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Validation of a fish-based index of biotic integrity for streams and rivers of central Mexico

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Abstract

An existing version of a fish assemblage-based index of biotic integrity (IBI) for the streams and rivers of west central Mexico was tested with independent data to validate its usefulness as a measure of ecosystem quality and to determine the geographic area where it is effective. Fish assemblages from 63 upland sites in 10 basins in central Mexico (Armería, Ameca, Coahuayana, Marabasco, Purificación, Grande de Morelia, Grande de Santiago, Lerma, Balsas and Pánuco) were assessed using the metrics and scoring criteria from the existing IBI and then compared with independent evaluations of habitat and water quality. IBI scores were congruent with habitat and water quality values in the Armería, Purificación and Marabasco basins, where the IBI was first developed, as well as in the adjacent Ameca and Coahuayana basins. We conclude that the IBI can be used without modification to assess environmental quality in non-coastal streams and rivers within these five basins. Further data are needed from the Grande de Morelia, Grande de Santiago and middle Lerma basins, but our results suggest that the existing IBI may also be effective here. However, the existing IBI does not consistently reflect habitat and water quality conditions in the Balsas and Pánuco basins and must be modified before it can be applied there. Necessary modifications in the Balsas basin appear to be small and related primarily to changes in the scoring criteria for metrics. However, in the Pánuco basin more substantive changes in the nature of the metrics are required. Changes in the IBI for these basins are proposed. The IBI is now validated for use in river monitoring, conservation and restoration efforts in 5 basins in west central Mexico and suggestions for its application in other basins are available here.

Introduction

Aquatic ecosystems in Mexico have been severely degraded since the beginning of the 20th century. Degradation has accelerated, especially during the last 30 years, and fish populations in streams and rivers of central Mexico have been reduced or have significantly changed in structure and composition (Lyons et al., 1995, 1998; Soto-Galera et al., 1998, 1999). Overexploitation and environmental pollution of rivers, caused by increasing human populations, are the main reasons that fish assemblages have declined.

In order to prevent further damage and begin to restore environmental quality, it is necessary to comprehensively evaluate the extent to which aquatic ecosystems have been altered. Traditional environmental assessment methods have been valuable in the evaluation of the water quality of streams and rivers but have several shortcomings. They do not take into account naturally occurring levels of some substances or consider sublethal effects of pollutants. They do not assess the synergistic effects of different combined contaminants. Moreover, they do not measure the effects of other, non-chemical anthropogenic alterations such as changes in river flow, habitat modifications, overharvest, elimination of riparian vegetation, and introduction of exotic species (Karr, 1981).

With modern bio-assessment techniques, it is possible to establish the significance of the cummulative and combined effects of human alterations on aquatic ecosystems (Loeb and Spacie, 1994). Using abundance and composition data from biotic communities we can estimate the overall environmental quality or health of an ecosystem (Lyons et al., 1995). Biotic communities are sensitive to a wide variety of environmental factors and offer an integral perspective on the environmental conditions of a given habitat. Thus, they provide an objective and defensible basis for establishing conservation and restoration efforts in aquatic ecosystems.

Alterations to the chemical, physical or biological attributes of a river lead to changes in the structure, composition and behavior of biotic communities. These changes are reflected in a loss of biotic integrity in the river. Biotic integrity has been defined as "the capability of supporting and maintaining a balanced, integrated, adaptive community of organisms having a species composition, diversity, and functional organization comparable to that of the natural habitat of the region" (Karr and Dudley, 1981). This concept has played a significant role in the assessment of environmental quality and degradation, especially in aquatic systems (Karr, 1987, 1990, 1991, 1993; Lyons, 1992). The analysis of compositional, structural and functional data has helped integrate a series of measures into an index representing ecosystems ranging from relatively undegraded to highly degraded (Fausch et al., 1990; Karr, 1991; Lyons et al., 1995; Simon and Lyons, 1995). Measures that have been used to establish this gradient of ecosystem condition include: species richness; species composition; indicator species or guilds; trophic and reproductive function; organismal abundance; and individual condition. Hence, an index of biotic integrity (IBI) regards a site with "good" environmental quality as one where all biological and physical-chemical components and the processes that support them are present at the appropriate level or rate for an area with specific biogeographic characteristics.

Fish have been particularly important in the development of IBIs, given the availability of relatively complete information about their: life history and ecology; position in trophic webs; relative ease of identification; and sensitivity to a wide range of anthropogenic stressors (Karr, 1981; Plafkin et al., 1989). Many fish-based IBIs have been developed to evaluate the environmental quality of rivers and streams in the U.S. and other temperate countries. These IBIs have proven helpful in establishing river restoration and conservation strategies. However, to date, only two Mexican IBIs have been published in the scientific literature; one for rivers and streams of west central Mexico (Lyons et al., 1995), and the other for the lakes of central Mexico (Lyons et al., 2000). The river IBI was derived from previously published versions for other regions in North America and modified to reflect the unique attributes of the west-central Mexican stream-fish assemblages (Table 1). However, it retained the conceptual framework of previous IBIs. This version of the IBI has already been used to follow changes over time in the environmental quality of the Ayuquila River in the state of Jalisco, México (Luis Manuel Martínez-Rivera, Universidad de Guadalajara; and Norman Mercado-Silva, University of Wisconsin – Madison; unpublished data).

Evaluation of environmental quality is of particular importance for the conservation of freshwater fishes in central Mexico. The fish fauna of this region is not especially diverse but has a high degree of endemism, with each basin having unique species and assemblages owing to the complicated geological history of the area. Central Mexico has at least

Table 1. Index of biotic integrity for streams and rivers of West Central Mexico. Scoring criteria and metrics (from Lyons et al., 1995)

Metric	Basin area (km^2)	Criteria for each scoring category Poor (0)	Fair (5)	Good (10)
Number of native species	>400	<4	4–6	>6
	≤400	0–1	2–4	>4
Benthic species individuals (%)	All	<5	5–25	>25
Number of water column species	>400	<2	2–4	>4
	≤400	0	1–2	>2
Number of sensitive species	All	0	1–2	>2
Tolerant species individuals (%)	All	>90	90–10	<10
Exotic species individuals (%)	All	>25	25–5	<5
Omnivore individuals (%)	All	>95	95–85	<85
Native live-bearing species individuals (%)	All	<25	25–75	>75
Number of fish per half-hour sampling	>400	<60	–	>60
	≤400	<30	–	>30
Diseased, deformed, eroded-fin, lesionous or tumorous individuals (%)	All	>5	5–1	<1

80 endemic freshwater fish species, and little similarity is to be expected among the fish faunas in adjacent river basins in the area (Miller, 1986; Miller and Smith, 1986; Guzmán-Arroyo, 1990). Many fish assemblages have been drastically altered as a consequence of anthropogenic habitat effects (Guzmán-Arroyo, 1990). At least five native species are now extinct as a result of exotic species introduction, water quality and quantity changes, and habitat modifications (López-López and Díaz-Pardo, 1991; Lyons et al., 1998; Soto-Galera et al., 1998, 1999).

In view of the need to reduce environmental degradation, conserve species and restore the rivers of central Mexico it is important that we identify objectively those sites most in need of protection or rehabilitation. The IBI is an ideal method for evaluating streams and rivers with respect to environmental degradation. Our objectives, in this paper, are to test the validity of the existing river IBI using independent data, determine the geographical range where this IBI is valid, and suggest modifications for its use in areas where it does not provide enough sensitivity. Validation involved documenting that IBI scores and ratings accurately and consistently reflected environmental quality ratings developed from independent physical and chemical assessments.

Materials and methods

For this paper, river basins in central Mexico, an area defined as between 23° and 18° N, were studied. All sites are in mountainous areas above 100 m elevation; we excluded sites in the coastal plain where fish assemblages are often dominated by marine or estuarine species. Our study area includes rivers and streams draining to the Pacific Ocean and Gulf of Mexico as well as an endorrheic basin (Río Grande de Morelia), and represents about 40% of the surface area of Mexico. This area is characterized by a major latitudinal gradient and high climatic and landscape diversity. We included 63 different sites in 10 basins for this study (Figure 1). The Ameca and Pánuco basins were each divided into two sub-basins based on natural and well documented within-basin differences in fish faunas (Miller and Smith, 1986). Basins and sub-basins included in this study, with the number of sites in parenthesis, were Río Grande de Santiago (2), Upper Ameca (8), Lower Ameca (2), Purificación (1), Marabasco (1), Armería (7), Coahuayana (8), Balsas (6) middle Lerma (3), Grande de Morelia (4), Pánuco-Tampaón (16) and Pánuco-Moctezuma (5) (Figure 1). The IBI was originally developed in part from samples from the Purficación, Marabasco and Armería basins. For this study, new data were obtained from these basins; three of the sites originally used for the construction of the IBI were re-sampled.

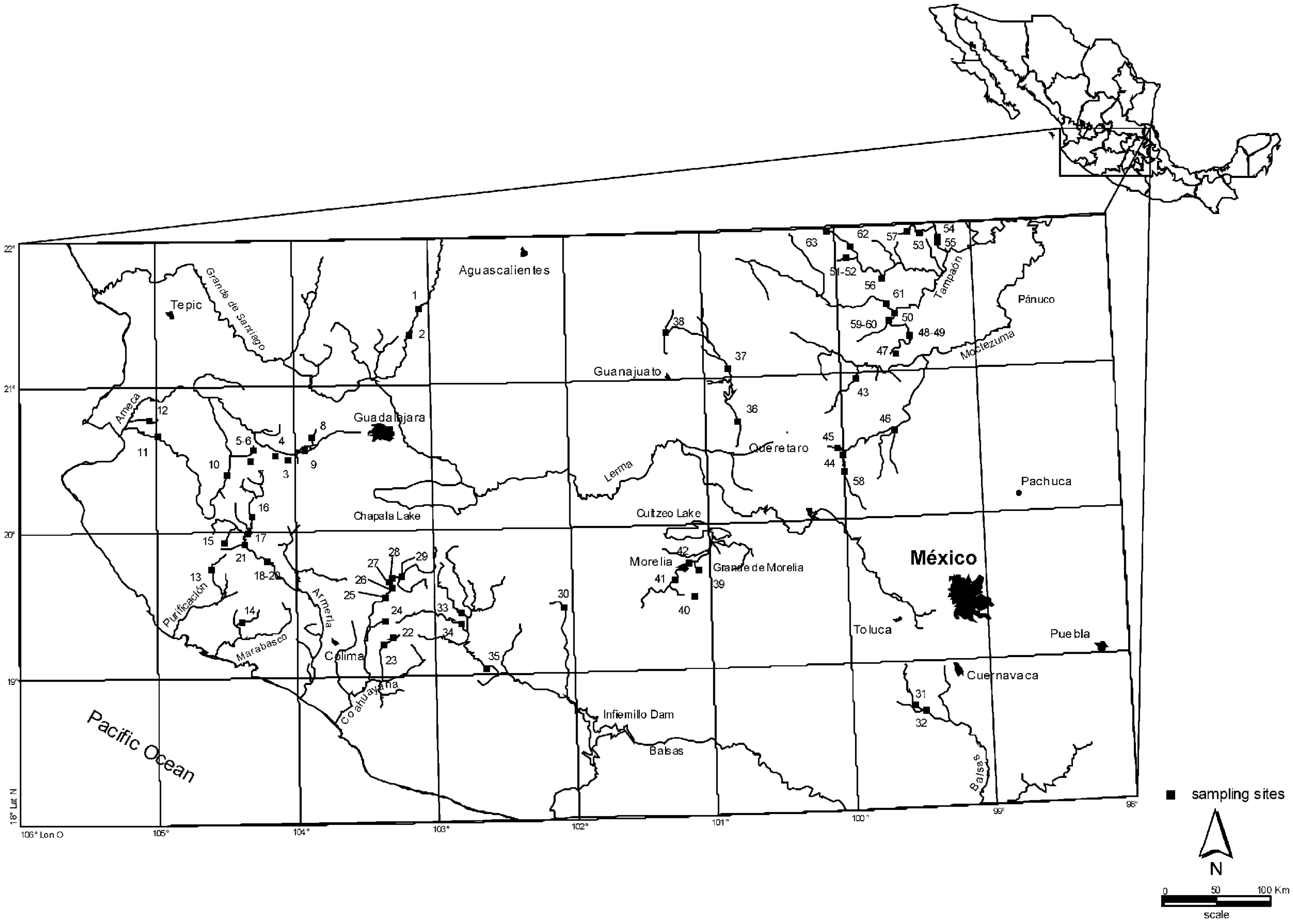

Figure 1. Map of Central Mexico showing general drainage patterns and the study sites. Sites are numbered with reference to Appendix 2. Marks on the map may indicate more than one sampling site. For clarity, many smaller river systems are not shown.

Each site was sampled during daylight between December 1995 and January 2001 during low flow periods. Standardized fish sampling occurred at all of our sites following procedures described in Lyons et al. (1995). At each site all habitat types present were sampled with either backpack electroshockers, small-mesh seines and dipnets, cast nets, or direct observation to obtain a representative sample of the fish fauna. Each site was sampled continuously until our efforts failed to yield new species or major changes in the proportional abundance of species. Each site was located using GPS or maps and a series of measures and observations were made on water depth, different physical-chemical parameters (e.g., temperature, dissolved oxygen), number of habitats available for fish, quality of riparian vegetation and presence of environmental problems (e.g., erosion, trash, channelization). All fish captured were identified, counted, and checked for disease, deformities, eroded fins, lesions and tumors. Voucher specimens were deposited in scientific collections at various institutions (Instituto Manantlán de Ecología y Conservación de la Biodiversidad, Universidad de Guadalajara; School of Biology of the Universidad Autónoma de Querétaro; Laboratory of Ichthyology of the Instituto Politécnico Nacional; University of Michigan Museum of Zoology; Tulane University Museum of Zoology; University of Wisconsin Zoological Museum), most fish, however, were released after processing.

To calculate the IBI, fish were first classified according to origin, typical position in the water column, tolerance to environmental degradation, feeding habits, and mode of reproduction (Appendix 1). Origin for each species was established using literature on their distribution (Contreras-Balderas and Escalante, 1984; Espinoza et al., 1993a; Espinoza et al., 1993b; Miller, 1986; Miller and Smith, 1986). Species collected were grouped as benthic or water column based on direct observation of their position. We categorized species as sensitive, medium or tolerant based on field observations and existing literature (Ledesma-Ayala, 1987; Lyons et al., 1995; Soto-Galera et al., 1999). If a species only occurred in good quality water and habitat it was considered sensitive; if it was relatively abundant at a wide range of sites with e.g., low dissolved oxygen, heavy organic pollution, high levels of sedimentation and turbidity or extensively degraded habitat, the species was considered tolerant; if it did not occur at the worst sites but was not restricted to the best ones the species was considered moderate. Species were characterized as herbivorous (>75% plant material in stomach content), omnivorous (>25% plant and >25% animal materials in stomach content), filtering (as judged from their feeding habits) or carnivorous (>75% animal material in stomach content) (Karr, 1981; Karr et al., 1986) based on information available from voucher specimens and other bibliographic sources (Lyons et al., 1995, 2000; as well as our own unpublished data) (Appendix 1). Once the species had been classified, the metrics and scores for the IBI were calculated following guidelines in Lyons et al. (1995) (Table 1). The final IBI score can range from 0–100 with 100 being optimal. Environmental quality was assessed at each sampling site based on the habitat and water quality criteria and methodology taken from Lyons et al. (1995) and scaled from 0–100.

Data were analyzed in two different groups; one to test the validity of the IBI for the basins where it was originally constructed and a second to determine the geographic range where the IBI could be used successfully without modification. In the first case, we analyzed new data from three of the four basins used to construct the original IBI. In the second we analyzed data from sites distributed across seven other basins covering much of central Mexico. In each case, environmental quality (EQ) scores for each site were compared with IBI scores. When there were 8 or more sites in one basin, we used Pearson's correlation coefficient to compare both indices (Minitab, 1996). Sites analyzed in this manner were in the Ameca (upper and lower sub-basins) (n = 10), Coahuayana (n = 8) and Pánuco (Moctezuma and Tampaón sub-basins) (n = 21) basins and combined sites from the Purificación (n = 1), Marabasco (n = 1) and Armería (n = 7) basins (n = 9 total). If IBI scores from a basin were significantly correlated with the EQ scores with one or no outliers, we concluded that the existing IBI was effective for measuring environmental quality. If a basin did not have enough sites for a correlation analysis then we compared the differences between EQ scores and IBI scores individually by site (e.g., the Grande de Santiago [n = 2], Balsas [n = 6], middle Lerma [n = 3], and Grande de Morelia [n = 4]). The original IBI was developed with samples from the lower Lerma sub-basin, but the middle Lerma sub-basin has a somewhat different fish fauna (Díaz-Pardo et al., 1993; Soto-Galera et al., 1998), so we used the middle Lerma to determine the geographic range rather than to validate the IBI. We also made a non-statistical intra-basin site comparison for the upper and lower Ameca sub-basins and the Moctezuma and Tamuín sub-basins in the Pánuco system. When correlations between scores were not significant or there was more than one site with disagreement in EQ and IBI scores we considered the same data in more detail. If EQ scores were low, relative to IBI scores, we re-examined the available water and habitat quality information to confirm that the EQ scores were indeed inappropriate. If IBI scores were low relative to EQ scores, we analyzed each of the individual metrics to determine if the IBI reflected biological stresses not measured by our physical and chemical data (e.g., exotic species, barriers to fish migration). If the EQ value was valid and the IBI did not indicate obvious biological stresses then we concluded that the existing IBI was not sensitive enough to represent the ecosystem quality of the site. We then proposed changes to the IBI, such as eliminating or adding metrics or changing scoring criteria, to increase its sensitivity.

Results

Across all 63 sites, EQ scores ranged from 20–90 and IBI scores ranged from 25–95 (Appendix 2). Seventy six percent of sites were rated as having good environmental quality (EQ $\geq$ 70), 6% as poor (EQ $\leq$ 40), and 18% as fair (EQ 50–60). The sites had a more even distribution of IBI scores, with 41% rated as good (IBI $\geq$ 70), 14% as poor (IBI $\leq$ 40) and 45% as fair (IBI 45–65).

Validity of the IBI

Our independent data validated the IBI as an accurate indicator of ecosystem quality in the Marabasco, Armería and Purificación basins. For the combined nine sites in these three basins, there was a positive significant correlation between IBI and EQ scores (Pearson's r = 0.899) (Figure 2). The Armería basin had sites with IBI scores ranging from 30 (poor) to 95 (good) and EQ scores of 30 (poor) to 90 (good) (Appendix 2). Sites in the Río Purificación and Río Marabasco basins had IBI scores of 70 (good) and 80 (good) and EQ scores of 50 (fair) and 70 (good), respectively. No outliers occurred in the Amería basin and all sites had IBI scores that closely corresponded to their EQ scores. Similarly, the Marabasco basin site had consistent EQ and IBI scores. In the Purificación basin there was a small difference in the EQ (fair) and IBI (good) ratings. The IBI score was elevated by the presence, in low numbers, of a sensitive species, *Xenotaenia resolanae* (Goodeidae), which boosted the scores for the metrics "number of native species", "number of water column species", and "number of sensitive species " and pushed the overall IBI rating from fair to good. A relatively high quality tributary entered the river not far upstream and the *X. resolanae* we captured may have originated from there and may not have been permanent residents of the study site.

Three sites used in the IBI design (Lyons et al., 1995) were re-sampled. Two of these showed little or no difference in EQ and IBI scores between both sampling periods (in the Armería and Marabasco basins) and one (in the Purificación basin) showed higher EQ and IBI scores than the previous sample. While the change in EQ scores between both sampling seasons was slightly greater than the change in IBI scores, both indices reflected improvement in the overall condition of the ecosystem at this site.

Geographic range of the IBI

The existing IBI appeared to be an accurate indicator of ecosystem quality in the Coahuayana and Ameca basins. In the Coahuayana basin, IBI and EQ scores were significantly positively correlated (Pearson's r = 0.781) with only one outlier (Figure 2). For the eight sites in this basin, IBI scores ranged from 40 (poor) to 80 (good) and EQ scores from 20 (poor) to 80 (good). Similarly, in the Ameca basin, IBI and EQ scores had a significant positive correlation (Pearson's r = 0.91) and no outliers were present (Figure 2). For the eight sites in the upper Ameca sub-basin, IBI scores ranged from 25 (poor) to 80 (good) (Appendix 2). The two sites in the lower Ameca sub-basin both had IBI scores of 80 (good) and EQ scores of 90 and 70 (good).

The IBI also performed well in the Grande de Santiago, Grande de Morelia and middle Lerma basins, although sample sizes were too small to conclude definitively that the IBI was a valid indicator of ecosystem health. The two Grande de Santiago basin sites had IBI scores of 55 and 60 (fair) and EQ scores of 50 (fair) and 70 (good) respectively (Appendix 2). The four sites in the Grande de Morelia basin also had congruent IBI and EQ scores, with IBI scores ranging from 50 (fair) to 70 (good) and EQ scores from 50 (fair) to 80 (good). For the three sites in the middle Lerma basin, two had similar IBI (50 and 60 [fair]) and EQ scores (50 [fair] and 70 [good], respectively). The third, La Quemada, had a major discrepancy between the IBI scores of 35 (poor)

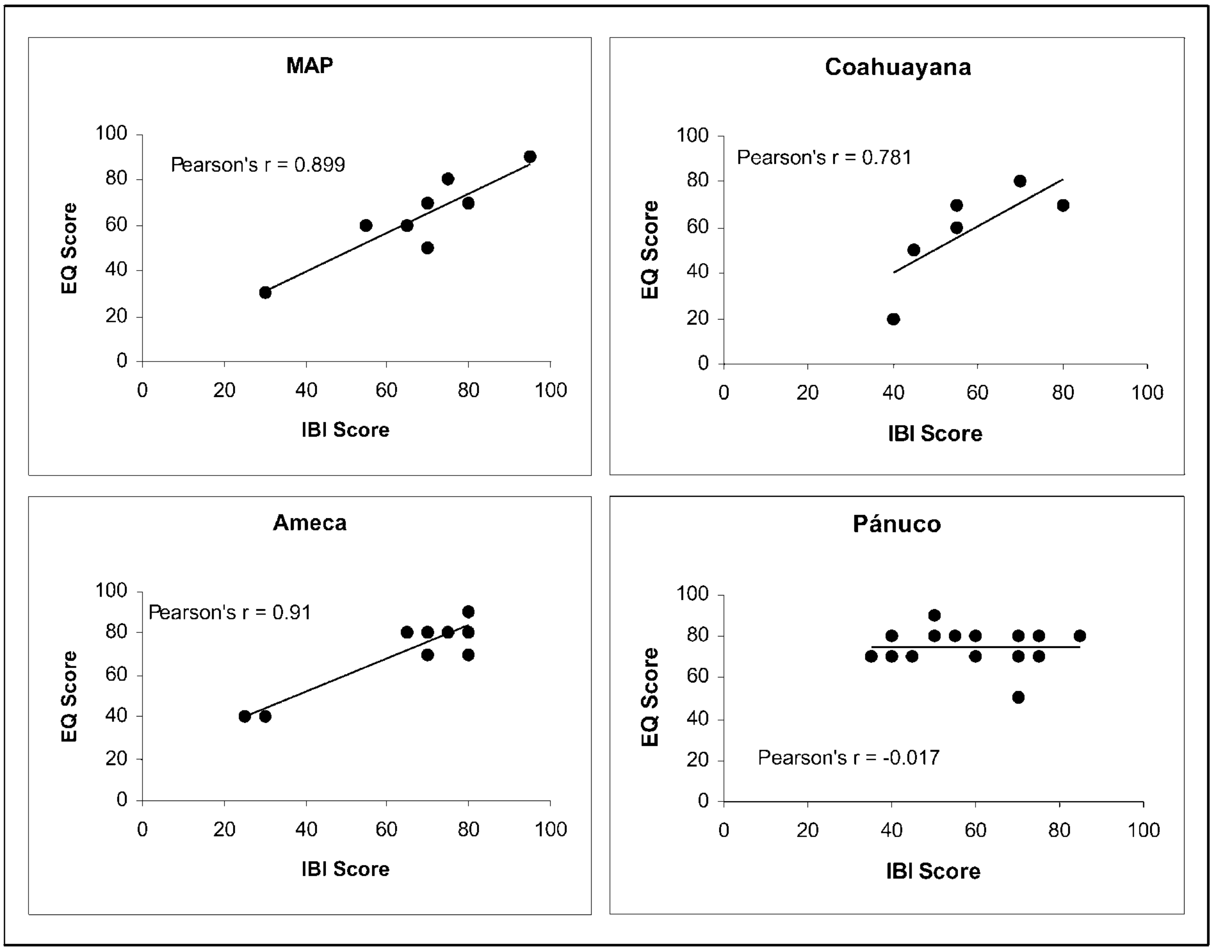

Figure 2. Correlations of index of biotic integrity and environmental quality scores for sites in the Ameca; Coahuayana; Pánuco and the Marabasco, Armería and Purificación (MAP) basins group. Pearson's "r" correlation values are indicated for each basin.

and the EQ score of 80 (good). Here the IBI score was probably a better indicator of ecosystem condition than the EQ score. The IBI score was low because the fish assemblage was dominated by an exotic, tolerant, omnivore: *Carassius auratus* (Cyprinidae). The high relative abundance of this species reduced the scores for 6 of the 10 metrics in the index. Thus the biotic community of the site was highly modified, and this was reflected in the low IBI score, but the physical and chemical characteristics of the site were good so the EQ score was high.

The IBI did not perform quite as well in the Balsas basin. For the six sites, IBI scores ranged from 50 (fair) to 80 (good) and EQ scores from 50 (fair) to 90 (good) (Appendix 2). However, three of the sites had discrepancies between their ratings, with good EQ scores but only fair IBI scores. One site, the Río El Oro, was a headwater stream with an EQ score of 90 but an IBI score of only 60. The IBI score was depressed because of what appeared to be inherently low fish species diversity (only two native, carnivorous, benthic, egg-laying species, *Hybopsis boucardi* [Cyprinidae] and *Ictalurus balsanus* [Ictaluridae]) owing to the small size and isolated position of the site. Three IBI metrics, "number of native species", "number of water column species", and "percent native live-bearing species individuals" had lower than expected values. A second site, Río Amacuzac 1, had an EQ score of 90 and an IBI score of 65. Here the river was large and accessible but the water was spring-fed and unusually cold, which apparently prevented several species known from elsewhere in the river (e.g., *I. balsanus*; the tolerant, omnivorous, water-column, live-bearer *Ilyodon whitei* [Goodeidae]; and the carnivorous, water-column, egg-layer *Nandopsis istlanum* [Cichlidae]) from occupying the site and thus caused depressed values for the same three metrics as at the Río El Oro. The third site, Río Amacuzac 2, had an EQ score of 70 and an IBI score of 50, but here the IBI score was probably a better measure of ecosystem quality. At this site, the assemblage had a high abundance of two exotic species *Poeciliopsis gracilis* (Poeciliidae) and *Archocentrus nigrofasciatum* (Cichlidae) (see also Contreras-MacBeath et al., 1998), reflecting an effect on the biotic community that was not apparent from the physical and chemical characteristics used to determine the EQ score.

The IBI performed the poorest in the Pánuco basin. In this basin there was not a significant correlation between EQ and IBI scores (Pearson's r = −0.017) (Figure 2). The 16 sites in the Tampaón sub-basin of the Pánuco had EQ scores from 50 (fair) to 90 (good) and IBI scores from 40 (poor) to 85 (good) (Appendix 2). However, nine of the sites had EQ ratings of good but IBI ratings of only fair (n = 7) or poor (n = 2). Similarly at the five sites in the Moctezuma sub-basin, EQ scores ranged from 70 to 80 (good) and IBI scores from 35 (poor) to 75 (good), but three sites had had EQ ratings of good and IBI ratings of only fair (n =1) or poor (n = 2). The relatively low IBI scores in these two sub-basins seemed to be a consequence of inappropriate metrics and scoring criteria, and the scores did not appear to accurately reflect human impacts on the fish assemblage. In the Tampaón sub-basin, the reduced IBI scores were primarily the result of an apparently natural absence or scarcity of benthic species coupled with a relatively low abundance of native live-bearing species. The Moctezuma sites were in a desert region and had inherently low species richness with a natural dominance by tolerant omnivores, thus deflating the IBI scores.

Discussion

Validation with independent data is a critical yet often neglected aspect of IBI development and implementation (Karr and Chu, 1999). Our results validate the IBI for use in the streams and rivers of west central Mexico. We found a strong positive correlation without outliers between EQ scores and IBI scores based on new data collected from sites in three of the four basins from which the IBI had been originally developed, the Armería, Purificación, and Marabasco. Basins adjacent to these – the Coahuayana and Ameca – also had consistent positive relations between EQ and IBI scores, indicating that the IBI is also likely to provide an accurate measure of ecosystem quality in these basins. More data are needed to confirm the utility of the IBI in the Grande de Santiago basin but initial results are promising. We lacked any new data to directly validate the IBI for the lower Lerma, which was the fourth basin used in the development of the original index. However, bearing in mind the small sample sizes, the apparent success of the IBI in estimating ecosystem condition in the adjacent middle Lerma and Grande de Morelia basins suggests that the IBI is probably valid in the lower Lerma as well. Again, more data are required to finalize this conclusion. Previous studies have also found strong relations between characteristics of fish assemblages and environmental quality throughout the Lerma and the Grande de Morelia basins (López-López and Díaz-Pardo, 1991; Díaz-Pardo et al., 1993; Soto-Galera et al., 1998, 1999).

A strength of the IBI that was illustrated at La Quemada, one of our Lerma basin sites, is that it is broadly integrative, responding to physical, chemical, and biological perturbations of the ecosystem. The IBI detects biological impacts such as exotic species or overexploitation (see also Lyons et al., 2000) that are missed by physical and chemical measures. At La Quemada, and also at Río Amacuzac 2 in the Balsas basin, the IBI indicated biological problems related to exotics that were not detected by our EQ index, which reflected only water and habitat quality.

Although the existing IBI functioned well in the Grande de Morelia and middle Lerma systems, we recommend one modification that should improve its sensitivity in those basins. That is to include the native salamander *Ambystoma ordinatum* (Ambystomidae) as a "fish" in calculating IBI scores. The small, mountainous, headwater streams where this salamander tends to occur (including our sites Arroyo Irapeo and Arroyo Insurgentes in the Grande de Morelia basins) usually have only one or two fish species, and the salamander is functionally equivalent to a fish in these ecosystems (Anderson and Worthington, 1971). *Ambystoma ordinatum* is neotenic and completely aquatic throughout its life, and it is an environmentally sensitive benthic, and carnivorous egg-layer.

The existing IBI does not perform adequately in all areas of central Mexico, which is not surprising given great variation in fish faunas among the basins of the region (Miller and Smith, 1986; Lyons et al., 1995). In the Balsas basin the IBI underestimated ecosystem condition in a small isolated headwater stream and in a larger but unusually cold river. Both sites had naturally low species richness. In general, the Balsas has low species richness relative to other basins in central Mexico (Miller, 1986; Miller and Smith, 1986). It appears that downward adjustments in scoring criteria for the metrics "number of native species", "number of water column species", "percent native live-bearing species individuals", and perhaps "number of sensitive species" would make the IBI a more accurate tool in the Balsas basin. However, additional fish assemblage data from high-quality sites are needed before specific changes in metric scoring criteria can be proposed.

More substantial modifications of the existing IBI are needed for the Pánuco basin. This was the only one of our study basins that drained to the Gulf of Mexico, and its fauna differs in many regards from the other study basins, which drain to the Pacific Ocean. One major difference is the very low abundance or absence of benthic species that appears to be typical of the Pánuco sites. We encountered only two benthic species in the Pánuco basin, *Ictalurus mexicanus* (Ictaluridae) and *Ictiobus labiosus* (Catostomidae), and they were limited to the Tampaón sub-basin where neither was common. An alternative to the metric "benthic species individuals" would improve the performance of the IBI in the Tampaón sub-basin. Because benthic species are considered habitat specialists that are sensitive to its modifications, one possibility would be to replace the "benthic species individuals" metric with a more general "number of habitat specialist species" or "habitat specialist individuals". Such a new metric would represent the same sort of response to habitat degradation as embodied in the "benthic species individuals" metric but in a more sensitive and appropriate form for the basin (Karr et al., 1986; Karr, 1987). Habitat specialists could include native species adapted for dwelling and feeding at the water surface (e.g., *Poecilia mexicana*, *Gambusia panuco*, *Xiphophorus montezumae* [Poeciliidae]) and others adapted to deep pools with cover (*Herichthys* and *Nandopsis* species [Cichlidae]), as well as the two benthic species.

Another necessary modification for the Tampaón sub-basin would be to lower the scoring criteria for the metric "native live-bearing species individuals". Although a variety of live-bearers in the family Poeciliidae occur in the Tampaón sub-basin, they did not dominate assemblages the way that live-bearers did in the basins draining to the Pacific Ocean. In Pacific basins more than 75% of the assemblage needed to be composed of native live-bearers before the site received the maximum score for the "native live-bearing species individuals" metric. In the Tampaón sub-basin this percentage might be more appropriately set at 33% although further data and analyses are needed to finalize this value.

At some sites in the Pánuco basin, mainly in the Moctezuma sub-basin but also including the Río Chubeje in the Tampaón sub-basin, metric substitution and scoring criteria adjustments will probably not be sufficient to make the IBI effective. These sites, because of their extreme natural environmental conditions and isolation from other systems, have inherently low fish species richness. The El Oasis, Río Estorax and Río Las Zúñigas sites in the Moctezuma sub-basin are located in a hot desert area, and they have high water temperatures during the summer, unusually high levels of dissolved substances in their water, and are typically isolated from other river reaches by long stretches of dry channel. Each has only one species, a native, tolerant, omnivore. The Río Chubeje site is on a small, spring-fed, headwater stream with unusually cold water that is typically isolated from warmer downstream reaches by dry channel. It had no native species and the only species we encountered there was the exotic *Oncorhynchus mykiss* (Salmonidae), a cold water specialist. At sites such as this, a fish based IBI is inappropriate and it is better to develop an IBI based on the macroinvertebrates or algae (Karr and Chu, 1999).

One type of IBI that might be effective in the Pánuco basin relates to the diversity, composition and function of the internal and external parasite fauna of the fish assemblage. The proportion of the parasite fauna composed of exotic species has proven to be a useful metric in an IBI for the lakes of central Mexico (Lyons et al., 2000). Even in an area of naturally low fish species diversity, such as the Moctezuma sub-basin, a relatively diverse parasite fauna may exist, allowing more unique biological measures of fish assemblage condition to be developed. However, a disadvantage of parasite metrics is that they require specialized expertise that ichthyologists or aquatic biologists, who typically carry out IBI calculations, usually lack. Trained parasitologists would be needed to apply parasite metrics in central Mexico.

Even though it has been validated, care should be observed in the application of the IBI in central

Mexico. The IBI is an empirical index and thus its structure and performance is a function of the characteristics of the fish assemblages from which it was developed. In central Mexico, little is known about the inherent attributes of the fish assemblages of many streams and rivers, which makes the application of bioassessment methods, such as the IBI, difficult. It is only through an iterative validation and, as necessary, modification process with different sets of data that the IBI can acquire the necessary scope and sensitivity to be used throughout central Mexico in the design of river conservation and restoration projects. There is a pressing need to understand the origin and characteristics of the natural differences in fish assemblages within and among the basins of the region. Because most of central Mexico has been greatly modified by human activities, which in many cases began long before the first scientific surveys of the fish fauna (e.g., Lyons et al., 1995, 1998), a particular challenge will be to determine which aspects of the fish assemblage are "natural" and which are consequences of long term, pervasive, human activities. Additional bibliographic, systematic, and ecological studies of the central Mexico fish fauna will undoubtedly be needed to address this issue and to allow continued development and application of the IBI concept in the region.

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Appendix 1. Classification of selected fish species of central México for IBI metric calculations, taken (and updated) from Lyons et al. (1995, 2000), and our own unpublished data. Note that the Cichlid genera *Archocentrus*, *Herichthys*, and *Nandopsis* were until recently all considered part of *Cichlasoma*. For Origin, N = Native and E = Exotic. Native status is based only on the distribution of species within our study area, which encompasses all of the Pacific slope and the upper portion of the Río Pánuco basin on the Atlantic slope in central México (see text). *Poecilia butleri* is an exotic species in the upper Río Ameca and Río Coahuayana basins but a native species elsewhere. *Poecilia mexicana* is an exotic species in the Río Lerma basin but a native species in the Río Pánuco basin. For Position, B = Benthic, EB = Exotic Benthic, and W = Water column. For Tolerance, S = Sensitive, ES = Exotic sensitive, M = Moderate, and T = Tolerant. For Feeding, FL = Filter, C = Carnivore, H = Herbivore, and O = Omnivore. For Reproduction, E = Egg layer, L = Live-bearer, EL = Exotic live-bearer

Family and species	Origin	Position	Tolerance	Feeding	Reproduction
Petromyzontidae					
Lampetra geminis	N	B	S	FL	E
Lampetra spadicea	N	B	S	FL	E
Characidae					
Astyanax mexicanus	N	W	T	O	E
Astyanax cf. *aeneus*	N	W	T	O	E
Cyprinidae					
Algansea aphanea	N	W	S	O?	E
Algansea avia	N	W	M?	O?	E
Algansea barbata	N	W	S	O?	E
Algansea lacustris	N	W	M	C?	E
Algansea monticola	N	W	M?	O?	E
Algansea popoche	N	W	S	O?	E
Algansea tincella	N	W	M	O	E
Aztecula sallei	N	W	S	O?	E
Carassius auratus	E	EB	T	O	E
Ctenopharyngodon idella	E	W	M	H	E
Cyprinus carpio	E	EB	T	O	E
Dionda catostomops	N	W	S?	O	E
Dionda dichroma	N	W	S?	O	E
Dionda ipni	N	W	S?	O	E
Dionda mandibularis	N	W	S?	O	E
Dionda rasconis	N	W	S?	O	E
Evarra bustamantei	N	W	S	C?	E
Evarra eigenmanni	N	W	S	C?	E
Evarra tlahuacensis	N	W	S	C?	E
Hybopsis amecae	N	W	S	C	E
Hybopsis boucardi	N	B	S	C?	E
Hybopsis calientis	N	W	S	C	E
Hybopsis cf. *calientis*	N	W	S?	C?	E
Yuriria alta	N	W	T	O	E
Yuriria chapalae	N	W	S?	C	E
Catostomidae					
Ictiobus bubalus	N	B	M	C	E
Ictiobus labiosus	N	B	S	C	E
Scartomyzon austrinus	N	B	S	C	E
Scartomyzon mascotae	N	B	S	C	E
Ictaluridae					
Ictalurus balsanus	N	B	M?	C	E
Ictalurus dugesi	N	B	M	C	E
Ictalurus mexicanus	N	B	M	C	E
Ictalurus punctatus	N	EB	M	C	E

Appendix 1. Continued

Family and species	Origin	Position	Tolerance	Feeding	Reproduction
Salmonidae					
Oncorhynchus mykiss	E	W	ES	C	E
Atherinidae					
Atherinella balsana	N	W	M?	C	E
Chirostoma aculeatum	N	W	M?	C	E
Chirostoma arge	N	W	M	C	E
Chirostoma attenuatum	N	W	M?	C	E
Chirostoma bartoni	N	W	S?	C	E
Chirostoma chapalae	N	W	T?	C	E
Chirostoma charari	N	W	S	C	E
Chirostoma compressum	N	W	S	C	E
Chirostoma consocium	N	W	T	C	E
Chirostoma estor	N	W	M?	C	E
Chirostoma grandocule	N	W	M?	C	E
Chirostoma humboldtianum	N	W	S?	C	E
Chirostoma jordani	N	W	T	C	E
Chirostoma labarcae	N	W	M?	C	E
Chirostoma lucius	N	W	S?	C	E
Chirostoma melanoccus	N	W	S?	C	E
Chirostoma patzcuaro	N	W	M?	C	E
Chirostoma promelas	N	W	S?	C	E
Chirostoma riojai	N	W	S	C	E
Chirostoma sphyraena	N	W	S?	C	E
Gobiesocidae					
Gobiesox fluvialitis	N	B	S	O?	E
Cyprinodontidae					
Cualac tessellatus	N	W	S	O?	E
Poeciliidae					
Gambusia panuco	N	W	M?	C?	L
Gambusia vittata	N	W	M?	C?	L
Heterandria bimaculata	E	W	T	C?	EL
Poecilia butleri	N/E	W	T	H?	L/EL
Poecilia chica	N	W	T?	H?	L
Poecilia latipunctata	E	W	T?	H?	EL
Poecilia maylandi	N	W	T?	H?	L
Poecilia mexicana	N/E	W	T?	H?	L/EL
Poecilia reticulata	E	W	T	O	EL
Poecilia sphenops	N	W	T	H?	L
Poeciliopsis balsas	N	W	T?	H?	L
Poeciliopsis baenschi	N	W	T	O	L
Poeciliopsis gracilis	E	W	T	O	EL
Poeciliopsis infans	N	W	T	O?	L
Poeciliopsis scarlli	N	W	T?	O?	L
Poeciliopsis turneri	N	W	T?	H?	L
Xiphophorus birchmanni	N	W	S	O?	L
Xiphophorus continens	N	W	S	O?	L
Xiphophorus cortezi	N	W	S	O?	L
Xiphophorus helleri	E	W	T?	O?	EL
Xiphophorus malinche	N	W	S	O?	L
Xiphophorus montezumae	N	W	S	O?	L
Xiphophorus multilineatus	N	W	S	O?	L
Xiphophorus nezahualcoyotl	N	W	S	O?	L
Xiphophorus nigrensis	N	W	S	O?	L
Xiphophorus pygmaeus	N	W	S	O?	L
Xiphophorus variatus	E	W	T	O	EL
Goodeidae					
Allodontichthys hubbsi	N	B	S	C	L
Allodontichthys polylepis	N	B	S	C	L
Allodontichthys tamazulae	N	B	S	C	L

Appendix 1. Continued

Family and species	Origin	Position	Tolerance	Feeding	Reproduction
Allodontichthys zonistius	N	B	S	C	L
Alloophorus robustus	N	W	M	C	L
Allotoca catarinae	N	B	S?	C	L
Allotoca diazi	N	W	M	C	L
Allotoca dugesi	N	W	S	C	L
Allotoca goslinei	N	W	S	C?	L
Allotoca maculata	N	W	M?	C?	L
Allotoca meeki	N	W	M?	C?	L
Allotoca regalis	N	W	S?	C?	L
Ameca splendens	N	W	S	O?	L
Ataeniobus toweri	N	W	S?	O?	L
Chapalichthys encaustus	N	W	T?	O?	L
Chapalichthys paradalis	N	W	M?	O?	L
Girardinichthys multiradiatus	N	W	S	C	L
Girardinichthys viviparus	N	W	S	C	L
Goodea atripinnis	N	W	T	O	L
Hubbsina turneri	N	W	S	C	L
Ilyodon furcidens	N	W	T	O	L
Ilyodon whitei	N	W	T	O	L
Skiffia bilineata	N	W	S	O?	L
Skiffia francesae	N	W	S	O	L
Skiffia lermae	N	W	S	O?	L
Skiffia multipunctata	N	W	S	O	L
Xenotaenia resolanae	N	W	S	O	L
Xenotoca eiseni	N	W	M	O?	L
Xenotoca melanosoma	N	W	S	O?	L
Xenotoca variata	N	W	T	O?	L
Zoogonecticus quitzeoensis	N	W	M	O	L
Zoogonecticus tequila	N	W	S	O	L
Mugilidae					
Agonostomus monticola	N	W	S	O	E
Centrarchidae					
Lepomis cyanellus	E	W	T	C	E
Lepomis macrochirus	E	W	M	C	E
Micropterus salmoides	E	W	M	C	E
Cichlidae					
Archocentrus nigrofasciatum	E	W	M	C	E
Herichthys cyanoguttata	E	W	M	C	E
Herichthys cf. *cyanoguttata*	N	W	M	C	E
Herichthys tamasopoensis	N	W	M	C	E
Nandopsis bartoni	N	W	M	C	E
Nandopsis beani	N	W	M	C	E
Nandopsis istlanum	N	W	M	C	E
Nandopsis labridens	N	W	M	C	E
Nandopsis steindarchneri	N	W	S?	C	E
Oreochromis aureus	E	W	T	O	E
Oreochromis niloticus	E	W	T	O	E
Oreochromis mossambicus	E	W	T	O	E
Tilapia rendalli	E	W	M	O	E
Tilapia zilli	E	W	M	O	E
Eleotridae					
Dormitator latifrons	N	W	T?	C	E
Eleotris picta	N	B	M?	C	E
Gobiomorus maculatus	N	B	M?	C	E
Gobiomorus polylepis	N	B	S?	C	E
Gobiidae					
Awaous banana	N	B	S	C	E
Sicydium multipunctatum	N	B	S	H	E

Appendix 2. Index of biotic integrity (IBI) and environmental quality (EQ) scores for sites located in different rivers in Central Mexico. Sites located in basins used in the design of the IBI for west central Mexico (Lyons et al., 1995) are indicated in italics. A = Arroyo; Santiago = Río Grande de Santiago; Morelia = Río Grande de Morelia; PánucoM = Pánuco Moctezuma; PánucoT = Pánuco Tampaón; AmecaU = Upper Ameca basin; AmecaL = Lower Ameca basin

Site	Basin	EQ scores	IBI score
1. Río Juchipila 1	Santiago	50	55
2. Río Juchipila 2	Santiago	70	60
3. Río Potrero Grande	AmecaU	80	80
4. Rancho Paraíso	AmecaU	40	25
5. Río de la Pola 1	AmecaU	70	70
6. Río de la Pola 2	AmecaU	80	75
7. Río Diábolos	AmecaU	80	65
8. Canal Teuchitlán	AmecaU	40	30
9. Río Salado	AmecaU	80	65
10. Río Atenguillo	AmecaU	80	70
11. Río Mascota	AmecaL	90	80
12. Arroyo Carboneras	AmecaL	70	80
13. *Río Tecolote*	Purificación	50	70
14. *Río Cuzalapa*	Marabasco	70	80
15. *A. Ahuacapán*	Armería	80	75
16. *Río Ayuquila 1*	Armería	30	30
17. *Río Ayuquila 2*	Armería	60	55
18. *Río Ayuquila 3*	Armería	60	65
19. *Río Ayuquila 4*	Armería	70	80
20. *Río Ayuquila 5*	Armería	70	70
21. *Río Ayuquila 6*	Armería	90	95
22. A. San Jose del Tule	Coahuayana	80	70
23. Río Terrero	Coahuayana	70	80
24. A. Puente San Pedro	Coahuayana	80	70
25. Río Tuxpán 1	Coahuayana	50	45
26. Río Tuxpán 2	Coahuayana	20	40
27. A. San Jerónimo 1	Coahuayana	60	55
28. A. San Jerónimo 2	Coahuayana	70	55

Appendix 2. Continued.

Site	Basin	EQ scores	IBI score
29. A. Contla	Coahuayana	70	80
30. Río Cupatitzio	Balsas	70	80
31. Río Amacuzac 1	Balsas	90	65
32. Río Amacuzac 2	Balsas	70	50
33. Río El Oro	Balsas	90	60
34. Río Maravillas	Balsas	90	80
35. Grande de Tepalcatepec	Balsas	50	60
36. Río Laja	Lerma	50	50
37. Comonfort	Lerma	70	60
38. La Quemada	Lerma	80	35
39. A. Irapeo	Morelia	80	70
40. A. Insurgentes	Morelia	80	70
41. Canal de Puente Blanco	Morelia	50	50
42. A. La Mintzita	Morelia	60	65
43. Río Estorax	PánucoM	70	35
44. A. Presa El Carmen	PanucoM	70	45
45. A. Presa Los Pirules	PánucoM	80	75
46. El Oasis	PánucoM	70	35
47. Río Chubeje	PánucoT	80	50
48. Río Jalpan 1	PánucoT	80	50
49. Río Jalpan 2	PánucoT	70	60
50. Río Santamaría	PánucoT	80	50
51. Río Calabazas 1	PánucoT	70	75
52. Río Calabazas 2	PánucoT	80	85
53. Río Los Otates	PánucoT	80	70
54. Río Gallinas	PánucoT	70	60
55. La Planta	PánucoT	80	75
56. Pirihuán	PánucoT	80	55
57. Canoas	PánucoT	70	70
58. Río Las Zuñigas	PánucoM	80	40
59. Ayutla 1	PánucoT	70	45
60. Ayutla 2	PánucoT	70	40
61. Conca	PánucoT	90	50
62. Santa Catarina	PánucoT	80	60
63. Anteojitos	PánucoT	90	70