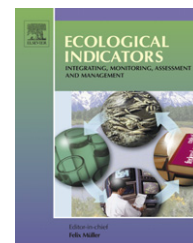


available at www.sciencedirect.comjournal homepage: www.elsevier.com/locate/ecolind

The level of agreement among experts applying best professional judgment to assess the condition of benthic infaunal communities

Stephen B. Weisberg^{a,*}, Bruce Thompson^b, J. Ananda Ranasinghe^a,
David E. Montagne^c, Donald B. Cadien^c, Daniel M. Dauer^d,
Douglas Diener^e, John Oliver^f, Donald J. Reish^g,
Ronald G. Velarde^h, Jack Q. Wordⁱ

^a Southern California Coastal Water Research Project, 3535 Harbor Blvd., Costa Mesa, CA 92626, USA

^b San Francisco Estuary Institute, 7770 Pardee Lane, Oakland, CA 94621, USA

^c County Sanitation Districts of Los Angeles County, P.O. Box 4998, Whittier, CA 90607, USA

^d Department of Biological Sciences, Old Dominion University, Norfolk, VA 23529, USA

^e P.O. Box 5196, Oceanside, CA 92052, USA

^f Moss Landing Marine Laboratories, Moss Landing, CA 95039, USA

^g Department of Biological Sciences, California State University, Long Beach, Long Beach, CA 90840, USA

^h City of San Diego Marine Biology Laboratory, 2392 Kincaid Road, San Diego, CA 92101, USA

ⁱ NewFields Northwest Port Gamble, WA 98364, USA

ARTICLE INFO

Article history:

Received 16 October 2006

Received in revised form

15 January 2007

Accepted 17 January 2007

Keywords:

Benthos

Best professional judgment

Indices

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.

© 2007 Elsevier Ltd. All rights reserved.

* Corresponding author.

E-mail address: steveuw@scwrrp.org (S.B. Weisberg).

1470-160X/\$ – see front matter © 2007 Elsevier Ltd. All rights reserved.

doi:10.1016/j.ecolind.2007.04.001

1. 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.

Table 1 – Characteristics of the samples assessed by the experts

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

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

[illegible]

Table 3 – Condition categories assigned to samples by the benthic experts

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

Each column represents a different benthic ecologist. Key to condition categories—R: reference; M: marginal deviation from reference; A: affected; S: severely affected.

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

Table 4 – Criteria used by benthic experts to rank and categorize samples

Criteria	Importance	S.D.	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

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; 5, not used. N is the number of experts that used the criterion.

Table 5 – Indicator taxa identified by the experts

Indicator taxon	Importance	S.D.	N
Tolerant taxa			
<i>Capitella capitata</i> complex	1.0	0.0	9
Oligochaeta	1.3	0.5	9
<i>Streblospio benedicti</i>	2.0	1.1	9
<i>Dorvillea</i> (<i>Schistomeringos</i>) spp.	2.2	1.3	8
<i>Mediomastus</i> spp.	2.3	1.1	8
<i>Armandia brevis</i>	2.6	1.7	7
<i>Pseudopolydora</i> spp.	3.0	1.4	7
<i>Exogone</i> spp.	3.0	1.4	7
<i>Grandiderella japonica</i>	3.0	1.0	8
<i>Euphilomedes</i> spp.	3.1	1.2	7
<i>Monocorophium</i> spp.	3.1	1.2	8
<i>Neanthes acuminata</i> complex	3.2	1.3	7
<i>Musculista senhousia</i>	3.2	1.2	7
<i>Notomastus</i> spp.	3.4	1.6	5
<i>Ophiura</i> 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
<i>Ampelisca abdita</i>	2.7	1.8	6
NCOS ^a	3.0	1.5	6
Corophiidae	3.2	1.8	5
<i>Spiophanes duplex</i> and <i>S. berkeleyorum</i>	3.2	1.7	5
Crustacea	3.7	1.6	2
Amphipodidae	4.1	1.8	2

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; 5, not used. N is the number of experts that identified the taxon as an indicator.

^a Nemertea, Cnidaria, Opisthobranchia and Sipuncula.

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.

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

4. 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 do not 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 and 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.

REFERENCES

- Bilyard, G.R., 1987. The value of benthic infauna in marine pollution monitoring studies. *Mar. Pollut. Bull.* 11, 581–585.
- Borja, A., 2005. The European Water Framework Directive: a challenge for nearshore, coastal and continental shelf research. *Cont. Shelf Res.* 25, 1768–1783.
- Borja, A., 2006. The new European Marine Strategy Directive: difficulties, opportunities, and challenges. *Mar. Pollut. Bull.* 52, 239–242.
- 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. Pollut. Bull.* 50, 787–789.
- 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. Pollut. Bull.* 40, 1100–1114.
- Borja, A., Muxika, I., Franco, J., 2003. The application of a Marine Biotic Index to different impact sources affecting soft-bottom benthic communities along European coasts. *Mar. Pollut. Bull.* 46, 835–845.
- Borja, A., Franco, J., Muxika, I., 2004. The biotic indices and the water framework directive: the required consensus in the new benthic monitoring tools. *Mar. Pollut. Bull.* 48, 405–408.
- Boyle, T.P., Smillie, G.M., Anderson, J.C., Bieson, D.R., 1990. A sensitivity analysis of nine diversity and seven similarity indices. *J. Water Pollut. Control Federat.* 62, 749.
- Dauer, D.M., 1993. Biological criteria, environmental health and estuarine macrobenthic community structure. *Mar. Pollut. Bull.* 26, 249–257.
- Dauer, D.M., Luckenbach, M.W., Rodi Jr., A.J., 1993. Abundance biomass comparison (ABC method): effects of an estuarine gradient, anoxic/hypoxic events and contaminated sediments. *Mar. Biol.* 116, 507–518.
- Dauvin, J., 2007. Paradox of estuarine quality: benthic indicators and indices, consensus or debate for the future. *Mar. Pollut. Bull.* 55, 271–281.
- Diaz, R.J., Solan, M., Valente, R.M., 2004. A review of approaches for classifying benthic habitats and evaluating habitat quality. *J. Environ. Manage.* 73, 165–181.
- Engle, V.D., Summers, J.K., 1999. Refinement, validation, and application of a benthic condition index for Northern Gulf of Mexico estuaries. *Estuaries* 22, 624–635.
- Gibson, G.R., Bowman, M.L., Gerritsen, J., Snyder, B.D., 2000. Estuarine and Coastal Marine Waters: Bioassessment and Biocriteria Technical Guidance. EPA 822-B-00-024. US Environmental Protection Agency, Office of Water, Washington, DC.
- Jonge, V.N., Elliot, M., Brauer, V.S., 2006. Marine monitoring: its shortcomings and mismatch with the EU Water Framework Directive's objectives. *Mar. Pollut. Bull.* 53, 5–19.
- Llansó, R.J., Scott, L.S., Hyland, J.L., Dauer, D.M., Russell, D.E., Kutz, F.W., 2002. An estuarine benthic index of biological integrity for the Mid-Atlantic region of the United States. II. Index Development. *Estuaries* 25, 1231–1242.
- Long, E.R., MacDonald, D.D., 1998. Recommended uses of empirically derived, sediment quality guidelines for marine and estuarine ecosystems. *Hum. Ecol. Risk Assessment* 4, 1019–1039.
- Muxika, I., Borja, A., Bonne, W., 2005. The suitability of the marine biotic index (AMBI) to new impact sources along the European coasts. *Ecol. Indic.* 5, 19–31.
- Muxika, I., Borja, A., Bald, J., 2007. Using historical data, expert judgement and multivariate analysis in assessing reference conditions and benthic ecological status, according to the European Water Framework Directive. *Mar. Pollut. Bull.* 55, 16–29.
- Paul, J.F., Scott, K.J., Campbell, D.E., Gentile, J.H., Strobel, C.S., Valente, R.M., Weisberg, S.B., Holland, A.F., Ranasinghe, J.A., 2001. Developing and applying a benthic index of estuarine condition for the Virginian Biogeographic Province. *Ecol. Indic.* 1, 83–99.
- Pearson, T.H., Rosenberg, R., 1978. Macrobenthic succession in relation to organic enrichment and pollution of the marine environment. *Oceanogr. Mar. Biol. Annu. Rev.* 16, 229–311.
- Ranasinghe, J.A., Mikel, T.K., Velarde, R.G., Weisberg, S.B., Montagne, D.E., Cadien, D.B., Dalkey, A., 2005. The prevalence of non-indigenous species in southern California embayments and their effects on benthic macroinvertebrate communities. *Biol. Invasions* 7, 679–686.
- Smith, R.W., Bergen, M., Weisberg, S.B., Cadien, D.B., Dalkey, A., Montagne, D.E., Stull, J.K., Velarde, R.G., 2001. Benthic response index for assessing infaunal communities on the southern California mainland shelf. *Ecol. Appl.* 11, 1073–1087.
- Thompson, B., Lowe, S., 2004. Assessment of macrobenthos response to sediment contamination in the San Francisco Estuary, California, USA. *Environ. Toxicol. Chem.* 23, 2178–2187.
- Van Dolah, R.F., Hyland, J.L., Holland, A.F., Rosen, J.S., Snoots, T.R., 1999. A benthic index of biological integrity for assessing habitat quality in estuaries of the southeastern USA. *Mar. Environ. Res.* 48, 269–283.
- Weisberg, S.B., Ranasinghe, J.A., Dauer, D.M., Schaffner, L.C., Diaz, R.J., Frithsen, J.B., 1997. An estuarine benthic index of biotic integrity (B-IBI) for Chesapeake Bay. *Estuaries* 20, 149–158.