APPENDIX H

The Level Of Agreement Among Experts Applying Best Professional Judgment To Assess The Condition Of benthic Infaunal Communities

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Abstract

Benthic infaunal communities are frequently used to assess aquatic environmental condition, but interpretation of benthic data is often subjective and based on best professional judgment. Here, we examine the repeatability of such assessments by providing species-abundance data from 35 sites to 9 independent benthic experts who ranked the sites from best to worst condition. Their site rankings were highly correlated, with an average correlation coefficient of 0.91. The experts also evaluated the sites in terms of four condition categories: 1) Unaffected, 2) Marginal deviation from reference, 3) Affected, or 4) Severely affected. At least two-thirds of the experts agreed on site categorization for 94% of the samples and they disagreed by more than one category for less than 1% of the assessment pairs. The experts identified seven parameters used in making their assessments, with four of those parameters (dominance by tolerant taxa, presence of sensitive taxa, species richness, and total abundance) used by all of the experts. Most of the disagreements in site categorization were due to philosophical rather than technical differences, such as whether the presence of invasive species indicates a degraded community. Indices are increasingly being used as an alternative to best professional judgment for assessing benthic condition, but there have been inconsistencies in how sites are selected for validating such indices; the level of agreement found among experts in this study suggests that consensus expert opinion can be a viable benchmark for such evaluations.

Introduction

Biocriteria are increasingly being used to assess ecological integrity, with both the US Environmental Protection Agency (Gibson et al., 2000) and the European Water Framework Directive (Borja 2005, 2006; Jonge et al., 2006) providing guidance that promotes the use of biocriteria for coastal and estuarine assessments. Benthic infauna are prominent indicators in this guidance because their habitat exposes them to many anthropogenic influences: contaminants accumulate in the sediment, eutrophication leads to excess organic matter on the bottom and water column stratification facilitates hypoxia below the pycnocline. Additionally, the wide range of physiological tolerances, feeding modes, trophic interactions, and limited mobility among the diverse benthic taxa makes them responsive as a group to this array of environmental stressors (Bilyard, 1987; Diaz et al., 2004).

The European and US directives recognize four approaches to developing biocriteria: comparison to historical conditions, comparison to present reference conditions, models and consensus professional judgment. Many numerical indices have been developed to minimize the need for subjective judgment to assess attainment of biocriteria (Weisberg et al., 1997; Engle and Summers, 1999; Van Dolah et al., 1999; Borja et al., 2000; Paul et al., 2001; Smith et al., 2001; Thompson and Lowe, 2004). However, even these objective indices involve subjectivity in several steps of their development and application, such as metric selection, site selection for index calibration, and index approach selection (Boyle et al., 1990; Borja et al., 2004).

Application of best professional judgment (BPJ) often follows from general models of benthic community response to stress (Pearson and Rosenberg, 1978; Dauer, 1993). However, experts with different backgrounds may emphasize different aspects or elements of these models, leading to uncertainty regarding the extent to which experts agree in their application of BPJ. The objective of this paper is to quantify concordance among experts in their application of BPJ to assess benthic impairment when each expert is provided with the same data.

Materials and Methods

Nine benthic ecologists were provided species composition and abundance data from 35 sites and asked to determine condition of the benthos at each site. The experts were selected to represent a range of affiliations and experience and are included among the authors of this paper. Three were from academic institutions, three from municipalities that implement benthic monitoring programs to assess the effect of discharge outfalls, two from private consulting firms, and one from a nonprofit research organization. Their experience in benthic monitoring ranged from 20 to 50 years, with an average of 32 years. All had experience with benthos from the west coast of the United States, although one is presently working on the east coast.

Twenty-four of the sites were located in southern California coastal bays and eleven in San Francisco Bay. The sites were selected from a large California sediment quality database by ordering the data according to Long and MacDonald's (1998) mean Effects Range-Median quotient (ERMq); samples were then systematically selected so that a range of contamination exposure conditions within each geography was represented (Table 1). While chemical contamination was used to ensure a range of site conditions was included in the assessment, the experts were not provided the chemical data. The experts were only provided salinity, sediment texture, and species abundance information. They were also told whether each site was from northern or southern California, but were not given specific site locations.

The experts were asked to rank the relative condition of each site from best to worst within each region, based on the benthic community data. They were also asked to assign each site to one of four categories of absolute condition: 1) Unaffected: a community that would occur at a reference site for that habitat; 2) Marginal deviation from reference: a community that exhibits some indication of stress, but is within measurement variability of reference condition; 3) Affected: a community that exhibits clear evidence of physical, chemical, natural, or anthropogenic stress; 4) Severely Affected: a community exhibiting a high magnitude of stress. The experts were not asked to differentiate among potential causes for affected condition as it is generally recognized that current models of benthic response to stress do not discriminate between chemical contamination and other sources of disturbance (Borja et al., 2003).

The benthic experts were asked to list the attributes of the benthos used to determine site rankings and condition categories, and to rate the importance of the attributes as follows: 1) Very important; 2) Important, but secondary; 3) Marginally important; 4) Useful, but only to interpret other factors. Attributes that were not used by an expert for site classification were assigned a rank of 5 for the purpose of calculating an average importance of that attribute among experts. As all the experts identified indicator species as one of the attributes used in their assessment, they were also asked to list the organisms used as indicator species and to rank the species importance using the same scale.

Results

The relative ranking of sites was highly correlated among the experts, with an average Spearman correlation coefficient of 0.91 (Table 2). There was no difference in the average correlation among experts between sites in San Francisco Bay and southern California. None of the experts deviated notably from their peers, with the correlation coefficient for each reviewer in relation to the average of the other reviewers ranging between 0.90 and 0.98.

For only three sites did all of the experts agree on the condition category. However, eight of the nine experts agreed on the condition category for more than 50% of the sites, and seven of the nine experts agreed on the condition category for 75% of the sites (Table 3). Only two sites elicited less than two-thirds agreement among the experts. Moreover, when disagreement occurred, the difference in site assignment was almost always between adjacent categories (e.g., unaffected versus marginally affected, affected versus severely affected, etc.); the experts disagreed by more than one category for less than 1% of the assessment pairs

The experts used seven criteria for assessing benthic assemblage condition, and all but one criterion were used as assessment parameters by at least half of the experts (Table 4). The three most important criteria were the proportion of tolerant taxa, the presence of sensitive indicator species, and species richness. Total abundance was also used by all of the experts, but many of them ranked this criterion as of lesser importance because they only used it as an indicator when abundance was low. Other criteria that were used included the abundance of selected higher taxa, presence of nonindigenous species and the diversity of functional/feeding groups.

There was considerable consistency in the indicator taxa identified by the experts (Table 5). The taxa most frequently recognized as tolerant were the polychaetes Capitella capitata complex and Streblospio benedicti, and oligochaetes. The most frequently recognized sensitive taxa were ophiuroids and amphipods. Although the tolerant taxa were generally identified at the species or genus level, most of the sensitive taxa were higher-level taxonomic groups. Some of the experts also indicated that they placed different emphasis or used different indicator taxa for southern California and San Francisco Bay.

Of the four parameters used by all experts, taxa richness was the most highly correlated with the consensus site rankings of the experts (Table 6). Abundance correlated most poorly of the four parameters, but only one site with less than 200 organisms was ranked as non-degraded. All of these individual biological parameters correlated more highly with the expert rankings than did ERMq.

Discussion

The experts generally agreed on the criteria used for assessment, but often disagreed on their relative importance. Nevertheless, conclusions about community condition were robust to these differences. This probably reflects a high degree of correspondence among many of the preferred assessment parameters, suggesting that benthic assessments are robust to differences in metrics commonly used in benthic assessment approaches.

When there was disparity in interpretation among the benthic ecologists, the differences were generally associated with philosophical, rather than technical, issues. For example, the experts disagreed about whether communities altered by the presence of an invasive species, such as the mussel Musculista senhousia, should be classified as an affected site; M. senhousia affects community composition by adding habitat structure and heterogeneity, which can facilitate an increase in species abundance and diversity (Ranasinghe et al., 2005). Another example of classification uncertainty was related to communities in which the presence of a mature filter feeder might lower species richness by impeding recruitment through consumption of larvae. In these examples, differences in condition classification were limited to an adjacent category because effects manifested in only a subset of parameters, such as number of taxa; other properties, such as the types of species present, minimized differences in interpretation of condition.

Benthic indices are increasingly being used as an alternative to BPJ for assessing benthic community condition in many estuarine and marine systems (Weisberg et al., 1997; Van Dolah et al., 1999; Engle and Summers, 1999; Borja et al., 2000; Paul et al., 2001; Smith et al., 2001; Llansó et al., 2002; Thompson and Lowe, 2004). Most of these indices include abundance or proportions of sensitive and tolerant taxa as important assessment metrics, which have become a focal point for European assessments (Borja et al., 2000; Muxika et al., 2005; Dauvin, 2007). For the sensitive and tolerant taxa parameters at least, benthic indices should provide a means of improving upon the experts' assessments because the list of species relied upon by an individual expert is typically limited or is a broad generalization applied to higher-level taxa (e.g., Gammaridea). Every species occurring at a site provides information regarding community condition and indices that integrate empirical data from many samples to capture information for a larger number of taxa may lead to more accurate assessments. Consensus lists of such taxa are well developed in Europe (Borja and Muxika, 2005).

Indices also have the advantage of being objective and transparent, but at a potential cost of information loss associated with a formulaic approach that does not incorporate all aspects of expert judgment. For example, reliance on indicator species alone can lead to misapplication when small numbers of individuals are present (Borja and Muxika, 2005) or soon after a recruitment event that yields large numbers of small juveniles that don't survive to maturity (Dauer et al., 1993). Such situations would be recognized by experts and assessments adjusted accordingly (Muxika et al., 2007).

The agreement we found among experts in use of BPJ presents new opportunities for index validation. The primary means for validating benthic indices has been to assess whether sites with extreme conditions, identified through use of chemical or toxicological measures, could be distinguished by an index. This has been a substantial impediment to the development of benthic indices in geographic regions where extreme conditions are rare because few data are available to evaluate the performance of indices. The agreement among experts found in this study indicates that consensus expert opinion is a viable evaluation benchmark, as recently demonstrated by Muxika et al. (2007). However, further study to evaluate the appropriate number of experts to reach consensus for such applications is warranted.

Consensus expert opinion as an evaluation benchmark may facilitate evaluation of how the indices are performing in assessing sites experiencing intermediate levels of disturbance. This is a more difficult, but more relevant, assessment challenge for indices. The use of expert opinion also provides a benchmark to assess index performance. Index developers have generally identified an index as successful if it correctly differentiated 80% of sites with extreme conditions. A better evaluation benchmark would be an index's ability to classify sites with a level of correlation comparable to that among experts.

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Table 1. Characteristics of the samples assessed by the experts. Definitions of sensitive and tolerant taxa include taxa in Table 5identified by more than half of the experts. ERMq is the mean ERM quotient Long and MacDonald (1998).

Sample	ERMq	Abundance	Number of taxa	Percent of abundance as sensitive taxa	Percent of abundance as tolerant taxa
1	1.28	140	6	0.0	88.9
2	0.95	914	40	75.1	11.3
3	1.32	2409	50	89.2	4.2
4	1.37	71	2	0.0	68.8
5	0.17	2161	49	72.2	15.8
6	0.13	728	32	9.2	54.8
7	0.16	865	55	32.0	20.0
8	0.82	64	3	0.0	93.1
9	0.51	877	25	63.3	71.4
10	0.13	929	53	65.2	31.0
11	1.82	3489	23	16.6	82.1
12	1.16	1433	28	1.5	84.3
13	0.69	213	26	1.9	34.7
14	0.04	204	51	34.3	23.0
15	0.82	636	31	2.8	76.6
16	0.03	380	52	36.1	6.3
17	0.92	553	10	0.5	98.9
18	0.03	306	43	15.7	41.8
19	3.83	161	14	29.8	90.1
20	1.08	376	35	9.0	2.4
21	2.00	1140	24	0.8	64.2
22	0.03	883	24	45.3	88.4
23	1.13	162	17	3.7	2.5
24	0.94	2022	23	12.3	74.3
25	0.93	288	10	0.0	96.9
26	0.85	169	27	19.5	27.2
27	0.73	620	12	8.4	93.4
28	0.03	977	73	22.4	36.8
29	0.82	1789	11	0.3	99.2
30	0.02	1	1	0.0	0.0
31	0.02	950	68	16.2	5.6
32	1.44	190	26	2.6	79.5
33	0.02	2791	30	1.3	74.1
34	0.60	172	34	4.1	15.7
35	0.79	1029	48	11.1	45.1

Table 2. Spearman correlation coefficients between rankings of samples by benthic ecologists. Each letter represents a different benthic ecologist.

A. San Francisco Bay
(n=11; p< 0.01 in all cases)

	A	B	C	D	E	F	G	H
B	0.92							
C	0.96	0.96						
D	0.92	0.81	0.91					
E	0.94	0.89	0.90	0.83				
F	0.90	0.87	0.90	0.82	0.96			
G	0.95	0.95	1.00	0.91	0.90	0.90		
H	0.95	0.93	0.98	0.91	0.92	0.92	0.98	
I	0.89	0.84	0.86	0.82	0.96	0.98	0.85	0.87

B. Southern California Bays
(n=24; p<0.0001 in all cases)

	A	B	C	D	E	F	G	H
B	0.88							
C	0.91	0.96						
D	0.92	0.90	0.89					
E	0.92	0.93	0.96	0.90				
F	0.92	0.93	0.92	0.93	0.95			
G	0.93	0.92	0.93	0.94	0.92	0.93		
H	0.93	0.91	0.92	0.93	0.93	0.95	0.96	
I	0.81	0.83	0.84	0.80	0.88	0.90	0.80	0.81

Table 3. Condition categories assigned to samples by the benthic experts. Each column represents a different benthic ecologist. Key to condition categories: R=Reference, M=Marginal deviation from reference, A=Affected, and S=Severely affected.

A. San Francisco Bay

Sample	A	B	C	D	E	F	G	H	I
1	S	S	S	S	A	A	S	S	S
2	R	R	R	R	R	R	R	R	M
3	R	R	R	M	R	R	R	R	M
4	S	S	S	S	S	S	S	S	S
5	M	R	R	A	R	R	R	R	M
6	A	M	M	M	M	M	M	M	M
7	M	R	R	R	R	R	R	R	R
8	S	S	S	S	S	S	S	S	S
9	A	M	A	M	M	M	A	A	M
10	M	R	R	R	R	R	R	R	R
11	A	M	A	A	M	M	A	A	A

B. Southern California Bays

Sample	A	B	C	D	E	F	G	H	I
12	A	M	M	A	M	M	A	A	M
13	M	M	M	M	M	M	M	M	A
14	R	R	R	R	R	R	R	R	M
15	M	M	M	A	M	M	M	M	M
16	R	R	R	R	R	R	R	R	M
17	S	S	S	S	S	S	A	S	S
18	R	R	R	R	R	M	R	R	A
19	S	S	S	A	S	A	S	S	S
20	M	R	R	M	M	M	M	R	M
21	A	M	M	M	A	A	A	A	A
22	A	A	A	M	A	A	A	A	A
23	A	A	M	A	M	A	M	M	A
24	A	M	A	A	A	A	A	A	A
25	S	S	S	S	S	S	A	S	S
26	M	A	M	M	M	M	M	M	A
27	S	S	S	S	S	A	S	S	A
28	R	R	R	R	R	R	M	R	R
29	S	S	S	S	S	S	A	S	A
30	A	S	S	S	S	S	S	S	S
31	R	R	R	R	R	R	M	R	R
32	S	A	S	A	S	A	A	A	A
33	A	A	A	A	A	A	A	A	A
34	M	R	M	M	A	M	R	M	M
35	R	R	R	R	M	R	M	R	R

Table 4. Criteria used by benthic experts to rank and categorize samples. Importance is the average importance for all experts, where: 1=very important; 2=important, but secondary; 3=marginally important; 4=useful, but only to interpret the other factors; and 5=not used. N is the number of experts that used the criterion.

Criteria	Importance	Std. Dev.	N
Dominance by tolerant indicator taxa	1.0	0.0	9
Presence of sensitive indicator taxa	1.2	0.4	9
Species richness (number of taxa)	1.4	0.7	9
Abundance of, or dominance by, specific higher level taxa	2.7	1.2	8
Total abundance	2.8	1.0	9
Presence of nonindigenous species	3.6	1.4	6
Diverse functional and feeding groups	3.7	1.6	4

Table 5. Indicator taxa identified by the experts. Importance is the average importance for all experts, where: 1=very important; 2=important, but secondary; 3= marginally important; 4=useful, but only to interpret the other factors; and 5=not used. N is the number of experts that identified the taxon as an indicator.

Indicator Taxon	Importance	Std. Dev.	N
Tolerant taxa			
Capitella capitata complex	1.0	0.0	9
Oligochaeta	1.3	0.5	9
Streblospio benedicti	2.0	1.1	9
Dorvillea (Schistomeringos) spp.	2.2	1.3	8
Mediomastus spp.	2.3	1.1	8
Armandia brevis	2.6	1.7	7
Pseudopolydora spp.	3.0	1.4	7
Exogone spp.	3.0	1.4	7
Grandiderella japonica	3.0	1.0	8
Euphilomedes spp.	3.1	1.2	7
Monocorophium spp.	3.1	1.2	8
Neanthes acuminata complex	3.2	1.3	7
Musculista senhousia	3.2	1.2	7
Notomastus spp.	3.4	1.6	5
Ophiura spp.	4.7	1.0	1
Sensitive taxa			
Ophiuroidea	1.4	1.3	8
Amphipoda	1.8	1.3	8
Gammaridea (most species)	1.9	1.8	7
Mollusca	2.2	1.2	8
Ampelisca abdita	2.7	1.8	6
NCOS*	3.0	1.5	6
Corophiidae	3.2	1.8	5
Spiophanes duplex and *S. berkeleyorum*	3.2	1.7	5
Crustacea	3.7	1.6	2
Amphiuridae	4.1	1.8	2

* Nemertea, Cnidaria, Opistobranchia and Sipuncula

Table 6. Spearman correlation coefficients between benthic parameters and site rankings by the experts.

Number of taxa	0.83
Abundance	0.29
Percent of abundance as sensitive taxa	0.67
Percent of abundance as tolerant taxa	-0.59
ERMq	-0.27