calculation for a given assessment unit is relatively straightforward, though laborious. In Catalonia, the routine monitoring programme for fish offers the possibility of determining the SBC index using indicators of abundance both in terms of the density (number of individuals per hectare) and in terms of biomass (kilograms of alien fish per river hectare).

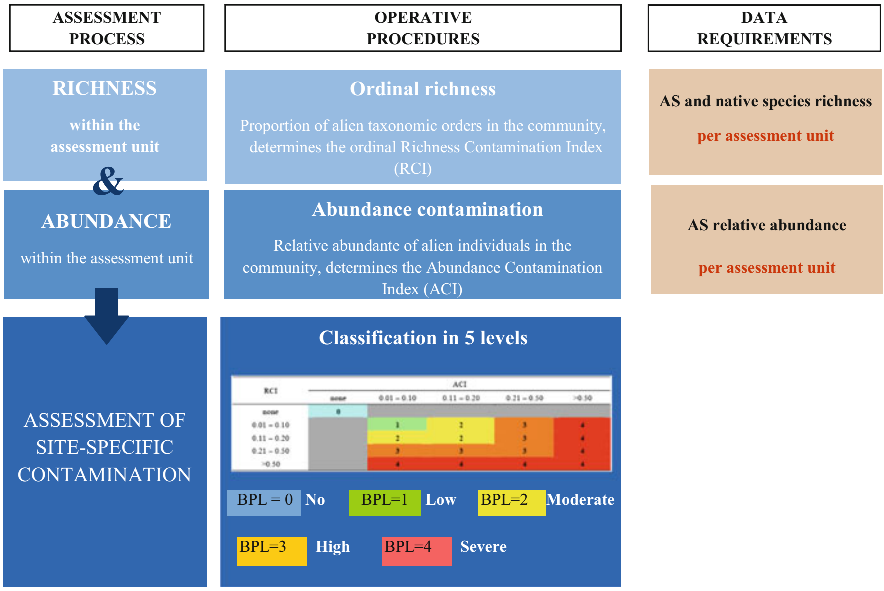

Fig. 1 Procedure for the determination of the site-specific biocontamination (SBC) level. *Source*: Own elaboration based on [11]

The results of the calculation (plotted in Annex I) for the two assessment periods and the two possible metrics of abundance do not differ markedly depending on the metric used (density or biomass). Accordingly there is moderate and more than moderate biocontamination (suggesting less than good ecological status) in one third of the monitored sites (34% in 2002–2003; 35% in 2007–2008) and around a half of the sites with fish communities (47% in both campaigns). In both assessment periods, the results show a negligible worsening (involving up to six sites) when biomass indicators are used, with minor decreases in moderate and high biocontamination and ensuing increases in high and severe biocontamination.

An issue in relation to the use of this indicator is getting polarised results. Most of the resulting biocontamination levels are concentrated at the extremes, as shown in Table 3. Moreover, the presumption of alien species effects simply derived from the alien to native species ratios can be arguable as not all alien species are damaging. In any case, the SBC is an easy-to-estimate indicator based on the existing monitoring routines. It can be used for a quick assessment of the state of biocontamination, provided that there is available data on relative AS abundance at the site level.

Table 3 Percentage of assessment units per SBC level (2007–2008, abundance as kg/ha)

SBC index value	Biocontamination	Number of water bodies (*N.*)
0	No	125
1	Low	0
2	Moderate	2
3	High	40
4	Severe	68
n.a	Without fish	76

Source: Estimated based on data provided by ACA

2.2 Integrated Biopollution Risk (IBPR) Index, a Quick Risk Assessment

Relying on the assumption that risk-based assessments are useful to support cost-effective decisions consistent with the precautionary principle, Panov et al. [8, 9] developed an approach based on the general appraisal of invasiveness according to three elements of risk. Such elements are dispersal, establishment in new environments and generation of ecological and/or socioeconomic impacts, combined as shown in Fig. 2.

The authors also provide some practical guidelines for the evaluation of each one of the descriptors of risk (also indicated in Fig. 2), which involves information about richness and relative abundance of AS in each one of the assessment units. Eventually the IBPR index, scoring from 0 to 4, is estimated with reference to the proportion of species present in specific locations that are included in one or more of three lists (black, grey or white), classified according to a formal listing procedure.

The assessment does not require proof of actual impact in the assessment unit but is entirely based on the existing information about the species' impacts according to the literature or other reliable source of knowledge. Of course, there are different methods to establish generic impact of species. Nentwig et al. [17] propose a scoring system (0–5) using subcategories of environmental and economic impacts multiplying the total rating by the percentage of occupied area and test it for alien mammals in Europe. Magee et al. [18] estimate the magnitude of the stress caused by in situ alien species using an index that summarises the frequency of occurrence and the potential ecological impact, demonstrating the use in the case of streamside vegetation of a river basin. Sandvik et al. [19] classify species based on two axes (invasion potential and local ecological effect), using a list of specific criteria, such as mean expansion rate and interactions with keystone species. They test the proposed system for several AIS still absent from Norway, their geographic area of interest. In the case of the IBPR assessment process, the evaluation is rather simple and only requires one positive response to a list of question about possible types of ecological and socioeconomic impacts (see Fig. 2).

The idea of using standardised procedures to classify AS into grey, white and black lists in order to provide a common framework for management is not new

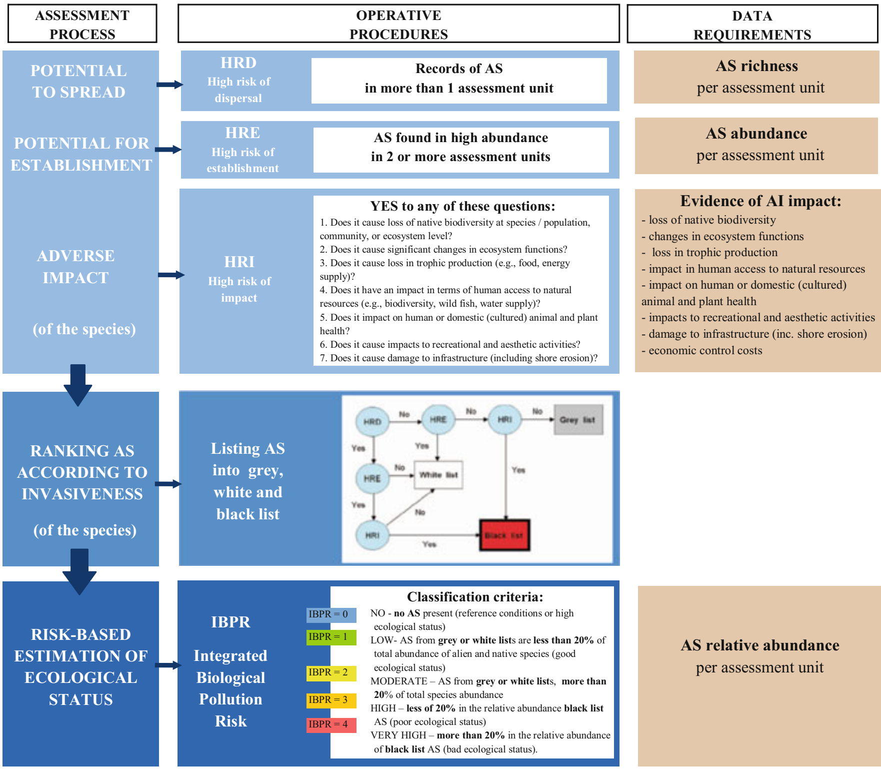

Fig. 2 Procedure for the determination of the integrated biopollution risk (IBPR) index. *Source*: Own elaboration based on [8]

[20, 21]. The IBPR index builds on this background to propose a listing system involving the following categories:

(a) Black list, for species with high potential to cause impact, together with species that are with high potential to spread and establish; their presence should be prevented or deemed as an element of necessary control.
(b) White list, for species with high potential to spread and/or high potential for establishment but low potential to cause impact; their presence can be deemed as acceptable.
(c) Grey list, for species with unknown potential to spread, establish and cause impact; for precautionary reasons, the set of 'no' responses is not interpreted as low-risk potential for all risk elements, but as a need of permanent monitoring to expand knowledge about the species.

Using the information about the number of sites with the presence of the species, their relative abundance and known impacts from the literature, a classification of alien fish detected in Catalonia through the standard monitoring system is presented in Table 4. Note that, in the listing scheme presented in Table 2, 'yes' means that

Table 4 Results of listing species according to the IBPR methodology

Species	HRD (2003)	HRE (2003)		HRD (2007)	HRE (2007)		HRI	List (2003)		List (2007)	
		Ind/ha	Kg/ha		Ind/ha	Kg/ha		Ind/ha	Kg/ha	Ind/ha	Kg/ha
Alburnus alburnus	22	10	3	28	11	6	YES	Black	Black	Black	Black
Ameiurus melas	1	1	1	3	0	0	YES	Black	Black	White	White
Barbatula barbatula	5	2	0	9	4	0	NO	White	White	White	White
Barbus graellsii	26	13	13	25	5	9	NO	White	White	White	White
Carassius auratus	5	2	2	6	3	2	YES	Black	Black	Black	Black
Cyprinus carpio	62	21	39	57	13	32	YES	Black	Black	Black	Black
Esox lucius	1	1	1	1	0	0	YES	Black	Black	Black	Black
Gambusia holbrooki	11	9	1	16	11	2	YES	Black	White	Black	Black
Gobio lozanoi	5	1	0	11	5	1	NO	White	White	White	White
Lepomis gibbosus	18	5	1	23	10	5	YES	Black	White	White	White
Micropterus salmoides	5	1	0	6	0	0	YES	White	White	White	White
Misgurnus anguillicaudatus	N.A.	N.A.	N.A.	1	0	0	YES	N.A.	N.A.	Black	Black
Oncorhynchus mykiss	6	1	4	6	2	4	YES	White	Black	Black	Black
Parachondrostoma miegii	4	4	3	5	3	3	NO	White	White	White	White
Perca fluviatilis	N.A.	N.A.	N.A.	1	0	0	YES	N.A.	N.A.	Black	Black
Phoxinus sp.	18	13	2	31	23	13	NO	White	White	White	White
Pseudorasbora parva	1	0	0	7	0	0	YES	Black	Black	White	White
Rutilus rutilus	2	1	1	14	4	4	YES	White	White	Black	Black
Salmo trutta	9	4	6	3	1	1	YES	Black	Black	White	White
Sander lucioperca	2	0	0	2	0	0	YES	White	White	White	White
Scardinius erythrophthalmus	17	3	2	8	1	1	YES	Black	Black	White	White
Silurus glanis	5	0	1	6	1	4	YES	White	White	White	Black

Gray shade means high risk. HRD high risk of dispersal, based on number of sites with presence of the species (>1), HRE high risk of establishment, based on the number of sites with relative abundance (>20%), HRI high risk of adverse ecological and/or socioeconomic impacts
Source: Own elaboration based on data provided by ACA

information on potential invasiveness of the species is available, while 'no' means information is not available or 'unknown'.

Some comments stemming from the results on listing species are the following ones:

- All the species are classified either in the black or the white lists, and none within the grey one. According to the information on richness and abundance of the listed fish in Catalonia, the only species that could have been considered for the grey list are *Ameiurus melas*, *Esox lucius*, *Misgurnus anguillicaudatus*, *Perca fluviatilis* and *Pseudorasbora parva*. In all cases, available information about impacts of these species has put them automatically in the black list.
- In 12 cases (55% of the assessed species), the classification is consistent across periods and metrics of abundance, either in the black list (*Alburnus alburnus*, *Carassius auratus*, *Cyprinus carpio*, *Esox lucius*) or in the white list (*Barbatula barbatula*, *Barbus graellsii*, *Gobio lozanoi*, *Micropterus salmoides*, *Parachondrostoma miegii*, *Phoxinus* sp., *Sander lucioperca*).

  It is worth noticing that the white-list species are either species native to the Ebro basin and other Iberian watersheds translocated into the IBC – with meagre information about impacts – or high-impact AS which are not very abundant in the water bodies where they are present, which suggests low risk of establishment. Improved knowledge about the impact of the species or future increase in their abundance would result in a change of the classification from white to black.

- In the other cases, the categorisation changes between or within periods. In five cases (23% of the species), the classification changes between periods, for different reasons. Among the several casuistries, it is remarkable the case of *Rutilus rutilus* that increases dramatically in distribution and relative abundance over time, thus becoming a black-list species. In three cases (13.6% of the species), results for the same period vary according to the metric used for assessing the risk of establishment. This is related with species of high-impact potential that may be locally abundant in numbers but which individuals are smaller in size compared with other caught fish of the community (*Gambusia holbrooki*, *Lepomis gibbosus*) or species which size is bigger than other individuals of the community, although may not be as frequently caught (*Oncorhynchus mykiss*, *Silurus glanis*).

Based on these results about the species, and using the classification criteria mentioned in Fig. 2, the IBPR index for each one of the assessed water bodies can be calculated. The results for the two assessment periods (plotted in Annex II) are more distributed among classes than the ones of the BSC index. Yet they are still polarised results, as it is shown in Table 5.

Results differ slightly depending on the metric used (density or biomass). Using biomass indicators of abundance (kg/ha) tends to bring sites graded from the 2 (moderate) and 3 (high) biopollution risk levels to the 1 (low) and 4 (severe) levels, as nearly symmetrical changes in the number of sites can be observed in relation to the assessment done with density indicators of abundance (individuals/ha). This is probably due to the high abundance of small-sized white-list species. In general, the effect is to obtain slightly worse general results when using indicators of abundance based on fish density. Accordingly, there is an indication of moderate and more than moderate biopollution risk (suggesting less than good ecological status) in one third of the monitored water bodies (29–33%) and around 40% of the water bodies with fish communities.

In summary, the IBPR methodology offers a feasible process to assess potential biopollution in different water bodies in Catalonia, based on certain operative assumptions on the impacts of the species. As a risk index, IBPR method is helpful

Table 5 Percentage of assessment units per IBPR level (2007–2008, abundance as kg/ha)

IBRP index value	Biopollution risk	Number of water bodies (*N.*)
0	No	125
1	Low	12
2	Moderate	16
3	High	27
4	Severe	55
N.A.	Without fish	76

Source: Estimated based on data provided by ACA to frame the need for management with an account of possible impacts of AS. The method does not require proof of actual impacts and therefore does not distinguish properly the different effects that the same species may have in different hosting ecosystems. Besides the results for the different assessment units, the process provides with a (non-stable) classification of alien species according to their potential invasiveness, also a useful management tool.

2.3 Biopollution Level Index (BPL), the (Too?) Perfect Assessment of State

If the purpose of assessing biopollution is to understand changes in ecological quality associated with bioinvasions, a precise recognition of the real effects of AS may be more advisable than the appraisal of their possible impacts. In this respect, Olenin et al. [10] proposed a method able to make an explicit account of AS abundance and distribution ranges, together with the actual impact of the AS on native species or communities, habitats or ecosystem functioning, based on scientific evidence. The evaluation procedure, shown in Fig. 3, provides with a classification of water bodies along five levels from 'no' biopollution (BPL = 0) to 'massive' biopollution (SBC = 5), which can be inversely associated with levels of biological quality according to the classification scheme of the WFD.

Later on, the method was also refined for its implementation to marine waters [6, 7]. A system to facilitate the BPL calculation and information-sharing based on an online platform was designed by Narščius et al. [22]. This method has been applied in several cases, mostly associated with estuarine or coastal areas in the Baltic using macroinvertebrates of phytoplankton [23–25]. A test of the biopollution levels of coastal areas of Catalonia was also undertaken by Ballesteros et al. [26]. The researchers using this method admit that requires substantial research effort, although praise its usefulness for interregional comparisons and the evaluation of effects of individual AS [23].

A priori, the BPL index has excellent properties to grasp the condition of the water bodies regarding biopollution. However, there are difficulties to implement BPL for the case of fish in rivers of Catalonia so far, for the following reasons:

- Lack of detailed information about the species abundance, ranges of distribution and effects of the species within each one of the water bodies. In particular, in the case of fish, the distribution and mobility within the water bodies is poorly studied.
- There is scientific reluctance to assert impact of fish species in situ, due to the high complexity of the aquatic ecosystems and the number of different stressors involved besides the presence of AS themselves.
- From the management point of view, the large amount of effort and resources needed to improve knowledge about local distribution and actual impacts of

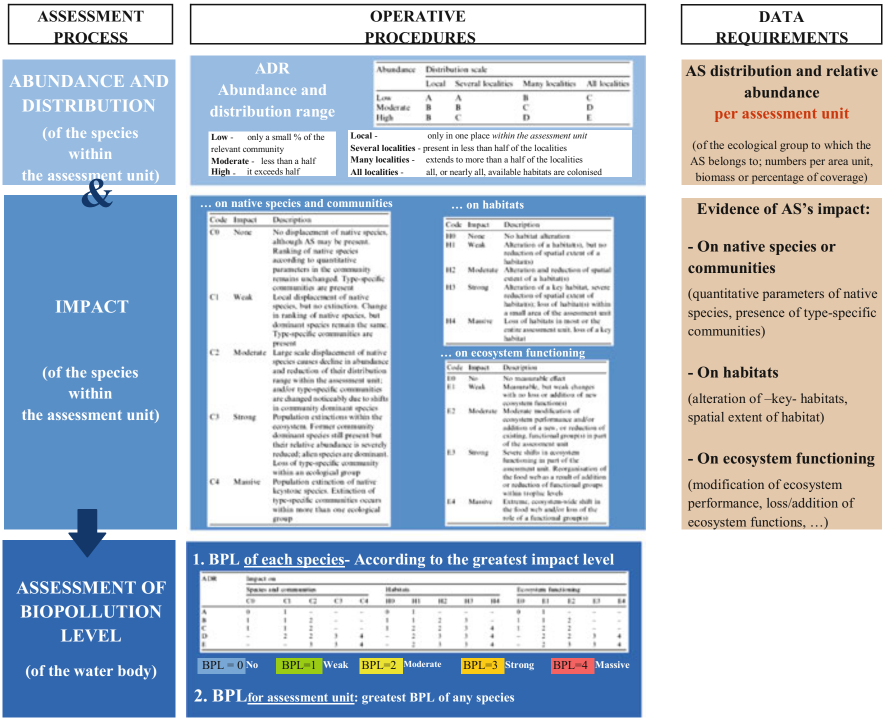

Fig. 3 Procedure for the determination of biopollution level (BPL). *Source*: Own elaboration based on [7].

high-risk AS may be better allocated in preventing the degradation of the state that in confirming *ex post* such degradation.

In sum, in Catalonia BPL could be applied to certain water bodies with the presence of specific AS where research can provide reliable information. That is the case, for instance, of the assessment of biopollution in coastal areas, where the team of researchers in charge have accumulated primary data for decades. In general, that is not the case of fish in river ecosystems, and data requirements for this method largely exceed the current state of data availability. If, in the future, knowledge improves, the BPL is a good candidate indicator for a precise evaluation of the state in relation to biopollution.

2.4 *Comparison of Methods and Use of Results*

To conclude the test of applicability of these methodologies for the assessment of BC&BC, this section elaborates on the use of results and compares the results of the two indices that have been calculated, using the date for 2007–2008, estimated with biomass as indicator of abundance.

There is 82% coincidence in the results between SBC and IBPR. Discrepancies are related to water bodies where there is low abundance of black-list species (with results tending less favourable using IBPR) or areas with high richness of white-list species (with more favourable results using IBPR). In ca. 5.1% of the water bodies, this discrepancy leads to a totally different signal in terms of the assessment, and compliance (in terms of achievement of good status) is dependent on the evaluation method chosen (Table 6).

In relation to the possible use of results, BP&BC can be helpful in several ways. Figure 4, plotting the results of IBPR, will be used as an illustration. First, the

Table 6 Comparison of results SBC and IBPR levels (2007–2008 sampling period) (abundance as biomass). A total of 235 water bodies were analysed

Type or results	SBC values	IBPR values	Number of water bodies	% of water bodies
Same result	0	0	125	53.2
	3	3	18	7.7
	4	4	49	20.9
Different result, same signal	2	3	1	0.4
	3	2	5	2.1
	3	4	6	2.6
	4	2	11	4.7
	4	3	8	3.4
Different signal	2	1	1	0.4
	3	1	11	4.7

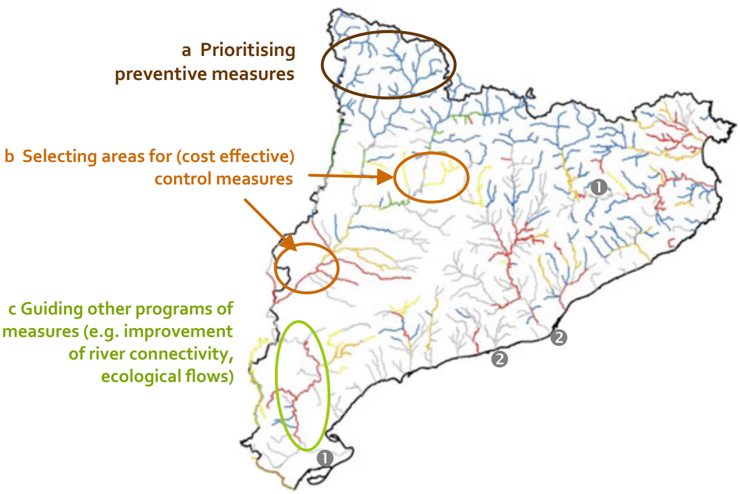

Fig. 4 Results of biopollution risk assessment by using the IBPR index in Catalonia, data gathered in 2007. *Note*: Colours after the corresponding IBPR levels, except for two types of *grey areas*: ❶ water bodies different than rivers; ❷ rivers without fish

identification of areas with low levels of biocontamination or risk of biopollution supports the development of preventive measures, at it is clear that these areas must remain as priority zones for conservation of native species (for instance, the area ‘a’ in the map). Second, the allocation of available resources can be guided by a cost-effectiveness principle, employing them in areas where the biopollution risk is still moderate or low, instead of where it is severe, and therefore the intervention may result in a future situation of compliance (e.g. the choice between areas ‘b’ in the map). Third, BP&BC assessment can support programmes of measures with effects in the biotic communities. Thus, for example, the improvement of river connectivity or the implementation of ecological flows, put in place in order to recover the hydromorphological quality of the river, may have also adverse effects in relation to alien species, facilitating their spread to area where they were previously absent. The planning of such measures may take into account likely effects in BP&BC as one of the criteria for intervention.

3 Are the BP&BC Indices Good ‘State’ Indicators?

As indicated at the beginning of this chapter, a clear association between stressors and the indicator used for quality status is considered a necessary property for the identification of suitable candidates to be state indicators. Then, a pertinent question would be whether the BC&BP levels are correlated with the gradient of pressure in the water bodies.

Anthropogenic activities or actions that may have an impact on ecosystem health are considered to be pressures [27]. In order to characterise the pressures in the sampling sites, the values of a stressor gradient assessment proposed by Munné and Prat [28] for the intercalibration process were obtained. This stressor gradient synthesises the combined effect of different pressures, such as land use types and several types of contamination sources, together with the dilution capacity of the river ecosystem. A general stressor gradient value (that combines quality chemical elements and land use parameters) was available for the year 2003 for water bodies matching 246 sites in with available data on BP&BC in 2003 and 235 sites in 2007.

The scatter plotting of the BP&BC levels and the stressor indicator (Fig. 5) pointed to a certain association of the variables: the higher the stressor value, the highest the BC&BP levels. Some visible outliers were confirmed not to be errors, and therefore they were not excluded from the dataset. Then using a simple bivariate correlation analysis, which indicates how variables or rank orders are related, weak positive linear associations were found between BP&BC and the pressures in the water body. Similar results were found computing the correlations – based on the consideration of BP&BC indicators as ordinal variables – using two nonparametric correlation measures: Spearman’s rho and Kendall’s tau-b, run with Statistical Package for the Social Sciences (IBM SPSS version 21.0) (Table 7). There is a statistically significant correlation between both SBC and IBPR and the pressure indicators both in 2003 and 2007, with coefficients ranging from 0.215–0.315 (2003) to 0.208–0.313 (2007). For both periods, the IBPR levels were

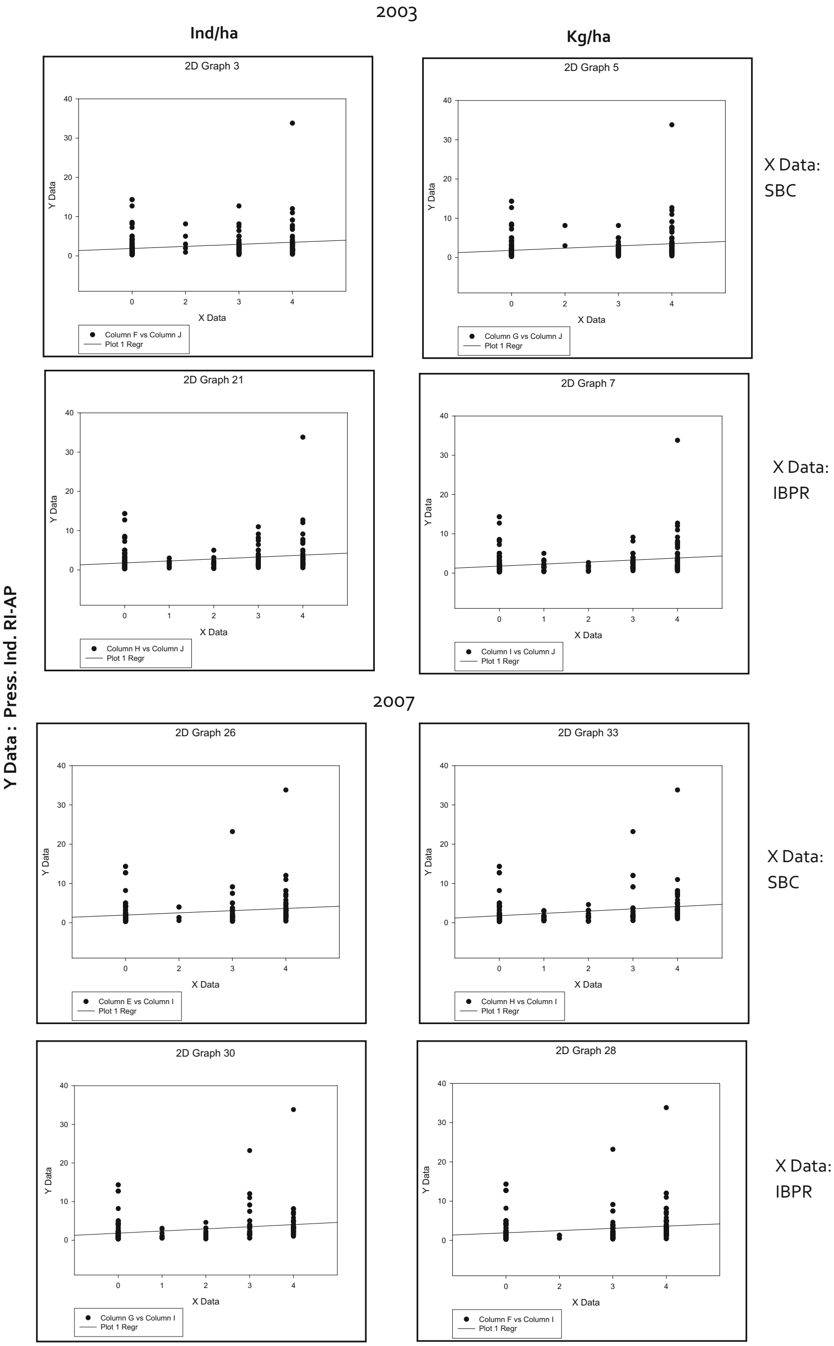

Fig. 5 Scatter plot of stressor gradient across SBC and IBPR levels

Table 7 BP&BC levels and pressures, results of the correlation analysis

Test			RI_AP (BP&BC 2003)	RI_AP (BP&BC 2007)
Kendall's tau-b	SBCindha	Correlation coefficient	0.215**	0.219**
		Sig. (2-tailed)	0.000	0.000
		N	246	235
	SBCkgha	Correlation coefficient	0.240**	0.208**
		Sig. (2-tailed)	0.000	0.000
		N	246	235
	IBPRindha	Correlation coefficient	0.243**	0.224**
		Sig. (2-tailed)	0.000	0.000
		N	246	235
	IBPRkgha	Correlation coefficient	0.240**	0.239**
		Sig. (2-tailed)	0.000	0.000
		N	246	235
	RIAP	Correlation coefficient	1.000	1.000
		Sig. (2-tailed)	–	–
		N	295	311
Spearman's rho	SBCindha	Correlation coefficient	0.274**	0.282**
		Sig. (2-tailed)	0.000	0.000
		N	246	235
	SBCkgha	Correlation coefficient	0.305**	0.271**
		Sig. (2-tailed)	0.000	0.000
		N	246	235
	IBPRindha	Correlation coefficient	0.315**	0.296**
		Sig. (2-tailed)	0.000	0.000
		N	246	235
	IBPRkgha	Correlation coefficient	0.310**	0.313**
		Sig. (2-tailed)	0.000	0.000
		N	246	235
	RIAP	Correlation coefficient	1.000	1.000
		Sig. (2-tailed)	–	–
		N	295	311

Note: **Correlation is significant at the 0.01 level (2-tailed)
Source: Own elaboration. Full results in Annex III

slightly more correlated with the pressure indicator RI_AP than the SBC levels, regardless the indicator of fish abundance used (density or biomass).

The use of the Pearson correlation coefficient was also tested, and it pointed out the same result, although the results are not included in the dissertation as this coefficient is admittedly more appropriate for scale variables.

These results suggest that biopollution and biocontamination are indeed associated with the gradient of pressures to the water bodies, although the current data availability does not point to a very strong association. The knowledge on pressures is expected to improve over time. In case a more precise or sensitive indicator of pressures pointed out to similar or more intense association, the result herein presented would be confirmed.

4 Are the Results of BP&BC Redundant with the Indicators of Biological Quality?

After the WFD, the biological quality of rivers is assessed according to different biological quality elements (BQE): aquatic flora, invertebrates and fish. In relation to the other BQE, fish tend to signal larger spatial and temporal scale processes. As fish are often at the top of the trophic chain, they are sensitive to influences in the rest of aquatic communities. Moreover, fish have relatively higher social visibility and economic relevance than other BQE [13]. Being a part of popular culture and traditional ecological knowledge [29], changes in fish communities can be traced through historical and ethnographic research.

All the above reasons make fish a good base for assessing biological quality. Among the different methodologies developed in this respect, the indices of biotic integrity based on Karr [30, 31] have become widely accepted. This conceptual approach assesses the composition and diversity of species, their abundance and the conditions of the fish. In Catalonia, the index based on this approach, first developed in 2003 [32] and further refined in 2010 [14], is called IBICAT. It was commissioned by the watershed authority that uses it for guiding water quality assessment in rivers, together with indicators for the other BQE [13]. The index allows generating different quality levels based on the score for the different metrics included.

The process to refine IBICAT took particular care of the issue of alien species during the stage of selecting candidate metrics to be part of the assessment. Then, it is a pertinent question whether the results of this index in relation to the issue of AS made it redundant the calculation of an ad hoc BP&PC indicator as the ones that have been tested in this section.

In order to compare both types of information, data on the scores (from 1 to 5) for two different versions of the index (IBICAT$_{2010}$ [$n_{\mathrm{WB}} = 234$], IBICAT$_{2b}$ [$n_{\mathrm{WB}} = 235$]) was obtained, with permission of the watershed authority, for rivers in Catalonia. The data corresponds to the fish monitoring in the period 2007–2008, that is, the same raw data that they used for the calculation of the BP&BC indices of that period. Levels 1 and 2 correspond to very good and good quality level and, therefore, would point at water bodies in compliance with the WDF; levels 3, 4 and 5 correspond to moderate, deficient and bad quality levels and would indicate incompliance with the WFD.

The results of the different quality levels for the both versions of the IBICAT index, compared with the corresponding level of BP&BC, are shown in Table 8. The cells highlighted in light brown indicate the water bodies in which the assessment of biological integrity and BP&BC provide the same signal (either compliance or incompliance). Meanwhile, white cells indicate divergent results between these two kinds of assessment.

Based on this table of frequencies, it is possible to calculate the probability of coincident results and non-coincident result, shown in Table 9. Looking at the different combinations of indices, it is clear that the probability of coincident results (ranging between 79% and 88%) is always higher than the probability of non-coincident results (12–21%). Being the probability of coincident results remarkably in both versions of the biological quality index, $IBICAT_{2b}$ seems to capture better the issue of BP&BC than $IBICAT_{2010}$ for each one of the indices and metrics used for the assessment of BP&BC.

Focussing on the non-coincident results, two situations are possible: that BP&BC indices indicate compliance, while the biological quality index indicates incompliance, or the other way around. The first situation may be explained by the fact that the fish community suffers from a pressure unrelated to the issue of alien species. The second situation is more problematic from the point of view of the topic addressed in this dissertation. If the biological quality index indicates compliance, there would not be any signal for the water managers to engage in policy measures of ecological improvement, as the state of the water body would be

Table 8 Crosstabs of BC&BP levels and scores of the biological quality assessment for fish, frequencies, $n_{WB} = 234, 235$, sampling period 2007–2008

BC&BP level		$IBICAT_{2010}$ Score					$IBICAT_{2b}$ Score				
		1	2	3	4	5	1	2	3	4	5
SBC(ind/ha)	0	30	60	17	13	5	29	77	18	1	0
	2	0	1	1	1	0	0	1	0	2	0
	3	1	9	21	8	0	2	4	22	11	0
	4	0	1	13	34	19	1	2	11	40	14
SBC(Kg/ha)	0	30	60	17	13	5	29	77	18	1	0
	2	0	1	0	1	0	0	1	0	1	0
	3	1	8	23	8	0	3	4	22	11	0
	4	0	2	12	34	19	0	2	11	41	14
IBPR(ind/ha)	0	30	60	17	13	5	29	77	18	1	0
	1	0	3	4	0	0	1	2	4	0	0
	2	0	3	5	11	0	2	2	8	6	2
	3	1	4	16	9	3	0	2	16	15	0
	4	0	1	10	23	16	0	1	5	32	12
IBPR(kg/ha)	0	30	60	17	13	5	29	77	18	1	0
	1	0	5	6	1	0	3	2	5	2	0
	2	0	2	3	10	0	0	2	7	5	2
	3	1	3	13	9	1	0	1	13	13	0
	4	0	1	13	23	18	0	2	8	33	12

Table 9 Coincidence of results between BC&BP levels and biological quality scores. Probability of coincident/non-coincident results

BC&BP level		IBICAT2010 Score		IBICAT2b Score	
		1 2	3 4 5	1 2	3 4 5
SBC(ind/ha)	0 2 3 4	20 %	80 %	12 %	88 %
SBC(Kg/ha)	0 2 3 4	20 %	80 %	12 %	88 %
IBPR(ind/ha)	0 1 2 3 4	21 %	79 %	13%	87%
IBPR(kg/ha)	0 1 2 3 4	21%	79%	13%	87%

Note: Compliance (C) means levels 0,1 for BC&BP and scores 1,2 for biotic integrity indicators; noncompliance (NC) means levels 2,3,4 for BC&BP and scores 3,4,5 for biotic integrity indicators

considered as good or very good from the point of view of the fish communities. However, the BP&BC indices would be pointing out at the existence of a problem of bioinvasions in that particular water body.

With this in mind, the conditional probability of these two situations was estimated for the different indicators involved (Table 10). In conditional probabilities, they are calculated according to the formula $P(A|B) = P(A \cap B)/P(B)$ when $P(B) > 0$, where the event of interest A is either the biological quality indicator (BQI)'s noncompliance (NC) or compliance (C) and the restricted sample space B is the opposite result in BC&BP level. The results shown in the table indicate that the probability of BC&BP compliance and biotic integrity incompliance (highlighted in orange) ranges between 15% and 30%, and it is always higher than probability of BC&BP incompliance and biotic integrity compliance (highlighted in purple), ranging between 4% and 12%.

This later result is relevant, because it demonstrates that the standard quality assessment fails to completely pinpoint the issue of alien species. While the probability that this happens is relatively low, the failure is systematic regardless the indicator used. Of course, the considerations on uncertainty about the BP&BC indices presented along this section should be taken into account when interpreting this result.

In any case, based on the results presented in this section, it can be argued that the biological quality index used for fish in Catalonia and the BP&BC indices are not redundant. While there is an undeniably high level of coincidence between their

Table 10 Coincidence of results between BC&BP levels and biological quality scores. Conditional probability of non-coincident results

BC&BP level		$IBICAT_{2010}$ score		$IBICAT_{2b}$ score	
		C	NC	C	NC
SBC (ind/ha)	C		28%		15%
	NC	12%		9%	
SBC (kg/ha)	C		28%		15%
	NC	12%		9%	
IBPR (ind/ha)	C		30%		17%
	NC	9%		6%	
IBPR (kg/ha)	C		30%		19%
	NC	7%		4%	

Note: Compliance (C) means levels 0,1 for BC&BP and scores 1,2 for biotic integrity indicators; noncompliance (NC) means levels 2,3,4 for BC&BP and scores 3,4,5 for biotic integrity indicators

results, they do not reflect the same thing, and there is a small probability of systematic failure of the BQI to provide the required policy signals.

5 Concluding Remarks

The consideration of AS in the assessment of biological quality is necessary whenever there is evidence that AS constitute a pressure to or have an impact on the aquatic ecosystem. Some voices even claim that the high ecological status is unsuited for water bodies where AS are present. Yet taking up AS until the last consequences in ecological status assessment may be problematical for water managers. In Catalonia there are practically no water bodies without alien species. The eradication of most of them is environmentally or economically unfeasible. Should a strict AS-based quality assessment be adopted, the water policies would be locked in the predicament of recognising a problem of generalised poor ecological status without being able to effectively redress this situation. In this context, the existence of supplementary BP&BC indices is helpful to guide policies in support of increased biological quality. In the case of Catalonia, and using fish as biological element, two of the methodologies present in the literature can be estimated with the existing monitoring data and would not require further sampling effort beyond the routine monitoring.

The BP&BC indices thus estimated undoubtedly provide useful information for the management of AS in aquatic ecosystems. The classification of water bodies or, as a part of the calculation of IBPR, a classification of the AS themselves helps to prioritise efforts, targeting those management units or species whose control will have the most benefit for the available resources. In the case of the species, such a classification could be easily linked to regulatory frames. For instance, it could be helpful to communicate to the general public why the possession, sale or any other kind of management is restricted for 'black species'. In fact, impacts of the species are explicitly taken into account in two of the methodologies introduced, although in one case the impact is presumed based on the information from the literature and in the other requires actual evaluation in situ. A consideration regarding species' impacts is the extent to which the criteria for classification are discussed with stakeholders. Although the assessment itself must be guided by a systematic organisation of knowledge and, therefore, can be considered as a scientific endeavour, an agreement with stakeholders on the reasons why a particular species is considered as a hazard will benefit both the comprehensiveness of the analysis and the use of its results in policymaking.

In general, the indices fall short of portraying species whose impacts are not completely understood. Additionally, an element that is absent from the different BP&BC indicators, and that it would be likely to emerge as a result of an open discussion about AS impacts and biopollution, is the recognition of the ambivalence of the species. From the ecological point of view, the potential benefits of alien species include providing habitat or food resources to rare species, serving as functional substitutes for extinct *taxa* and providing desirable ecosystem functions [33]. Moreover, many of the AS, as some of those present in Catalonia, are economically important. Despite this, there is such a scant research done on the potential conservation benefits of alien species that make it think that the topic is a scientific taboo. With increase knowledge about these potential benefits, a new challenge would rise on the best way to integrate it in BP&BC assessment: can benefits be an offset for negative effects of the species?

This chapter closes with some final recommendations informed by the testing and analyses done. A major point here is that water bodies are not necessarily homogeneous in terms of the represented habitats, overall all in relation to flora species. A relative abundant species may cause diverse impact depending on the type of habitats along the water body. As a result, the attribution of the impact on habitats may differ. Therefore, a more precise assessment of biopollution, based on actual information about AS impacts, would benefit from changes in the monitoring protocols that involved data gathering about local distribution and effects on local ecosystems and biodiversity, even if it is under qualitative basis.

Another point is referred to the taxonomic groups to be included in the analysis. Due to data availability reasons, the assessment in this section has relied on fish species. As indicated above, most of the tests of biopollution and biocontamination have been done using macroinvertebrates. Potentially, the methodology can be used with any *taxa*. Then a question would be whether other types or organisms with very likely negative effects in ecological status (e.g. zoonotic organisms like parasites) should not be explicitly addressed outside the classical BQE including in the assessment of ecological state.

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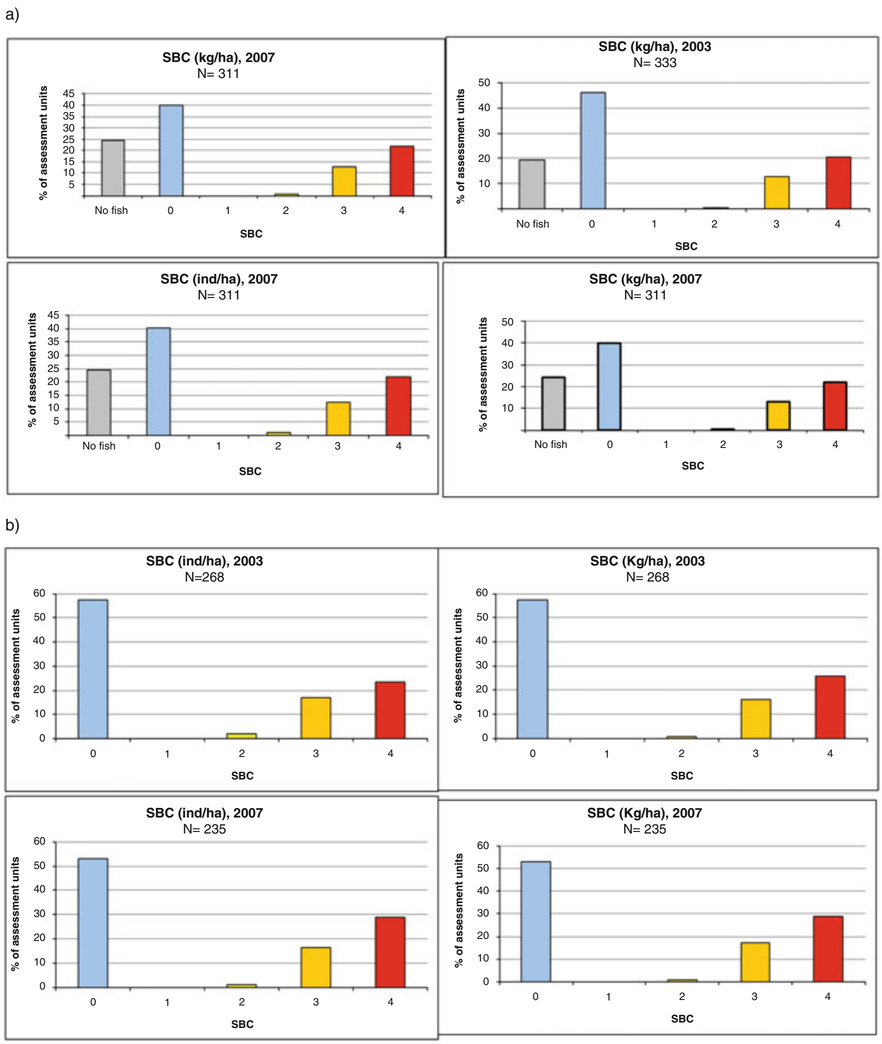
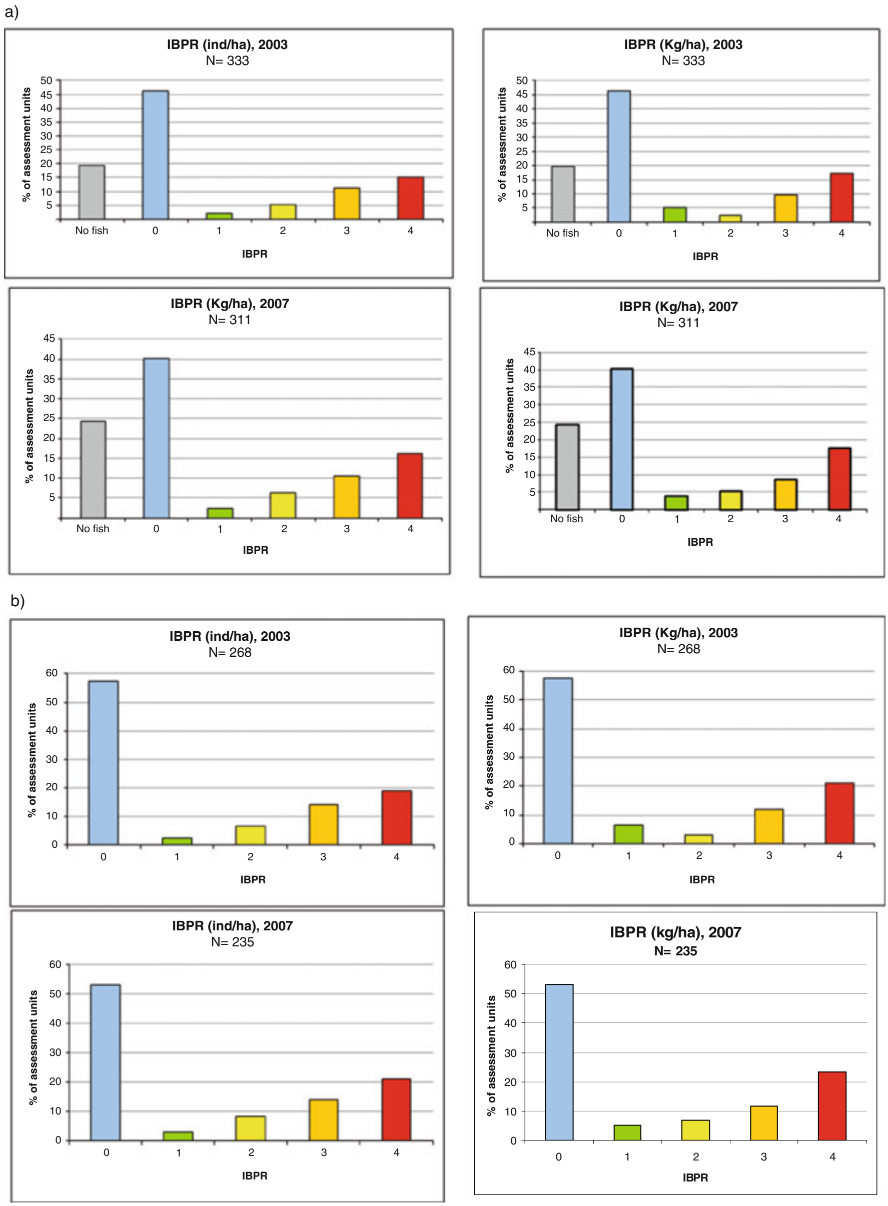
Annexes

Annex I



Results of the determination of the site-specific contamination level, using fish, for the water bodies in Catalonia (2002–2003 and 2007–2008), for different indicators of AS abundance (density [ind/ha] and biomass [kg/ha]). (**a**) Results for all assessment units. (**b**) Results for assessment units with fish fauna

Annex II



Results of the determination of biopollution risk index, using fish, for the water bodies in Catalonia (2002–2003 and 2007–2008), for different indicators of AS abundance (Ind/ha and kg/ha). (**a**) Results for all assessment units. (**b**) Results for assessment units with fish fauna

Annex III

BC&BP levels and pressures, results of the correlation analysis

			SBCindha	SBCkgha	IBPRindha	IBPRkgha	RIAP
Data on BP& BC in 2003							
Kendall's tau-b	SBCindha	Correlation coefficient	1.000	0.924**	0.891**	0.836**	0.215**
		Sig. (2-tailed)	–	0.000	0.000	0.000	0.000
		N	246	246	246	246	246
	SBCkgha	Correlation coefficient	0.924**	1.000	0.899**	0.902**	0.240**
		Sig. (2-tailed)	0.000	–	0.000	0.000	0.000
		N	246	246	246	246	246
	IBPRindha	Correlation coefficient	0.891**	0.899**	1.000	0.907**	0.243**
		Sig. (2-tailed)	0.000	0.000	–	0.000	0.000
		N	246	246	246	246	246
	IBPRkgha	Correlation coefficient	0.836**	0.902**	0.907**	1.000	0.240**
		Sig. (2-tailed)	0.000	0.000	0.000	–	0.000
		N	246	246	246	246	246
	RIAP	Correlation coefficient	0.215**	0.240**	0.243**	0.240**	1.000
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	–
		N	246	246	246	246	295
Spearman's rho	SBCindha	Correlation coefficient	1.000	0.965**	0.954**	0.927**	0.274**
		Sig. (2-tailed)	–	0.000	0.000	0.000	0.000
		N	246	246	246	246	246
	SBCkgha	Correlation coefficient	0.965**	1.000	0.957**	0.959**	0.305**
		Sig. (2-tailed)	0.000	–	0.000	0.000	0.000
		N	246	246	246	246	246
	IBPRindha	Correlation coefficient	0.954**	0.957**	1.000	0.964**	0.315**
		Sig. (2-tailed)	0.000	0.000	–	0.000	0.000
		N	246	246	246	246	246
	IBPRkgha	Correlation coefficient	0.927**	0.959**	0.964**	1.000	0.310**
		Sig. (2-tailed)	0.000	0.000	0.000	–	0.000
		N	246	246	246	246	246
	RIAP	Correlation coefficient	0.274**	0.305**	0.315**	0.310**	1.000
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	–
		N	246	246	246	246	295

(continued)

Data on BP& BC in 2007							
Kendall's tau-b	SBCindha	Correlation coefficient	1.000	0.967**	0.886**	0.877**	0.219**
		Sig. (2-tailed)	–	0.000	0.000	0.000	0.000
		N	235	235	235	235	235
	SBCkgha	Correlation coefficient	0.967**	1.000	0.894**	0.900**	0.208**
		Sig. (2-tailed)	0.000	–	0.000	0.000	0.000
		N	235	235	235	235	235
	IBPRindha	Correlation coefficient	0.886**	0.894**	1.000	0.959**	0.224**
		Sig. (2-tailed)	0.000	0.000	–	0.000	0.000
		N	235	235	235	235	235
	IBPRkgha	Correlation coefficient	0.877**	0.900**	0.959**	1.000	0.239**
		Sig. (2-tailed)	0.000	0.000	0.000	–	0.000
		N	235	235	235	235	235
	RIAP	Correlation coefficient	0.219**	0.208**	0.224**	0.239**	1.000
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	–
		N	235	235	235	235	311
Spearman's rho	SBCindha	Correlation coefficient	1.000	0.983**	0.949**	0.944**	0.282**
		Sig. (2-tailed)	–	0.000	0.000	0.000	0.000
		N	235	235	235	235	235
	SBCkgha	Correlation coefficient	0.983**	1.000	0.953**	0.956**	0.271**
		Sig. (2-tailed)	0.000	–	0.000	0.000	0.000
		N	235	235	235	235	235
	IBPRindha	Correlation coefficient	0.949**	0.953**	1.000	0.985**	0.296**
		Sig. (2-tailed)	0.000	0.000	–	0.000	0.000
		N	235	235	235	235	235
	IBPRkgha	Correlation coefficient	0.944**	0.956**	0.985**	1.000	0.313**
		Sig. (2-tailed)	0.000	0.000	0.000	–	0.000
		N	235	235	235	235	235
	RIAP	Correlation coefficient	0.282**	0.271**	0.296**	0.313**	1.000
		Sig. (2-tailed)	0.000	0.000	0.000	0.000	–
		N	235	235	235	235	311

**Correlation is significant at the 0.01 level (2-tailed)

References

1. Cardoso AC, Free G (2008) Incorporating invasive alien species into ecological assessment in the context of the Water Framework Directive. Aquat Invasions 3:361–366
2. Vandekerkhove J, Cardoso AC (2010) Alien species and the Water Framework Directive. Questionnaire results. European Commission - JRC scientific and technical reports, Ispra, Italy

3. Vandekerkhove J, Cardoso AC, Boon PJ (2013) Is there a need for a more explicit accounting of invasive alien species under the Water Framework Directive? Manage Biol Invasions 4:25–36. doi:10.3391/mbi.2013.4.1.04
4. Boudouresque CF, Verlaque M (2002) Biological pollution in the Mediterranean Sea: invasive versus introduced macrophytes. Mar Pollut Bull 44:32–38
5. Elliott M (2003) Biological pollutants and biological pollution--an increasing cause for concern. Mar Pollut Bull 46:275–280
6. Olenin S, Elliott M, Bysveen I et al (2011) Recommendations on methods for the detection and control of biological pollution in marine coastal waters. Mar Pollut Bull 62:2598–2604
7. Olenin S, Alemany F, Cardoso AC et al (2010) Marine Strategy Framework Directive – Task Group 2 report. Non-indigenous species. doi: 10.2788/87092
8. Panov VE, Alexandrov B, Arbaciauskas K et al (2009) Assessing the risks of aquatic species invasions via European inland waterways: from concepts to environmental indicators. Integr Environ Assess Manag 5:110–126
9. Panov V, Dgebuadze Y, Shiganova T et al (2007) A risk assessment of biological invasions in the inland waterways of Europe: the Northern Invasion Corridor case study. In: Biological invaders in inland waters: profiles, distribution, and threats. Springer, The Netherlands, pp 639–656
10. Olenin S, Minchin D, Daunys D (2007) Assessment of biopollution in aquatic ecosystems. Mar Pollut Bull 55:379–394
11. Arbačiauskas K, Semenchenko V, Grabowski M et al (2008) Assessment of biocontamination of benthic macroinvertebrate communities in European inland waterways. Aquat Invasions 3:211–230
12. Lee A (2009) ECOSTAT workshop on alien species and the EC Water Framework Directive. Final report. Ispra, Italy
13. Agència Catalana de l'Aigua (ACA) (2006) BIORI. Protocol d'avaluació de la qualitat biològica dels rius. Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona
14. Sostoa de A, Caiola NM, Casals F et al (2010) Ajust de l'índex d'Integritat Biòtica (IBICAT) basat en l'ús dels peixos com a indicadors de la qualitat ambiental als rius de Catalunya. Agència Catalana de l'Aigua, Departament de Medi Ambient i Habitatge, Generalitat de Catalunya, Barcelona
15. MacNeil C, Briffa M, Leuven RSEW et al (2010) An appraisal of a biocontamination assessment method for freshwater macroinvertebrate assemblages; a practical way to measure a significant biological pressure? Hydrobiologia 638:151–159
16. Šidagyte E, Višinskiene G, Arbačiauskas K (2013) Macroinvertebrate metrics and their integration for assessing the ecological status and biocontamination of Lithuanian lakes. Limnologica 43:308–318
17. Nentwig W, Kühnel E, Bacher S (2010) A generic impact-scoring system applied to alien mammals in Europe. Conserv Biol 24:302–311. doi:10.1111/j.1523-1739.2009.01289.x
18. Magee TK, Ringold PL, Bollman MA, Ernst TL (2010) Index of alien impact: a method for evaluating potential ecological impact of alien plant species. Environ Manage 45:759–778. doi:10.1007/s00267-010-9426-1
19. Sandvik H, Sæther B-E, Holmern T et al (2013) Generic ecological impact assessments of alien species in Norway: a semi-quantitative set of criteria. Biodivers Conserv 22:37–62
20. Genovesi P, Shine C (2004) European strategy on invasive alien species. Council of Europe Press, Strasbourg
21. Nehring S, Klingenstein F (2008) Aquatic alien species in Germany – listing system and options for action. In: Rabitsch W, Essl F, Klingenstein F (eds) Biological invasions – from ecology to conservation. NEOBIOTA 7. pp 19–33
22. Narščius A, Olenin S, Zaiko A, Minchin D (2012) Biological invasion impact assessment system: from idea to implementation. Ecol Inform 7:46–51

23. Zaiko A, Lehtiniemi M, Narščius A, Olenin S (2011) Assessment of bioinvasion impacts on a regional scale: a comparative approach. Biol Invasions 13:1–27
24. Olenina I, Wasmund N, Hajdu S et al (2010) Assessing impacts of invasive phytoplankton: the Baltic Sea case. Mar Pollut Bull 60:1691–1700
25. Wittfoth AKJ, Zettler ML (2013) The application of a biopollution index in German Baltic estuarine and lagoon waters. Manage Biol Invasions 4:43–50
26. Ballesteros E, Garcia M, Torras X et al (2010) Informe del Programa de vigilància de la qualitat de les aigües litorals de Catalunya en funció de les comunitats de macroalgues, segons la Directiva Marc de l'Aigua i de la prevenció de la implantació d'espècies invasores. Informe final 2010. Blanes
27. Conrad M (1979) Ecosystem stability and bifurcation in the light of adaptability theory. In: Gurel O, Rössler O (eds) Bifurcation theory and its application to scientific disciplines. New York Academy of Sciences, New York, pp 465–482
28. Munné A, Prat N (2009) Use of macroinvertebrate-based multimetric indices for water quality evaluation in Spanish Mediterranean rivers: an intercalibration approach with the IBMWP index. Hydrobiologia 628:203–225
29. Boquera Margalef M, Quiroga Raimundez V (2001) De la saboga al silur. Perscadors fluvials de l'Ebre a Tivenys. Generalitat de Catalunya - Centre de Promocio de la Cultura Popular i Tradicional Catalana, Barcelona
30. Karr JR (1981) Assessment of biotic integrity using fish communities. Fisheries 6:21–27. doi:10.1577/1548-8446(1981)006<0021:AOBIUF>2.0.CO;2
31. Karr JR (1987) Biological monitoring and environmental assessment: a conceptual framework. Environ Manage 11:249–256. doi:10.1007/BF01867203
32. Sostoa de A, Caiola NM, Vinyoles D et al (2003) Desenvolupament d'un índex d'integritat biòtica (IBICAT) basat en l'ús dels peixos com a indicadors de la qualitat ambiental dels rius de Catalunya. Aplicació de la Directiva marc en política d'aigües de la Unió Europea (2000/60/CE). Informe final del Dep. Departament de Medi Ambient, Generalitat de Catalunya., Barcelona
33. Schlaepfer MA, Sax DF, Olden JD (2011) The potential conservation value of non-native species. Conserv Biol 25:428–437. doi:10.1111/j.1523-1739.2010.01646.x

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