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# Synthesizing reference conditions for highly degraded areas through best professional judgment

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ABSTRACT

Reference sites, comparable in physical and chemical characteristics to test sites with the exception of the effect of interest, provide a set of species to contrast against test site data and assign a condition to test sites in the Reference Condition Approach. However, what if disturbance is ubiquitous and comparable reference sites are absent? Here, we use the Detroit River as a case study where development and industrialization has rendered reference sites absent. In this paper, a novel application of best professional judgment was developed to generate a set of species characteristic of reference conditions. The synthesized assemblage functions as substitute to a sampled reference site and can be applied analogously towards determining condition and assessing recovery. Members of the Huron–Erie Corridor Steering Committee, comprised of agency partners that manage the corridor, were surveyed to produce a hypothetical data matrix of the fishes present in the river in the absence of anthropogenic disturbance. The synthesized assemblages were assessed using an Index of Biotic Integrity and subsequently integrated into a Principal Coordinates Analysis with test site fish assemblage data. Recovery and response to remediation was determined by the position of the test sites within confidence ellipses. The results indicated signs of recovery in upstream sites of the Detroit River, but no recovery at downstream sites. The application of the best professional judgment approach towards reference conditions provides a novel and versatile method to interpret species assemblage change and allows practitioners the ability to select specific assemblages coincident with restoration objectives.



## Introduction

The Reference Condition Approach (RCA) uses the species assemblage at a set of sites minimally exposed to human disturbance to assess the condition of a test site probabilistically matched by habitat characteristics to test sites (Reynoldson et al., 1997; Bailey et al., 2004). The variation between abiotically equivalent reference sites is used to generate confidence ellipses, which can be used to determine the condition of a site. Inclusion of the test site within the confidence ellipse indicates that the site is characteristic of abiotic conditions that support the reference assemblage and is in good condition. Exclusion indicates dissimilarity between the test and reference sites. However, the application of the RCA is predicated on the availability of minimally disturbed reference sites. Highly degraded sites can lack regional reference sites to generate comparative species assemblages. In the absence of regional reference sites, species assemblages can be synthesized through several methods. Palaeoecological data or historical data can be used to reconstruct biological communities at the test site(s) (Hughes, 1995; McAllister, 2008). Assemblages can be also produced through quantitative methods that regress index values against disturbance or integrate habitat information (HSM), from experimental laboratory data or through the environmental filter method that produces a set of species based on abiotic tolerances (Reynoldson et al., 1997; Minns et al. 2001; Chessman, 2006). In this paper, we focus on highly degraded areas where reference assemblages cannot be generated through regional reference sites or empirical methods, requiring the synthesis of reference assemblages through novel methods. Here, we use the Detroit River as a case study for this scenario.

Disturbance is ubiquitous in the Detroit River. Development and industrialization of the river, which forms a boundary between Canada and the United States, has altered and disrupted the functioning of the aquatic connecting channel ecosystem. Much of the shores of the Detroit River are lined with industries. The transformation of the River into shipping channels led to the alteration of the shoreline and riverbed for navigation while population growth necessitated the construction of combined sewer outflows that terminate in the River (Hartig et al.,

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2009). The degradation resulted in the designation of the Detroit River as an Area of Concern (AOC) in 1987 and the implementation of several restoration projects including restoring eroded riparian corridors, dredging and removal of contaminated sediments, increasing fish habitat supply and quality, and the designation of the Detroit River International Wildlife Refuge (Esman, 2008; Green et al., 2010). Restoration projects are monitored through responses in the fish assemblage of the Detroit River, however, the confluence of industrialization and development has rendered the River devoid of unimpacted reference sites from which to generate a reference assemblage for comparison (Green et al., 2010; Zhang, 2008). The absence of regional reference sites and historical data, or applicability of empirical methods prevents the identification of species assemblages representative of reference conditions and, consequently, the interpretation of the response of the species assemblage to restoration activities.

Here, we present a novel application of best professional judgment (BPJ) to synthesize a set of species that are characteristic of reference condition sites for highly degraded sites. The method proposed here can be used to generate a species assemblage for a given condition when no other methods are appropriate. In this paper, we synthesize an assemblage for the Detroit River. Best professional judgment applies the expertise of individuals to decision making. It is a recognized method to calibrate the thresholds set for IBI metrics, to select reference sites, determine the abiotic parameters of the reference condition, or assign condition to a site based on its constituent species (Hughes, 1995; Scardi et al., 2008; Weisberg et al., 2008). However, BPJ has not been used to estimate the historical species composition of sites in reference condition (Borja et al., 2004). A survey was distributed to members of the Huron–Erie Corridor (HEC) Steering Committee to generate a set of species that could be integrated with field data in a multivariate analysis to assess changes in the fish assemblages in the Detroit River in response to restoration activities. This use of BPJ allows a formal evaluation of whether test sites over time are within the boundaries of the confidence ellipse and reflect reference conditions, are moving towards the reference target (i.e. improving), are moving away (degrading further), or are whether change over time is random — not indicating recovery.

## Methods

### *Synthesized reference assemblages*

A survey was delivered to members of the HEC Steering Committee through a one-time access link available online for a period of two months (March–May 2009). The HEC steering committee is composed of biologists and managers representing state, provincial, federal agencies, First Nations, academic institutions, stakeholders, and NGOs that co-manage the corridor. The survey contained introductory material and the questionnaire (Appendix A). The first page contained a preamble on the Detroit River and the purpose of the survey. The second page included questions on the respondent's professional affiliation, and experience in the geographical region and electrofishing methods. The third page described the Remedial Action Plan fish sampling protocol for the Detroit River. No information was given on season or specific site locations on the Detroit River. Pages 4 through 10 contained a list of the ichthyofauna of the Great Lakes basin organized taxonomically by family. The database was compiled to include all species (201 species within 35 families) detected in the Great Lakes basin identified in Coon (1999). The respondents were instructed to select species, expected to be collected by boat electrofishing, indicative of a reference condition for this region. Reference condition was defined as the absence of anthropogenic stress (i.e. undisturbed). The option to submit species not represented in the database was available on the last page.

The survey data were compiled and transformed into a site-by-respondent matrix with eight observations. The robustness of the synthesized reference assemblages was validated by calculating an Index of Biotic Integrity score for the each of the synthesized assemblages using a set of seven metrics from Hamilton's (1987) adaptation of the Karr (1981) IBI (Table 1). The IBI is designed to translate the presence of indicator species into a score indicative of the site condition. Each metric was calculated from the presence/absence data submitted by respondents. Proportion metrics were calculated from the total number of species selected by each respondent and the trophic composition designations were determined from the EPA Rapid Bioassessment Protocols (Barbour et al., 1999) and Scott and Crossman (1998). The IBI was calculated as the sum of the integer scores with a maximum score of 35. The scores were subsequently translated to a narrative rank 0–7 = very poor, 8–14 = poor, 15–21 = fair, 22–28 = very good, and 29–35 = excellent. High respondent IBI scores would indicate the selection of an assemblage consistent with a site in good condition.

### *Reference condition ordinations*

Field data were collected by boat electrofishing at six test sites (arranged upstream to downstream: C, A, Q, D, E, G) on the Detroit River (Fig. 1). The Detroit River was sampled in August 1990, August 2003, July and October 2004, May, June and September 2007, and July and October 2011. Each test site was sampled for 1000 s in either 500 m or 200 m transects. Sites after 1990 contain a nearshore (shallow water <2 m) and offshore (deep water > 2 m) transect. The BPJ data was integrated with data from each site to produce six matrices, each with the same respondent matrix. Each site assessment was made using an approach based on multivariate resemblances. Similarities using Pearson's phi resemblance measure were calculated from the matrices. The similarities were transformed to the square-root dissimilarity, $\sqrt{1-s}$, to render the distances metric (Jackson et al., 1989; Legendre and Legendre, 1998).

Two-dimensional Principal Coordinates Analysis (PCoA) ordinations were produced for each site from the dissimilarity matrices to summarize the dominant patterns of variation and facilitate visual interpretation. Ninety-nine percent and 90% two-dimensional confidence ellipses were

**Table 1**
Modified IBI from Hamilton's (1987) adaptation of the Karr (1981) IBI with seven metrics. Presence/absence data was used for the calculation of metrics. Trophic composition designations were obtained from Barbour et al. (1999) and Scott and Crossman (1998).

| Subcategory | Description | Scoring criteria | | | |
|---|---|---|---|---|---|
| | | 0 | 1 | 3 | 5 |
| Species richness and composition | Number of species in selected assemblage as a % of richness of all synthesized assemblages | 0 | 0–25% | 26–50% | >50% |
| | % Percid species in synthesized assemblage | 0 | 1 | 2 | ≥3 |
| | % Salmonid and Coregonid species in synthesized assemblage | 0 | 1 | 2 | ≥3 |
| Trophic composition | % insectivore species | 0% | 0–25% | 20–40% | >40% |
| | % omnivore or generalist species | 0% | ≤40% | 20–40% | >20% |
| | % piscivore species | 0% | <2% | 2–5% | >5% |
| Fish health | Number of species in selected assemblage as a % of richness of all synthesized assemblages | – | >5% | 1–5% | 0 |

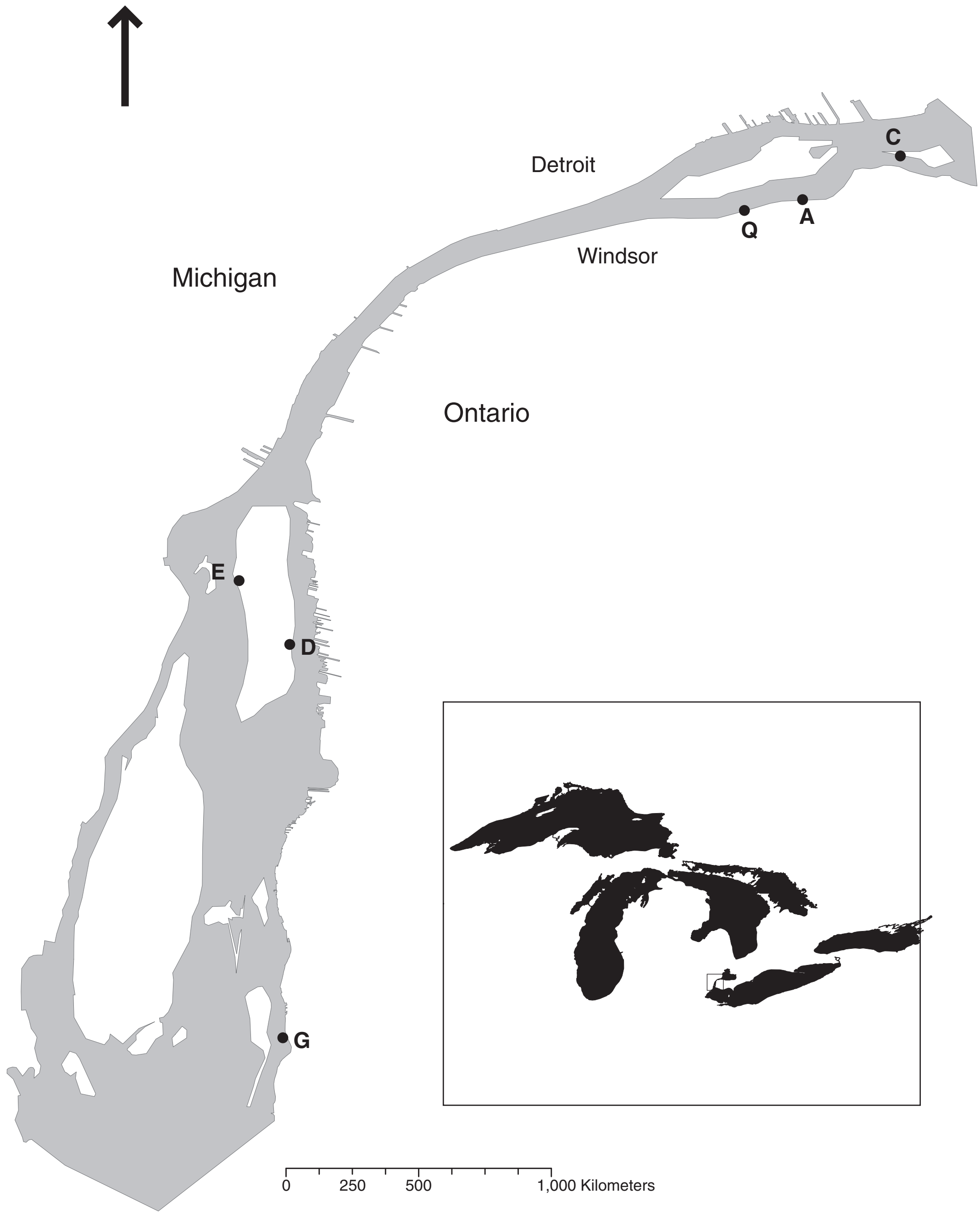


**Fig. 1.** Detroit River map with sampling sites marked. Site C is the most upstream site, while site G is the most downstream site. The inset depicts the location of the Detroit River within the Great Lakes.

superimposed on each site ordination to assess recovery in test sites after Reynoldson and Day (1998). The ellipses were divided into three bands where Band A denotes the two-dimensional area within the 90% confidence ellipse, Band B the area between the 90% and 99% confidence ellipse and Band C is the area outside the 99% confidence ellipse. Sites in Band A were considered equivalent to the reference assemblage. Sites in Band B demonstrated recovery and sites in Band C were not recovered. Thresholds were based on delineations in Reynoldson and Day (1998). We used a multivariate t-distribution to generate ellipses from the variation between BPJ synthesized reference assemblages created from each participant's response. All statistical analyses were executed using R (R Core Team, 2012).

## Results

### *Synthesized reference assemblages*

Eight participants completed the survey in its entirety generating a response rate of 23%. Seven respondents identified themselves as government biologists and one respondent was a doctoral student. Three respondents had over 20 years experience in the Huron–Erie corridor, the remainder had 1–10 years experience in the area. Respondents indicated that they were familiar with electrofishing. Most respondents had greater than 5 years experience with electrofishing methods, whereas, three respondents had 1–5 years experience with the method.

**Table 2**
IBI scores and translated narrative rank for each of the eight synthesized reference assemblages calculated from a modified Hamilton (1987) IBI (See Table 1).

| Respondent | IBI score | Narrative rank |
|---|---|---|
| 1 | 22 | Fair |
| 2 | 35 | Excellent |
| 3 | 24 | Good |
| 4 | 31 | Excellent |
| 5 | 31 | Excellent |
| 6 | 31 | Excellent |
| 7 | 18 | Fair |
| 8 | 28 | Excellent |

The IBI scores for the eight synthesized assemblages indicated the respondents selected assemblages consistent with sites in fair to excellent condition with an average score of 27.5 (Table 2). Five respondents produced assemblages that received an IBI score greater than 29, which translates to a narrative rank of "excellent."

Respondents selected 153 unique species with an average of 57 species for the reference condition. The respondents selected 101 species that were not detected in the sampling of the Detroit River, however, only 49 species were selected by more than one respondent. Included were several species in the families Catostomidae, Centarchidae, Clupeidae, Cyprinidae, Ictaluridae, Burbot and Umbridae. Lake sturgeon, lake trout, spotted gar, and northern brook lamprey were notably absent from the Detroit River, but included in the reference assemblage.

*Reference condition ordinations*

The reference condition sites and associated confidence ellipses indicate large differences between test sites and reference condition sites. Sites A, Q, and G did not have test sites that fell within the 99% confidence ellipse (Fig. 2, Table 3). However, sites C, D and E showed signs of recovery. Site E produced a test site community within Band B (between the 90% and 99% confidence ellipses) and site D fell in Band B in the summer sampling periods of 1990, 2003, and 2004. The greatest recovery was detected in site C, which indicated similar compositions between the synthesized reference assemblages. Summer test sites from 2003 to 2011 and the fall test site in 2011 fell within Band B. The 2007 fall site C showed the greatest similarity to the reference condition given that it was the only site within Band A (within the 90% confidence ellipse) (Table 3).

## Discussion

Through a combination of multivariate methods and a novel application of BPJ, we generated a method to synthesize reference sites for highly degraded sites that lack a method to interpret the condition of test sites. The inclusion of a reference assemblage facilitated the interpretation of recovery. Reference sites in the RCA are analogous to controls in experiments, which contextualize the results of an experiment. Here, the reference condition provides directionality to multivariate ordinations given similarity is expressed as distances. Test sites close to the reference site have similar species composition and indicate progression towards recovery targets, whereas, test sites further from reference sites have dissimilar species composition and restoration projects are not inducing changes in species composition. Distinct from trend analysis, the inclusion of the reference sites allowed us to assess changes over time. The addition of confidence ellipses generated from the variation in reference sites to the ordinations translates the observed distances in ordination space into condition. Sites within the most conservative confidence ellipse can be designated as restored while sites that plot within increasingly larger ellipses or distances and can be characterized as approaching recovery or not recovered. In the absence of reference sites, change in composition across time is indiscriminant. The synthesis of reference sites through BPJ allows the application of the RCA to highly degraded sites including the Detroit River. The synthesized reference sites revealed recovery at sites and seasonal patterns.

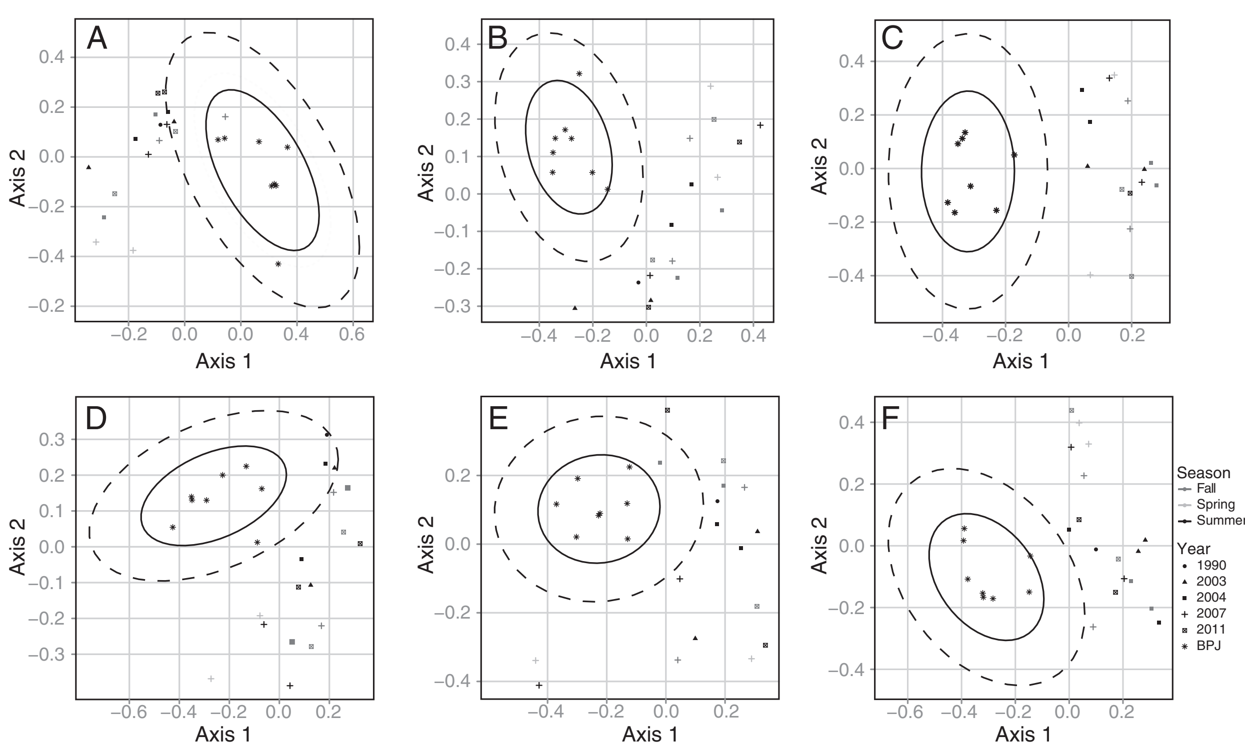


**Fig. 2.** PCoA results with confidence ellipses for each site sampled on the Detroit River plotted with test site data separated by season and year. The sites are ordered going from the most upstream to downstream site where A. Site C B. Site A C. Site Q D. Site D E. Site E F. Site G. The dashed line ellipse denotes a 99% confidence and the solid line indicates a 90% confidence ellipse.

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*Detroit site results*

The multivariate ordination and superimposed confidence ellipses indicated that site C is responding to restoration projects. Site C is the most upstream site sampled, is located away from the highly industrialized and urbanized portion of the river, and the site of restoration activities on Peche Island (Green et al., 2010). Site C also falls in an area of the river upstream from "impaired zones" (MacLennan, 1992), which likely contributed to its recovery rate. Sites A and Q fell consistently in Band C despite their location upstream and several restoration projects on Belle Isle (Esman, 2008). Farther downstream, sites D and E demonstrated weak signs of recovery. Sites D and E are located in areas of "moderate" impairment and, consequently, this area of the river is the target of several restoration activities along Fighting Island and wetlands along the eastern shore of the Detroit River (Green et al., 2010; MacLennan, 1992). Site D fell within Band B in the summer of 1990, 2003 and 2004, but fell outside Band B during the two subsequent sampling periods. This classification could be due to random natural variation, seasonality or indicative of declining condition. Site E fell within Band B for one sampling period in the fall, but did not appear in Band B or A for any other sampling period. The observed changes away from the reference condition in sites D and E could be due to emigration by target species, variation, or degradation. This result may indicate an initial response to the restoration projects but subsequent emigration to less impaired areas of the river. Site G did not show signs of recovery given that no sites fall within Bands A or B. The result is consistent with downstream impact where impairment is expected to be concentrated (MacLennan, 1992). The analysis suggests that more resources are necessary for restoration at sites at middle reach and downstream sites and additional monitoring is necessary to distinguish between random variation and progressive change.

*Seasonal patterns*

Among the three seasons sampled, a higher proportion of summer assemblages fell in Band B. However, only one site in the fall fell in Band A (Table 3). These patterns demonstrate sampling season can have an effect on assessment. Migration and spawning periods (fall and summer, respectively) can contribute to higher diversity and greater similarity to reference conditions. Future BPJ surveys can be designed to eliminate this effect by limiting the sampling season or sampling during periods of highest diversity.

**Table 3**
Classification of Detroit River sites over five sampling periods based on confidence ellipses. Band A indicates that the site fell inside the 90% ellipse. Band B denotes that the site fell between the 90% and 99% confidence ellipses. Band C denotes that the site fell outside the 99% confidence ellipse. Sites aranged upstream to downstream. Bold sites indicate recovery. Dashes denote no sampling was performed for that period/site.

| Season | Site | 1990 | 2003 | 2004 | 2007 | 2011 |
|---|---|---|---|---|---|---|
| Spring | Site C | – | – | – | Band C | – |
| | Site A | – | – | – | Band C | – |
| | Site Q | – | – | – | Band C | – |
| | Site D | – | – | – | Band C | – |
| | Site E | – | – | – | Band C | – |
| | Site G | – | – | – | Band C | – |
| | Site C | Band C | **Band B** | **Band B/C** | **Band B** | **Band B** |
| Summer | Site A | Band C | Band C | Band C | Band C | Band C |
| | Site Q | Band C | Band C | Band C | Band C | Band C |
| | Site D | **Band B** | **Band B** | **Band B** | Band C | Band C |
| | Site E | Band C | Band C | Band C | Band C | Band C |
| | Site G | Band C | Band C | Band C | Band C | Band C |
| | Site C | – | – | Band C | **Band A** | **Band B** |
| Fall | Site A | – | – | Band C | Band C | Band C |
| | Site Q | – | – | Band C | Band C | Band C |
| | Site D | – | – | Band C | Band C | Band C |
| | Site E | – | – | **Band B** | Band C | Band C |
| | Site G | – | – | Band C | Band C | Band C |

*The versatility of the BPJ survey method*

Here, we provide a versatile method to synthesize species assemblages characteristic of reference conditions. The BPJ survey method allows users to define the species matrix, thus affording the user the ability to select specific species or assemblages. This dynamic method also allows the definition of reference condition to be specified. The user can implement a historical reference condition where historical sampling does not exist or a best attainable condition in areas where the severity of degraded conditions prohibits a return to an undisturbed state. Gear biases can also be integrated in the selection of a reference assemblage with this method. In the Detroit River, where long-term monitoring is carried out through electrofishing, the survey specified that the species selected should be susceptible to capture by electrofishing. We attempted to quantify electrofishing expertise among the respondents by including questions on their experience with the gear in the survey. Given our respondent sample size, we retained all of the responses including those with less than 5 years experience, however, future BPJ surveys could filter out respondents with less than the necessary amount of experience. Finally, this method can also be applied to the Remedial Action Plan process to set delisting targets previously defined by IBI scores (Green et al., 2010). The BPJ method provides a format to estimate the reference condition through cost-effective methods for areas where the expertise in the fauna of the region is available, but where other methods of estimating a reference condition assemblage are not feasible.

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## Appendix A. Supplementary data

Supplementary data to this article can be found online at http://dx.doi.org/10.1016/j.jglr.2013.12.002.

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