DOI: 10.1007/s00267-002-2702-y

# Development of a Bird Integrity Index: Using Bird Assemblages as Indicators of Riparian Condition

**SANDRA A. BRYCE***
**ROBERT M. HUGHES**
Dynamac Corporation
200 SW 35th St.
Corvallis, Oregon 97333, USA

**PHILIP R. KAUFMANN**
U.S. Environmental Protection Agency
200 SW 35th St.
Corvallis, Oregon 97333, USA

ABSTRACT / We describe the development of a bird integrity index (BII) that uses bird assemblage information to assess human impacts on 13 stream reaches in the Willamette Valley, Oregon, USA. We used bird survey data to test 62 candidate metrics representing aspects of bird taxonomic richness, tolerance or intolerance to human disturbance, dietary preferences, foraging techniques, and nesting strategies that were affected positively or negatively by human activities. We evaluated the metric responsiveness by plotting each one against a measure of site disturbance that included aspects of land use/land cover, road density, riparian cover, and stream channel and substrate conditions. In addition, we eliminated imprecise and highly correlated (redundant) metrics, leaving 13 metrics for the final index. Individual metric scores ranged continuously from 0 to 10, and index scores were weighted to range from 0 to 100. Scores were calibrated using historical species information to set expectations for the number of species expected under minimally disturbed conditions. Site scores varied from 82 for the least disturbed stream reach to 8.5 for an urban site. We compared the bird integrity index site scores with the performance of other measures of biotic response developed during this study: a fish index of biointegrity (IBI) and two benthic macroinvertebrate metrics. The three assemblages agreed on the general level of disturbance; however, individual sites scored differently depending on specific indicator response to in-stream or riparian conditions. The bird integrity index appears to be a useful management and monitoring tool for assessing riparian integrity and communicating the results to the public. Used together with aquatic indicator response and watershed data, bird assemblage information contributes to a more complete picture of stream condition.

Since passage of the Clean Water Act in 1972, with its objective of restoring and maintaining physical, chemical, and biological integrity in surface waters, there has been considerable interest in defining and assessing biointegrity (Davis and Simon 1995, Karr and Chu 1999). Presumably, aquatic ecosystems with biological integrity support biota that are the products of evolutionary and biogeographic processes with little influence from humans (Karr 2000). Indices of biointegriy have been developed for various aquatic assemblages, particularly fish (Karr and others 1986, Simon 1999), benthic macroinvertebrates (Kerans and Karr 1994, Fore and others 1996), and algae (Bahls 1993, Hill and others 2000). These indices are aggregate scores for a waterbody derived from a series of individually scored measures (metrics) developed from multiple species' proportionate abundance data. The US Environmental Protection Agency and many state environmental protection agencies use multimetric indices for bioassessments (Barbour and others 1999, Southerland and Stribling 1995). Indices of biointegrity also facilitate management planning, restoration activities, and communication with the public.

Management decisions are based on large bodies of diverse physical and biological data. Indices of biotic integrity attempt to convert or synthesize key aspects of biological assemblage data into quantitative statements of ecological condition. The primary indicators chosen for stream bioassessments are typically aquatic assemblages, usually fish or benthic macroinvertebrates. While water column and substrate conditions directly influence these indicator taxa, the effects of the terrestrial sources of many of these disturbances are inferred only indirectly from their responses. However, streams are physically linked via the riparian zone to their watersheds, and riparian areas are considered critical components of stream ecosystems (Ward 1989, Gregory and others 1991). In the watershed, the climate, geology, and soil of an area determine the substrate, seasonal discharge, channel morphology, and chemical properties of the waterbody. In riparian zones, vegeta-

KEY WORDS: Aquatic monitoring; Riparian ecosystem condition; Stream assessment; Index of biotic integrity; Bioassessment; Riparian birds; Disturbance

---

*Author to whom correspondence should be addressed; *email:* bryce.sandy@epa.gov

Environmental Management Vol. 30, No. 2, pp. 294–310

tion type and extent also contribute to instream physical habitat and influence water quantity and quality. Disturbances that disrupt the hydrology, geomorphology, or vegetation often diminish riparian structure and function, and the changes are reflected in both aquatic and riparian fauna. Riparian indicators may be an important addition to stream ecosystem assessments because they respond more directly to the terrestrial disturbances that precede changes in the aquatic environment. Brooks and others (1991) found that the differences between a minimally disturbed, forested watershed and an agricultural watershed in Pennsylvania were more clearly revealed by riparian indicators than by aquatic indicators.

In this study we test the utility of using bird assemblages as indicators of stream riparian condition. Riparian bird assemblages are the focus of high public concern; they are also sensitive to land-use changes and subsequent habitat alteration. For example, we have long known that some forest bird species, particularly area-dependent taxa, decline as woodland is fragmented (Forman and others 1976, Ambuel and Temple 1983, Freemark and Merriam 1986). When evaluating birds as indicators of condition and developing indices of biointegrity, we use such ecological information to relate patterns of bird species, guilds, or assemblages to the availability of habitat, degree of fragmentation, and amount of human disturbance in a region. We may be able to discern patterns or thresholds in habitat characteristics that allow some birds to persist while others disappear along a gradient of disturbance.

Quantifying bird response to disturbance may be achieved by classifying bird species abundance data into guilds, or groups of species that display similar behavioral traits. In early guild work, birds were listed in functional groups, such as foraging or nesting types (Root 1967, Severinghaus 1981, Verner 1984). However, strictly functional classifications frequently did not produce a clear signal of bird assemblage response to management; birds of the same foraging guild, for example, ranged across various habitat condition types. To address this problem, researchers transformed some functional guilds into response guilds by grouping species according to their tolerance to human activities (Best and others 1978, Szaro 1986, Croonquist and Brooks 1991). Croonquist and Brooks (1991) found, in a comparison of agricultural and minimally disturbed forested watersheds, that wetland-dependent species richness remained relatively constant as species with specific habitat requirements declined in disturbed watersheds. Metrics have been developed from bird guilds for lake riparian zones in the northeastern United States, where bird response provided an accurate reflection of shoreline and catchment impacts (Moors 1993, O'Connor and others 2000). For terrestrial habitats, O'Connell and others (1998) used bird response guild metrics to develop a regional view of condition in the Appalachian Mountains of the eastern United States. Cully and Winter (2000) refined a land condition monitoring method on military training lands in Kansas using grassland-dependent and woodland-dependent bird species richness, and Bradford and others (1998) tested metrics to indicate rangeland condition in the Great Basin.

For all these indicator taxa, early integrity indices and guild metrics were developed using measures chosen for their theoretical or conceptual value. However, while many traditional metrics are applicable in theory, they actually may be imprecise, redundant, unresponsive to disturbance, or exhibit a low signal-to-noise ratio. Hughes and others (1998) argued that candidate metrics should be evaluated for those characteristics before inclusion in a multimetric index. Our objectives in this paper were to systematically evaluate a large set of avian metrics for their indicator value and combine those selected into an index of avian integrity that could be used to evaluate the condition of individual stream reaches.

## Methods

### Study Area

In 1992 the Environmental Protection Agency's Environmental Monitoring and Assessment Program (EMAP) funded Oregon State University to undertake a four-year field survey of wadable streams in the Willamette River valley in western Oregon. The objective was to develop biological indicators and field methods for stream sampling in the western states. Fish, macroinvertebrates, and physical habitat were sampled throughout the study. In 1993 a bird survey was added to test the utility of bird assemblages as indicators of riparian condition. Most of the sample stream reaches were selected randomly to ensure that they were representative of first to third order wadable streams found as blue lines on 1:100,000-scale US Geological Survey topographic maps (Herlihy and others 1997). In addition, five sites were hand-selected to increase the range of disturbance types and intensities in developed areas. Streams were between 44° and 45° north latitude, and watershed sizes ranged from 0.3 to 75 km$^2$. Avian abundances were recorded at 13 sites (Figure 1; Table 1). Four sites were visited again the following field season to test for interannual variability.

The Willamette Valley includes the floodplain and

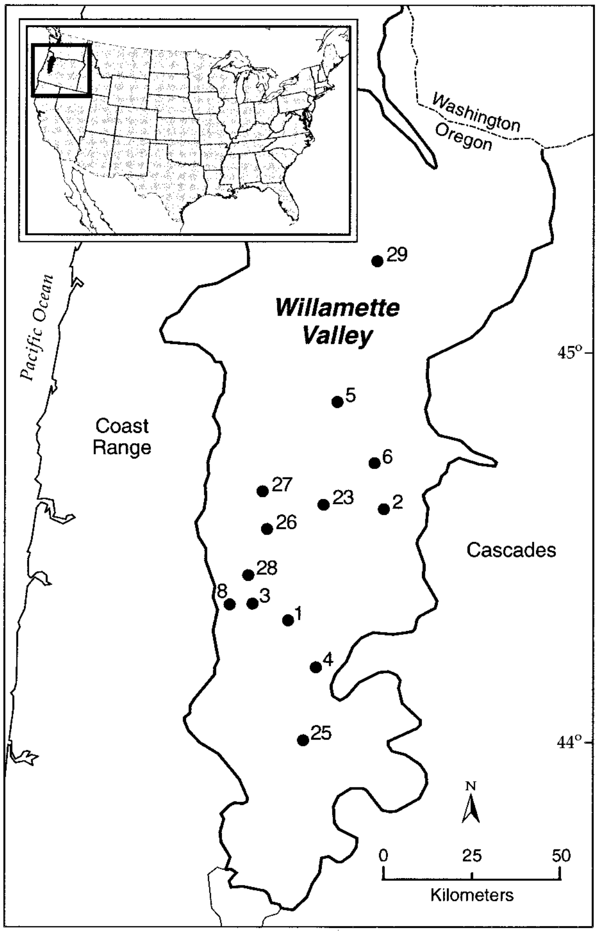

**Figure 1.** Location of bird survey sample reaches in the Willamette Valley, Oregon.

terraces of the Willamette River, as well as the surrounding foothills, partially forested with Oregon white oak (*Quercus garryana* Dougl.), bigleaf maple (*Acer macrophyllum* Pursh.), and Douglas fir [*Pseudotsuga menziesii* (Mirb.) Franco]. Elevations in the study area range from 50 m to 129 m, and average annual precipitation is 102 cm, falling mainly as winter rain. The valley land use is predominantly agricultural and urban. Hedgerows, fallow fields, and riparian woodland have been steadily depleted over the last 50 years to accommodate large industrial farm fields. Presently, riparian vegetation along valley streams is either absent or limited to narrow bands of Oregon ash (*Fraxinus latifolia* Benth.), black cottonwood (*Populus trichocarpa* Torr. and Gray), red alder (*Alnus rubra* Bong.), and Oregon white oak. The low-gradient, meandering streams are often channelized to maximize arable acreage. Summer drought and attendant irrigation withdrawals cause many streams to dry or become intermittent (Omernik and Gallant 1986).

### Field Methods

The bird sampling period extended from the last week in May through the first week of July. The sampling window matched the time of peak birdsong in western Oregon because typically in such surveys nearly all detections are auditory. The time frame also minimized the detection of transient migratory birds. The bird counts were conducted by a field observer trained to recognize regional bird songs. The observer's accuracy in bird identification exceeded a 90% standard when tested against a region-specific bird song audio tape. The surveys occurred from sunrise to 4 hours after sunrise following the guidelines of the US Fish and Wildlife Service Breeding Bird Survey (USFWS 1990).

At the stream reach, the observer followed a 1-km transect parallel to the stream bank, 0–25 m from the shore, the distance depending upon ease of travel as well as the amount of water-noise interference. Typically, the transect was centered on the randomly selected point (X site) that identified each stream reach; occasionally transects were shifted above or below the X site for access reasons or if there was insufficient stream length. In every case however, the bird transect subsumed the shorter sample lengths for fish and benthic macroinvertebrates. Bird counts were made using the point count method: the observer stopped every 100 m for 8 min of observation, and recorded all birds heard and seen. Initially, we expected to limit the detections to those within the radius of the 50-m point count circle. However, early in the survey, we determined that the actual detection radius often matched the distance of sound attenuation of bird calls. Although the sound of vigorous songs carried farther than 50 m, competing noises, such as wind, traffic, and stream rapids, tended to reduce the detection distance. Thus, we decided to record every bird heard at a sampling point to maximize the number of observations in the database, while taking care to avoid double recording any louder calls heard from one stop to the next. The object of the data collection was to characterize bird species composition and proportionate abundances for a particular stream reach rather than to determine avian population densities.

### Defining a Disturbance Gradient

Measures of landscape and habitat structure have been used to predict the presence of particular species; however, in bioassessment and monitoring we are concerned with the fauna that are actually using a particular habitat and how they are influenced by habitat

Table 1. Stream reach descriptions and Bird Integrity Index (BII) scores

| Site name | Description | Disturbance index score | BII score |
|---|---|---|---|
| ORV06 | Small watershed ½ cleared, but entire stream channel in extensive riparian woodland (width 1 km). Low grazing pressure. Large old trees, cold clear water. | 2 | 82 |
| ORV08 | Watershed located in valley foothills; 75% forested, of that 25% recently logged. Residences and farm fields in stream valley. Half of length of stream has minimal riparian buffer. Sampled reach has wooded riparian zone. | 3 | 80.1 |
| ORV03 | Upper watershed half forested, but heavily cut. Wide riparian buffer on lower half of stream. Wetlands present adjacent to stream reach. | 3 | 71.5 |
| ORV27 | Watershed 75% forested, 80% of that logged recently. Farm clearings and rural residential in flood plain. Most of stream length has narrow riparian buffer. | 3 | 67.2 |
| ORV02 | Watershed 2/3 agriculture, 1/3 forest. Forested portion 15% recently logged. Valley portion 1/3 channelized. Riparian buffers generally absent. Cattle in stream. | 4 | 55 |
| ORV29 | Entire watershed cleared. Small town in upper watershed. Headwaters have minimal riparian buffer. Lower 2/3 has wider wooded riparian zone. | 4 | 53.8 |
| ORV04 | Watershed 2/3 agriculture, 1/3 heavily cut forest land. Four residential areas in watershed. Mainstem and lower tributaries in valley highly channelized. Minimal riparian buffers. | 4 | 51.4 |
| ORV28 | Watershed 2/3 forested, of that 1/3 recently cut. Lower 1/3 on valley floor highly channelized. Roads follow stream and tributaries. Narrow wooded riparian buffer on stream reach. | 4 | 43.5 |
| ORV01 | Watershed 100% cleared. Intensive agriculture. Dredging, channelization. Only herbaceous riparian vegetation. | 5 | 35.8 |
| ORV05 | Entire watershed urbanized except sample reach with remnant farm fields and some riparian buffer. Spring fed stream, cold water. | 4 | 24.8 |
| ORV25 | Watershed 95% urban, 5% forested. Stream reach in channelized ditch, cement banks. | 5 | 19.7 |
| ORV26 | Watershed 2/3 urbanized, 1/3 mixed farm fields and oak woodland. Lower 2/3 channelized with no riparian buffer. Deep ditch in commercial district. Cement and riprap. | 5 | 15.1 |
| ORV23 | Watershed 100% cleared; urban area near sample site. Stream reach channelized into rectangle around perimeter of airport and neighboring freeway. High nutrient load, little riparian woodland; alien, invasive plants. | 5 | 8.5 |

differences among sites. In this case, riparian habitats variously affected by human activities represent the ecological hazards to which biota are exposed (Karr and Chu 1999). Therefore, to test the responsiveness of bird assemblages to human disturbance in the watershed and within the sampled riparian zone, we ranked the Willamette Valley survey sites on a disturbance gradient. Screening the stream reaches and their watersheds followed an iterative process of map analysis, aerial photo interpretation, inspection of Thematic Mapper satellite imagery, and the review of field physical habitat information using the method outlined in Bryce and others (1999a). We recorded and ranked the number, proximity, intensity, and extent of all human alterations to riparian and upland areas that were detectable using these data. The disturbance index integrated both watershed and reach information: it included aspects of land use/land cover, road density, riparian cover, and stream channel and substrate conditions. From an aquatic indicator perspective, the disturbance index incorporated some measures of stream channel condition, such as fish cover, amount of woody debris, shading, substrate, and visual sedimentation estimates (general water clarity and embeddedness), but it did not include other water column effects such as nutrient concentration, toxic pollutants, or suspended sediments.

Once we had cataloged the stressors affecting the stream reaches and watersheds, we classified the watersheds into scoring classes based on the accumulating severity of stressors. The stream reaches and their watersheds received a score of 1–5, minimal to high disturbance (Table 1). Scores of 2 denoted a relative lack of human influence, but had one or more disqualifying factors, such as a road paralleling the stream. A score of 3 denoted watersheds with intermediate risk of impairment, where, although human alteration was dominant, there were mitigating factors that tended to preserve stream quality. Those watersheds that scored 4 also had attributes mitigating the major impacts of intensive farming, mining, or urban development that placed others in the highest disturbance category (score of 5). The resulting disturbance index scores were consistent with measures of stream condition based on water chemistry and benthic macroinvertebrates, neither of which had been used in the scoring process. A possible disadvantage to this watershed disturbance measure was that it included habitat information at a coarser scale than the riparian scale at which the birds were sampled.

### Reference Condition

The concept of reference condition is indispensable to both the establishment of a disturbance gradient as well as index and metric development. Minimally disturbed streams and watersheds can serve as references against which to compare the condition of streams stressed by human activities (Hughes and others 1986, Hughes 1995, Bryce and others 1999b). Indices of biotic integrity score stream reaches along a minimal to high disturbance gradient based on comparison with a reference condition. However, in highly disturbed regions, where minimally disturbed systems are in short supply, historical or paleoecological information also may be used to model natural condition (Chovanec and others 1995, Hughes and others 1998). Because the Willamette Valley is heavily developed, with both intensive agriculture and growing population centers, most of the 13 watersheds in this study were highly disturbed. Only three streams were considered moderately disturbed and only one approached reference condition, receiving a score of 2 during the disturbance screening. This shortage of minimally disturbed sites affected bird species expectations and the metric scoring (discussed below).

### Candidate Metrics

We derived candidate metrics from the lists of bird species and relative abundances in the survey data set (Appendix). The metrics, 62 in all, represented aspects of bird taxonomic richness, tolerance or intolerance to human disturbance, dietary and foraging preferences, and nesting strategies.

*Taxonomic richness and abundance.* In addition to total number of individuals, we evaluated native species richness, warblers and neotropical migrants. From past experience and from examples in the ecological literature (Odum and others 1979, Odum 1985), we expected species richness to increase somewhat with moderate disturbance, and then decline with increasing impacts, a pattern that could make its use as a metric problematic. Metrics based on warblers and other neotropical migratory species (long-distance migrants) were expected to be responsive since many of these species are sensitive and known to be declining due to human disturbance and habitat fragmentation (Wilcove and Terborgh 1984, Terborgh 1989).

*Tolerance to human disturbance.* Both tolerant and intolerant bird species may be distinguished from ubiquitous species (widely found in both disturbed and undisturbed habitats), and generalists (adaptable to multiple habitats) by the use of literature review and field experience. We assigned intolerant status to those species considered most sensitive to human disturbance and accompanying habitat loss (Appendix). Intolerants included those species in decline in the Willamette Valley during the past 50 years: birds that inhabited oak savannah, cottonwood, conifers, or brushy habitats; grassland birds unable to nest successfully under the present harvest regime; and species that have been displaced by the alien European starling. Conversely, tolerants are those bird species that increase with disturbance or benefit from human activities.

*Foraging and dietary guilds.* Bird species have been classified into foraging guilds according to their feeding strategies (Ehrlich and others 1988). Commonly recognized foraging guilds used in metric development were foliage gleaners (woodland foliage), bark gleaners, ground gleaners (both woodland and grassland), and aerial foragers. Predominant food preferences during the breeding season, as indicated in Terres (1980), Ehrlich and others (1988), and DeGraaf and others (1991), determined the dietary guild assignments. If the references disagreed, we made a choice based on professional judgment and local field knowledge. Metrics based on dietary guilds included omnivores (consumers of both animal and vegetable material), granivores (grain eaters), insectivores, carnivores, and fruit, foliage, and nectar consumers.

*Nesting strategies.* We chose ground nesting and cavity nesting as the two strategies most likely to be affected by increasing human activities. Ground nesters included those birds nesting on or near the ground in low shrubs as identified in the references listed in the paragraphs above. Ground nesters experience increased disturbance, trampling, and predation by nest-robbing predators and pets near human habitation. Cavity nesters in the Willamette Valley are constrained not only by a shortage of trees, but, for some species, such as the hairy woodpecker and red-breasted nuthatch, trees of adequate size. Moreover, since the arrival of the alien European starling in Oregon in the mid-20th century, native cavity-nesting species have an aggressive competitor for nest sites. Starlings appropriate nest cavities early and have up to three broods per year. These observations suggested that a metric based on native cavity nesting could be responsive.

Table 2. Metric categories, expected response, and number of metrics in each category that were responsive to disturbance[a]

| Metric category | Expected response | Metrics responsive to disturbance |
|---|---|---|
| Total abundance | Increases with moderate disturbance, decreases with heavy disturbance | 0 |
| Native species richness | Increases with moderate disturbance, decreases with heavy disturbance | 1 |
| Neotropical migrants | Decrease | 2,3 |
| Warblers | Decrease | 1,3,4 |
| Tolerants | Increase | 3,4 |
| Intolerants | Decrease | 1,2,3 |
| Omnivores/granivores | Increase | 3,4 |
| Insectivores | Decrease | 1,3 |
| Ground gleaners | Increase | 3,4 |
| Foliage gleaners | Decrease | 2,3,4 |
| Bark gleaners | Decrease | 3,4 |
| Ground nesters | Decrease | 0 |
| Woodland ground nesters | Decrease | 2,4 |
| Cavity nesters | Decrease | 3 |
| Native cavity nesters | Decrease | 1,2,3 |
| Cavity + ground nesters | Decrease | 0 |
| Nest sensitive (woodland ground nesters + native cavity nesters) | Decrease | 1,2,3,4 |

[a]For each metric category (except total abundance and native species richness), four metrics were tested: number of species, number of individuals, percent species and percent individuals (labeled 1, 2, 3, or 4 in column 3 below). Of the 62 metrics tested, 32 showed a clear response to disturbance.

### Metric Development

Although we had encountered ideas for metric categories in the literature, we decided not to use existing metrics or indices as a model for this project. We wanted to begin with as few preconceived notions as possible. Indices of bird integrity have not existed long enough to have established rules for metric development. We also did not want to borrow too heavily from indices of fish assemblage integrity, where metric development guidelines have evolved. Thus, although the metric categories fit ecological precepts from the literature and/or field experience, we settled on individual metrics by testing a quartet of metrics for most categories (Table 2):(1) number of species, (2) number of individuals, (3) percent species (i.e., number of (metric category) species at a site divided by total number of species at the site), and (4) percent individuals (i.e., number of (metric category) individuals at a site divided by total number of individuals at the site).

For each metric, the scores for each site were plotted against the disturbance classification. To qualify for inclusion in the final index, metrics had to be responsive to varying levels of disturbance. By responsive we mean that, for those metrics expected to decrease with disturbance, plotted metric scores clearly declined from left to right as disturbance scores varied from 1 to 5 (minimal to high disturbance). We organized the plots by guild (four for each guild) and discarded those that showed little or no response to the disturbance measure (Figure 2).

To reduce the number of candidate metrics, we tested metric redundancy and year-to-year variability in metric response. Four of the Willamette Valley sites were resurveyed the following year. We prepared visit 1 versus visit 2 plots for each of the candidate metrics and visually identified those metrics with the highest repeatability (Figure 3), and we also used analysis of variance to evaluate the precision of BII scores (see Kaufmann and others 1999). Finally, we examined a 60 × 60 correlation matrix to find which metrics were highly correlated with each other.

### Metric and Index Scoring

After testing a 1–3–5 scoring system, we decided that metrics scored continuously between 0 and 10 and an index scored between 0 and 100 would better discriminate site conditions than a scoring system that placed sites into classes approximating good, fair, and poor condition. Thus, we used linear interpolation to place individual raw metric values on a scale of 0 to 10; the metric scores were calculated by dividing the raw metric value by its range and multiplying by 10. For species richness and proportional metrics, the range was defined as the lowest possible (0) to the highest number expected under reference conditions (discussed below); for the remaining metrics (e.g., numbers of individuals), the range was the lowest possible (0) to the highest recorded value in the database. While most of the bird assemblage attributes decreased with increasing human activity, the abundances of tolerants, omnivore/granivores, and ground gleaners increased with higher disturbance. We reversed the scoring for these metrics to make them range from 10 to 0. For each of these metrics, the raw score was matched with its complement on a 10 to 0 number scale. Finally, the index scores for each site were calculated as the sum of the metric scores multiplied by 10 and divided by the number of metrics (13) to keep them on a 0-to-100 scale.

Typically, indices of biotic integrity score stream reaches along a disturbance gradient based on comparison with a reference condition. However, minimally disturbed reference sites are rare in the highly altered Willamette Valley region. To determine species expec-

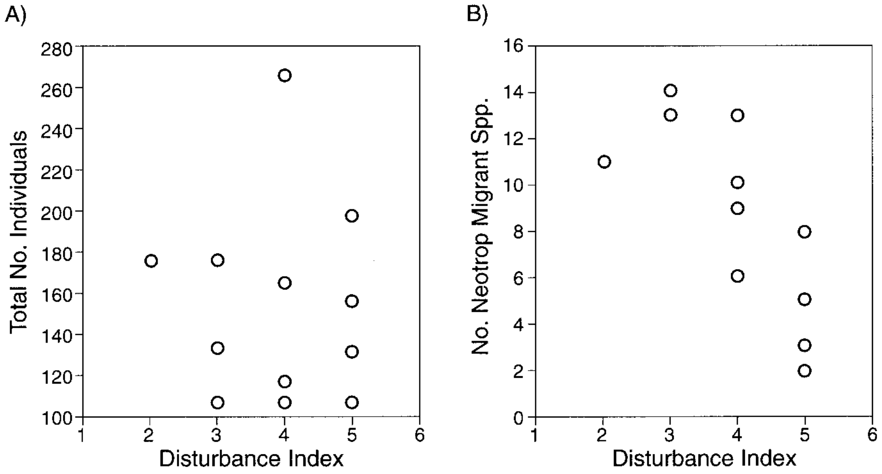

**Figure 2.** Examples of two candidate metrics: (**A**) one that was discarded due to a lack of responsiveness to the agricultural/urban disturbance gradient, and (**B**) a responsive metric that was retained in the first screening. Disturbance was based on attributes such as land use/land cover, road density, population density, riparian cover, and stream substrate conditions.

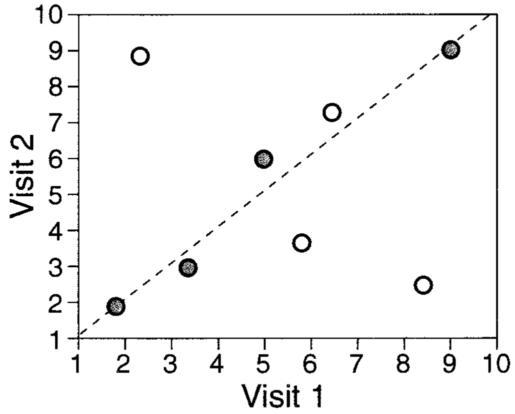

**Figure 3.** Examples of two generic metrics tested for interannual variability at revisited sites. One promising metric has high repeatability (*filled circles*) and the other has unacceptably high year-to-year variability (*clear circles*).

tations under less disturbed conditions for 7 of the final 13 metrics in the index, we adjusted the range to include bird species once present in the Willamette Valley, but now extirpated. We did not try to reconstruct species composition from presettlement times (a separate research effort), but based our estimate on the species present 50 years ago, preceding the recent population boom, the change in agriculture to favor large "clean" industrial farms and the arrival of the European starling. Through discussions with local expert birders and a review of historical condition (Altman and others 2001), we identified 15 species that had been extirpated from the valley or were in such reduced numbers that they were not detected in the present survey. Eight of these species were eliminated from the list because they were more typically grassland species (e.g., meadowlark, horned lark, vesper sparrow) or had wide-ranging territories (e.g., common nighthawk, short-eared owl). Our focus is on riparian condition and our assumption is that the extent of riparian woodland has been much reduced in the last 50 years. Thus, we added seven birds to the native species list that once benefited from more extensive riparian cover: Lewis' woodpecker, pileated woodpecker, western bluebird, Lazuli bunting, yellow warbler, yellow-breasted chat, and olive-sided flycatcher (see Appendix for scientific names of observed species).

This adjustment in species numbers meant that a raw metric score, when divided by the number of expected species (historic expectation), resulted in a lower score than if it had been divided by the highest number of species encountered during the present day field effort (Table 3). The reverse metrics (scoring 10 to 0) and the three metrics based on numbers of individuals were not adjusted in this way, because they were not as amenable to modeling an expected number of species or individuals under minimally disturbed conditions. If we had only used present-day field data in the denominator as the expected value or range, too many metrics would have scored 10 out of 10, inflating the condition assessment of the mostly disturbed valley streams. Using historic expectations meant that the best site in this highly altered region received a more realistic score of 82 out of 100. This is appropriate because this stream reach only matched the lower end of reference quality based on the disturbance gradient (score of 2). This stream was least disturbed rather than minimally disturbed. A score less than 100 also indicated that from a management standpoint, one could presumably apply best management practices to improve the score at this highest scoring site.

Table 3. Example of scoring process for each metric for highest scoring stream reach in the sample[a]

| Metric | Observed Field Value | Range (or scoring criteria) | Metric score | Comments on range (scoring criteria) |
|---|---|---|---|---|
| Native species richness | 33 | 40 | 8.3 | Added 7 extirpated woodland breeding species. |
| Number neotropical species | 14 | 18 | 6.1 | Added 4 of 7 extirpated species that are neotropical migrants. |
| % Warbler species | 11.4 | 18.2 | 6.3 | Added 2 extirpated warbler species to number of species detected (numerator); added 7 to total species (denominator). |
| Number Intolerant Individuals | 52 | 67 | 7.8 | Score not adjusted. Range or scoring criteria = highest observed value. |
| % tolerant species | 22.9 | 20 | 8.5 | ≤20 = 10; ≥40 = 0. Middle values (20–40) matched to their complement on 10–0 number line. Reverse metric upper cutoff (40) because of exponential nature of plot (see Figure 4). |
| % insectivore species | 48.6 | 70 | 6.9 | Added 7 insectivores (numerator); added 7 to total species (denominator). |
| % omni-granivore species | 40 | 35 | 7.5 | ≤35 = 10; ≥55 = 0. Middle values (35–55) matched to their complement on 10–0 number line. Reverse metric upper cutoff (55) because of exponential nature of plot (see Figure 4). |
| Number foliage gleaning species | 11 | 13 | 8.5 | Added 2 extirpated foliage gleaning species from list of 7. |
| % bark-gleaning species | 14.3 | 14.3 | 10 | Added 1 bark-gleaning species (numerator); added 7 to total species (denominator). (Resulting number the same). |
| % ground gleaning species | 37.1 | 35 | 9.2 | ≤35 = 10; ≥60 = 0. Middle values (35–60) matched to their complement on 10–0 number line. Reverse metric upper cutoff (60) because of exponential nature of plot (see Figure 4). |
| Number woodland ground-nesting individuals | 30 | 30 | 10 | Score not adjusted. Range or scoring criteria = highest observed value. |
| Number native cavity-nesting species | 9 | 12 | 7.5 | Added 3 cavity nesters from list of 7 extirpated species. |
| Number nest-sensitive individuals | 60 | 60 | 10 | Score not adjusted. Range or scoring criteria = highest observed value. |
| Sum of metric scores | | | 106.6 | In order to have the index score fall between 0 and 100, the sum of the metric scores (106.6) was divided by 13 and multiplied by 10 to yield a BII of 82 for the site. |

[a] The observed field value is divided by the range (scoring criteria) and multiplied by 10. Unless indicated otherwise, the range of each metric score was adjusted using historical information (50 years before present).

## Results and Discussion

### Bird Assemblages

Species richness varied from 16 to 35 (native species 14 to 33) across the 13 stream reaches. The urban reaches were dominated by species tolerant of human settlements, such as European starling, red-wing blackbird, violet-green swallow, and house sparrow (see Appendix for scientific names). The dominant species at the agricultural streams were grassland or edge inhabitants such as American goldfinch, Brewer's blackbird, American robin, song sparrow, and common yellowthroat. The robin and song sparrow were still abundant at the woodland sites, but they were matched in abundance by other woodland birds such as cedar waxwing, Swainson's thrush, and western wood peewee. The highest scoring stream reaches showed more species diversity with increasing presence of warblers, vireos, and cavity-nesting woodpeckers. The alien European starling was the most commonly occurring species, present at all but two reaches and in the top three in abundance at seven of the stream reaches.

### Metric Selection and Performance

To qualify for inclusion in the final index, metrics had to be responsive to our measure of disturbance, both visually and statistically. Initially, we were concerned that the disturbance index might be too coarse

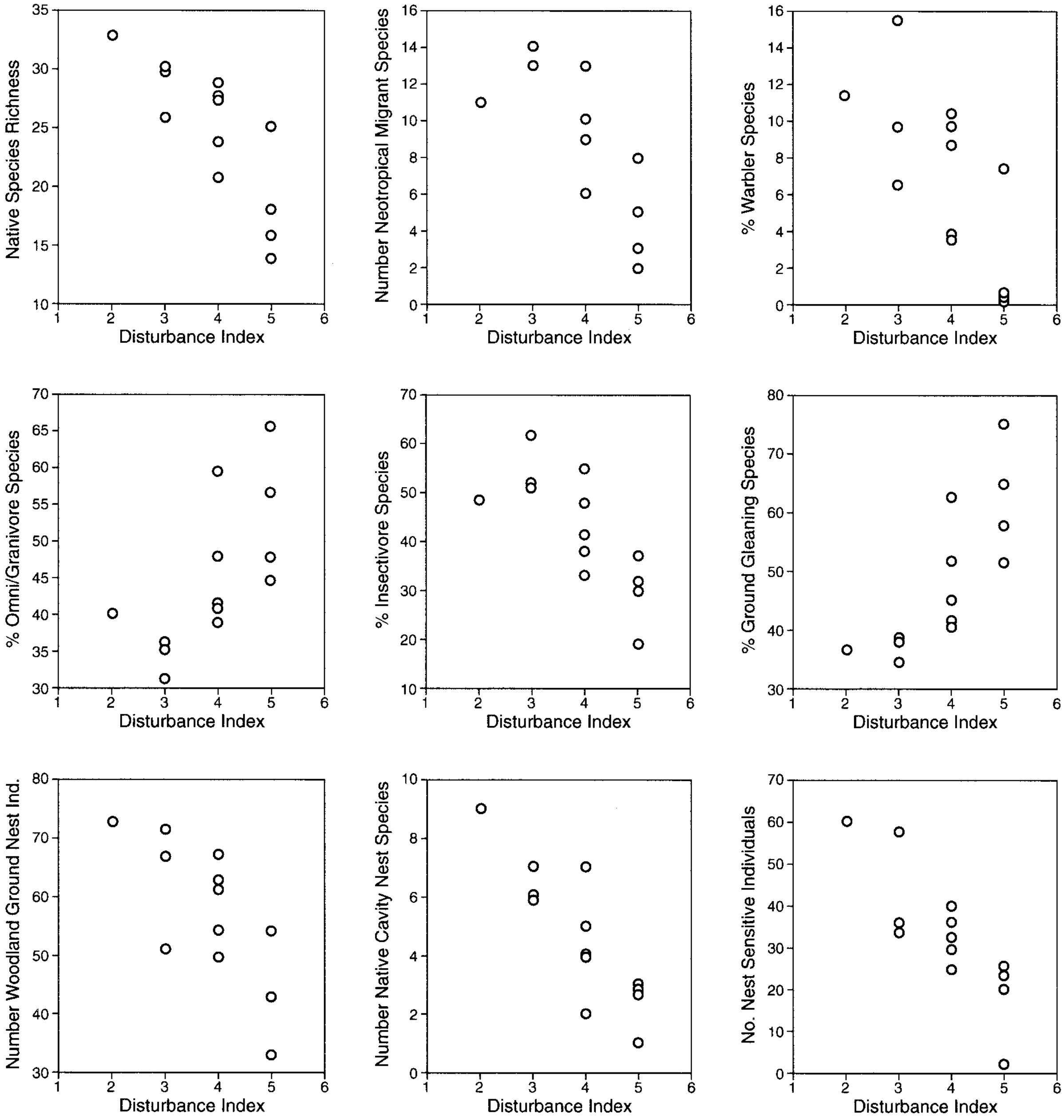

**Figure 4.** Legend appears on p. 303.

to distinguish bird response at the reach level because it integrated both reach level and watershed level information, and because the stream reaches were placed into only five disturbance classes. However, we found that the metrics were clearly responsive to this disturbance measure.

Of the initial 17 metric categories, 14 had one to four metrics that responded well to disturbance as interpreted from the plots of each metric against the disturbance index (Table 2; Figure 2B). Three metric categories, total abundance, ground nesters, and cavity + ground nesters, did not respond to the disturbance gradient (as in Figure 2A). Of the 62 individual metrics tested, 32 showed a clear response to the disturbance gradient in the plots. Visual analysis of the patterns in metric/disturbance gradient plots aids in developing an accurate and diagnostic index. Meaningful responses are not always linear. We also corroborated our visual assessment of the plots by examining the correlation between each responsive metric and the

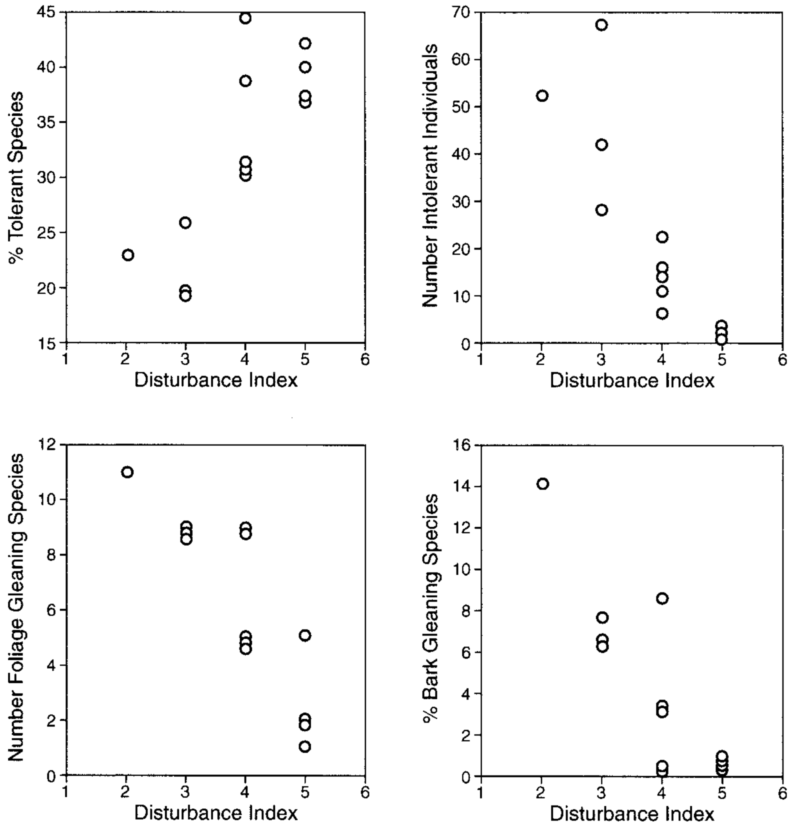

**Figure 4.** Final 13 metrics composing the BII plotted against an agricultural/urban disturbance gradient. All but three metrics declined as disturbance increased: % tolerant species, % ground-gleaning species, and % omnivore/granivore species represented those bird assemblages that benefit from human disturbance. Disturbance was based on attributes such as land use/land cover, road density, population density, riparian cover, and stream substrate conditions.

disturbance index. For the metrics in the final index, Spearman *r* values varied between −0.625 and −0.836.

The 32 responsive metrics represented attributes of taxonomic richness and abundance, tolerance or intolerance to human disturbance, dietary and foraging preferences, and nesting strategies:

*Taxonomic richness and abundance.* We expected species richness to increase somewhat with moderate disturbance, and then decline with increasing impacts (Odum 1985). However, perhaps since even our least-disturbed site was moderately degraded, we saw an overall decline in species richness with increasing disturbance across our sample. As expected, both metrics based on the relative abundances of warbler species and neotropical migratory bird species were responsive to our disturbance measure.

*Tolerance to human disturbance.* Of the species detected during the bird survey in the Willamette Valley, 29.5% were considered intolerants (Appendix), although several of these species occurred only as one or two individuals in the database. Intolerant individuals made up just 13.2% of the total number of individuals observed. Tolerant species made up 19.7% of the total number of species detected, and tolerant individuals comprised 40.4% of the total number of individuals observed. The number of tolerants increased with higher disturbance.

*Foraging and dietary guilds.* The ground, foliage, and bark gleaning metrics were the most promising of the foraging guild metrics. Members of other foraging guilds, such as aerial foragers (e.g., swallows), hawkers (e.g., flycatchers), and hover-and-gleaners (e.g., hummingbirds), had been encountered during the survey, but their numbers were not high enough to have an impact on the analysis. We also did not include aerial predators with large hunting territories because they functioned at a broader scale than the riparian reach scale. Similarly, the dietary preferences most useful in metric development were omnivores (consumers of both animal and vegetable material), granivores (grain eaters), and insectivores, although there were carnivores, fruit, foliage, and nectar consumers in small numbers in the data set. Unlike most of the other metrics, the relative abundances of omnivore/granivores and ground gleaners increased with increasing human activity.

*Nesting strategies.* The ground-nesters metric was not responsive to the disturbance gradient. One explanation for this was that there were two groups of ground nesters encountered in the study: woodland ground nesters in the wooded riparian buffers, and grassland ground nesters in the adjacent farm fields. To develop a metric that reflected the context of disturbance in this study, that is, the progressive degradation and elimination of wooded riparian zones, the ground-nesters metric was redefined as woodland ground nesters. The woodland ground-nesters metric was responsive to the disturbance gradient.

The cavity-nesting metric also was not responsive to the disturbance gradient. We suspected that the reason was the presence of the alien European starling that inflated the numbers of cavity nesters. However, although they use trees for nesting and roosting, starlings seem to prefer edge habitats and open areas for foraging. In this survey, they were absent from stream reaches with larger contiguous patches of woodland, such as the wooded foothill sites and the single valley reference stream, where the width of riparian woodland (which also contained old trees) reached nearly 1 km. These observations suggested, and subsequent testing showed, that the relative abundance of native cavity nesters was a better indicator of riparian condition. Another measure, the "nest-sensitive" metric, that integrated both the woodland ground-nesting and native cavity-nesting attributes, was also responsive to the disturbance gradient.

### Final Index and Distribution of Site Scores

Through a process of elimination we chose, for each metric category, the metric with the clearest relationship to disturbance, the lowest revisit variability, and the fewest high correlations (>0.900) with other metrics. Thirteen metrics survived the final screening to compose the final index (Figure 4). The bird integrity index (BII) scores ranged from 8.5 to 82, with an average of 47. The scores fell into three groups. Four stream reaches, ranging in score from 67.2 to 82, were near the perimeter of the valley floor or in the Coast Range foothills (Figure 5A, top four points). Four other streams, with narrow, wooded riparian buffers surrounded by agricultural fields, received scores between 43.5 to 55 (Figure 5A, middle four points). The third group included four urban streams, ranging in score from 8.5 to 24.8, and one agricultural ditch (score of 35.8) (Figure 5A, lowest 5 points). These three groups (hereafter called woodland, agricultural, and urban sites) suggest break points for setting good, fair, and poor condition classes. However, we must have a larger sample and further test the index on an independent data set before committing to threshold values.

### Precision of the Bird Integrity Index

The root mean square error (RMSE) of within-site variance (revisits to four sites in consecutive years) was 3.7, less than 5% of the observed BII range among sites. To be statistically significant (one-sided $t$ test, 1 *df*, $P <$ 0.10), differences between single BII measurements must exceed 11 (i.e., 3 × RMSE). The signal-to-noise ratio of the BII (variance among streams/variance of repeat visits) was 40, showing a large potential for discriminating among sites in this region. Generally when indices have a signal-to-noise ratio (S/N) $\geq 10$, measurement variance and short-term temporal changes produce insignificant obstacles to regression and correlation analyses (Kaufmann and others 1999). For example, an index with a S/N of 3 allows one to explain up to 56% of the variance between that index and some predictor variable of similar precision, while a S/N of 40 allows one to account for up to 98% of the variance between that index and another variable of similar precision. These results are promising, although the small number of repeat visits dictates that we must consider this precision estimate preliminary.

### Comparison with Other Indices

We compared the pattern of the BII scores with the performance of other measures of biotic response developed during the larger Willamette valley study: a fish index of biointegrity (IBI) and two benthic macroinvertebrate metrics (Hughes and others 1998, Li and others 2001, Bryce and Hughes 2002). All were plotted against the agricultural/urban disturbance gradient (Figure 5A–D). The comparisons are not consistent across all three assemblages because no multimetric benthic macroinvertebrate index was available. For birds and fish we had 9–13 metrics composing each index, but for macroinvertebrates we had just two individual metrics. Combining metrics into a multimetric index, analogous to averaging, often results in greater precision (Karr and Chu 1999). Therefore, it is not surprising that index association with disturbance is clearer than metric association with the same disturbance measure. However, we thought it would be instructive to see how three measures of biotic response reacted along the disturbance gradient.

Although index scores for birds and fish were in a similar range at either end of the disturbance gradient, fish IBI scores were generally higher than bird index scores for those streams receiving a score of 4 (fair condition). This pattern might suggest that birds were more sensitive to the disturbance gradient than fish. However, one explanation for the close association of bird scores with the disturbance index is that the first

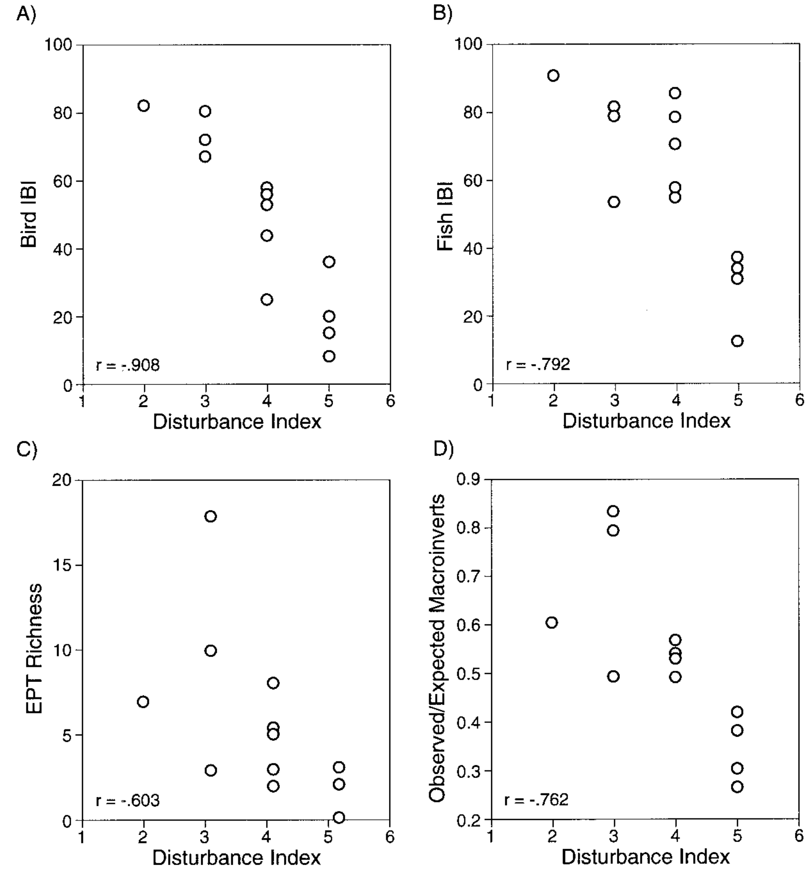

**Figure 5.** Site scores and *r* values for: (**A**) the bird integrity index, (**B**) fish index of biotic integrity, and two benthic macroinvertebrate metrics: (**C**) EPT richness (the number of Ephemoptera, Plecoptera, and Trichoptera taxa) and (**D**) observed/expected macroinvertebrate taxa, plotted against an agricultural/urban disturbance gradient. Disturbance was based on attributes such as land use/land cover, road density, population density, riparian cover, and stream substrate conditions.

round of bird metrics were selected partly by their responsiveness to this disturbance gradient. Thirty-two of the 62 metrics tested were responsive to the disturbance measure, and other factors were necessary to determine the final metrics composing the index.

Another reason for the differences between bird and fish response is that the disturbance index was developed as a general measure of human activity across the landscape. As a result, it may not capture all aspects necessary to characterize the response of a particular assemblage. Although it does contain stream channel measures, the disturbance index includes more riparian and watershed elements. Riparian cover is important to fish for shading and cover, but riparian structure, quality, and extent are vital to birds for food, shelter, and reproduction. Thus, it may be that fish are responding more to in-stream disturbances rather than the riparian or watershed elements composing the disturbance index. For example, in the fish IBI plot (Figure 5B), the topmost point in column 4 has an index score of 86.7; the same location received a bird index score of 24.8 that was more typical of an urban riparian zone (lowest point in column 4 on BII plot). However, the stream was an anomaly in the valley in that it was spring fed with a high volume of cold water that compensated for the loss of riparian cover. As a result, it supported anadromous and resident salmonids, the presence of which increased fish metric scores.

The macroinvertebrate metric, EPT richness (Figure 5C), is the number of Ephemeroptera, Plecoptera, and Trichoptera taxa (mayfly, stonefly, and caddisfly) found at each site. Although Bryce and others (1999a) demonstrated the necessity of adjusting EPT expectations for natural differences in stream geomorphic settings, the presence of these often sensitive taxa is commonly understood to indicate high-quality stream reaches (Plafkin and others 1989). While this metric distinguished between fair and poor sites (disturbance scores of 4 and 5), it showed high variability in scores for the less disturbed stream reaches (score of 3). Of the three sites in this class, the two highest EPT sites were the foothills streams, and the lowest a sluggish, silty, meandering valley stream that had good riparian habitat, but a high sediment load that would have decreased the likelihood of EPT presence. The second macroinvertebrate metric, observed number of taxa/expected number of taxa (Figure 5D), is based on comparing the taxa collected with those expected in similar habitats largely unaffected by humans (Wright 1995). This metric shows somewhat less variability in scores at lower disturbance levels than does EPT richness. Both macroinvertebrate measures give lower scores to the least disturbed site (disturbance score of 2) than did either the fish or bird index, possibly because of sedimentation.

These comparisons demonstrate the value of using multiple assemblages to assess stream and riparian habitats. The three assemblage indices agree on the general level of disturbance. For example, at agricultural stream reaches in this study, the plots for all three indicators (birds, fish, and aquatic insects) showed clear differences between scores for sites with and without wooded riparian buffers. However, individual sites scored differently depending on specific indicator response to conditions in stream substrate, water column, or channel and riparian habitat.

## Conclusions

Birds are a valuable addition to the list of routine indicators for stream ecosystem bioassessment. Although we could surmise the degradation of riparian condition through the fragmentation and loss of riparian habitat, we are highly concerned with the actual status of the inhabitants of the riparian zone. The BII has been developed as an indicator of riparian condition to relate it to ongoing efforts at assessing stream ecosystem condition, but the index is also an indicator of the condition of the bird assemblage itself. Birds elicit strong public interest and concern for their welfare. Many species are in decline due to loss of habitat, and they are worthy of our monitoring effort. From a logistical and programmatic point of view, bird surveys are cost effective in that the point count method of sampling has a simple plot design and low equipment expenditures. Species identification by a trained ear is immediate, meaning that the data are readily available for analysis and reporting.

The index methodology and metric categories presented in this paper provide a guide to index development in other temperate regions inhabited by nesting migratory birds and having similar patterns of agricultural/urban land uses. The metrics showed a clear response to the disturbance gradient because they were developed to emphasize the differences between woodland and agricultural grassland. Another contribution to the success of the index is that at these latitudes there is a discrete breeding season following the wave of spring migrants. The territoriality and general site tenacity of the nesting birds benefit index precision (repeatability). It is unknown how the index would respond in southern latitudes where the breeding season starts earlier, lasts longer, and overlaps migration. The metric categories will also need modification in forested regions, where there may be little difference between terrestrial forest and riparian woodland (except perhaps in logged areas with riparian buffer zones). Local species ecology and expectations of species maxima under minimally disturbed conditions will vary from region to region, suggesting changes to individual metrics.

To summarize, it seems unwise to limit our view to the aquatic habitat when conducting stream assessments. The value of a riparian indicator is to create an explicit connection between the aquatic system and terrestrial disturbances. Much of the evidence of the probable cause of stream impairment occurs in the terrestrial environment, and many of the solutions to improve stream condition are applied through land-based management practices. As we have seen, birds that inhabit the riparian interface between terrestrial and aquatic systems are a sensitive indicator of the types of watershed and riparian disturbances that can only be indirectly inferred from the response of aquatic indicators. The aquatic and riparian indicators, analyzed together with watershed landscape information, provide a comprehensive and defensible picture of stream condition.

## Acknowledgments

We thank Steve Paulsen, Phil Larsen, John Stoddard, and Alan Herlihy for supporting this indicator. Jane Ely and Aileen Buckley offered ideas and materials for the site disturbance rankings, Marge Hails provided meticulous data entry, and Suzanne Pierson created the map and figures. James Karr, Robert Brooks, Robert Altman, JoAnn Hanowski, F. Douglas Shields, and Matt Whiles provided helpful suggestions that clarified issues in the paper. The research in this article was funded by the US Environmental Protection Agency (EPA). This document was prepared at the EPA National Health and Environmental Effects Research Laboratory (NHEERL), Western Ecology Division (WED), in Corvallis, Oregon, through contract 68-D01-005 to Dynamac Corporation. It has been subjected to the agency's peer and administrative review and approved for publication.

## Literature Cited

Ambuel, B., and S. A. Temple. 1983. Area-dependent changes in the bird communities and vegetation of southern Wisconsin forests. *Ecology* 64:1057–1068.

Altman, R., M. Hayes, S. Janes, and R. Forbes. 2001. Wildlife communities of westside grassland and chaparral habitats. Pages 261–291 *in* D. H. Johnson and T. A. O'Neil (managing directors), Wildlife habitats and species associations in Oregon and Washington. Oregon State University Press, Corvallis, Oregon, 736 pp.

Bahls, L. L. 1993. Periphyton bioassessment methods for Montana streams. Montana Water Quality Bureau, Helena, Montana, 62 pp.

Barbour, M. T., J. Gerritsen, B. D. Snyder, and J. B. Stribling. 1999. Rapid bioassessment protocols for use in wadeable streams and rivers: Periphyton, benthic macroinvertebrates, and fish. EPA 841-B-99-002. US Environmental Protection Agency, Washington, DC, 313 pp.

Best, L. B., D. F. Stauffer, and A. R. Geier. 1978. Evaluating the effects of habitat alteration on birds and small mammals occupying riparian communities. Pages 117–124 *in* Proceedings of national symposlum on strategies for protection and management of floodplain wetlands and other riparian ecosystems, 11–13 December 1978. Pine Mountain, Georgia.

Bradford, D. F., S.E. Franson, A. C. Neale, D. T. Heggem, G. R. Miller and G. E. Canterbury. 1998. Bird species assemblages as indicators of biological integrity in Great Basin rangeland. *Environmental Monitoring and Assessment* 49:1–22.

Brooks, R. P., M. J. Croonquist, E. T. D'Silva, and J. E. Gallagher. 1991. Selection of biological indicators for integrating assessments of wetland, stream, and riparian habitats. Proceedings of Biological criteria: Research and regulation. 12–13 December 1990. Arlington, Virginia. US. Environmental Protection Agency, Office of Water, Washington, DC.

Bryce, S. A., and R. M. Hughes. 2002. Variable assemblage responses to multiple disturbance gradients: Oregon and Appalachia, USA, case studies. *In* T.P. Simon (ed.), Biological response signatures: Multimetric index patterns for assessment of freshwater assemblages, CRC Press, Boca Raton, Florida.

Bryce, S. A., D. P. Larsen, R. M. Hughes, and P. R. Kaufmann. 1999a. Assessing relative risks to aquatic ecosystems: A mid-Appalachian case study. *Journal of the American Water Resources Association* 35(1):23–36.

Bryce, S. A., J.M. Omernik, and D.P. Larsen, 1999b. Ecoregions: A geographic framework to guide risk characterization and ecosystem management. *Environmental Practice* 1:141–155.

Chovanec, A., V. Koller-Kreimel, O. Moog, and S. Weiss. 1995. Assessment of the ecological integrity of running waters—the Austrian approach. Proceedings of the international workshop on assessment and classification of rivers, 5–7 November 1995. Dusseldorf, Germany.

Croonquist, M. J., and R.P. Brooks. 1991. Use of avian and mammalian guilds as indicators of cumulative impacts in riparian-wetland areas. *Environmental Management* 15:701–714.

Cully, J. F., and S. L. Winter. 2000. Evaluation of land condition trend analysis for birds on a Kansas military training site. *Environmental Management* 25(6):625–633.

Davis, W. S., and T. P. Simon (eds.). 1995. Biological assessment and criteria: Tools for water resource planning and decision making. Lewis Publishers, Boca Raton, Florida, 415 pp.

DeGraaf, R.M., V.E. Scott, R.H. Hamre, L. Ernst, S.H. Anderson. 1991. Forest and rangeland birds of the United States: Natural history and habitat use. Agricultural Handbook 688. US Forest Service, Washington, DC, 625 pp.

Ehrlich, P. R., D. S. Dobkin, and D. Wheye. 1988. The birder's handbook: A field guide to the natural history of North American birds. Simon and Schuster, New York.

Fore, L. S., J. R. Karr, and R. W. Wisseman. 1996. Assessing invertebrate responses to human activities: Evaluating alternative approaches. *Journal of the North American Benthological Society* 15:212–231.

Forman, R. T., A. E. Galli, and C. F. Leck. 1976. Forest size and avian diversity in New Jersey woodlots with some land use implications. *Oecologia* 16:1–8.

Freemark, K. E., and H. G. Merriam. 1986. Importance of area and habitat heterogeneity to bird assemblages in temperate forest fragments. *Biological Conservation* 36:115–141.

Gregory, S. V., F. J. Swanson, W. A. McKee, and K. W. Cummins. 1991. An ecosystem perspective of riparian zones: Focus on links between land and water. *BioScience* 41:540–551.

Herlihy, A. T., P. R. Kaufmann, L. Reynolds, J. Li, and G. Robison. 1997. Developing indicators of ecological condition in the Willamette basin: An overview of the Oregon prepilot study for EPA's EMAP program. Pages 275–282 *in* A. Laenen and D. A. Dunnette (eds.), River quality, dynamics and restoration. Lewis Publishers, CRC Press, Boca Raton, Florida.

Hill, B. H., A. T. Herlihy, P. R. Kaufmann, R. J. Stevenson, F. H. McCormick, and C. Burch Johnson. 2000. Use of periphyton assemblage data as an index of biotic integrity. *Journal of the North American Benthological Society* 19(1):50–67.

Hughes, R. M. 1995. Defining acceptable biological status by comparing with reference conditions. Pages 31–47 *in* W. S. Davis and T. P. Simon (eds.), Biological assessment and criteria: Tools for water resource planning and decision making. Lewis Publishers, Boca Raton, Florida.

Hughes, R. M., D. P. Larsen, and J. M. Omernik. 1986. Regional reference sites: A method for assessing stream potentials. *Environmental Management* 10(5):629–635.

Hughes, R. M., P. R. Kaufmann, A. T. Herlihy, T. M. Kincaid, L. Reynolds, and D. P. Larsen. 1998. A process for developing and evaluating indices of fish assemblage integrity. *Canadian Journal of Fisheries and Aquatic Sciences* 55:1618–1631.

Karr, J. R. 2000. Health, integrity, and biological assessment: The importance of measuring whole things. Pages 209–226 *in* D. Pimentel, L. Westra, and R. F. Noss (eds.), Ecological integrity: Integrating environment, conservation, and health. Island Press, Washington, DC, 428 pp.

Karr, J. R., and E. W. Chu. 1999. Restoring life in running waters: Better biological monitoring. Island Press, Covelo, California, 206 pp.

Karr, J. R., K. D. Fausch, P. L. Angermeier, P. R. Yant, and I. J. Schlosser. 1986. Assessment of biological integrity in running water: A method and its rationale. Special Publication 5. Illinois Natural History Survey, Champaign, Illinois.

Kaufmann, P. R., P. Levine, E. G. Robison, C. Seeliger, and D. V. Peck. 1999. Quantifying physical habitat in wadeable streams. EPA 620/R-99/003. Environmental Monitoring and Assessment Program, US Environmental Protection Agency; Corvallis, Oregon, 102 pp. + appendices.

Kerans, B. L., and J. R. Karr. 1994. A benthic index of biointegrity (B-IBI) for rivers of the Tennessee valley. *Ecological Applications* 4:768–785.

Li, J., A. T. Herlihy, W. Gerth, P. R. Kaufmann, S. V. Gregory, N. S. Urquhart, and D. P. Larsen. 2001. Quantifying variation in stream macroinvertebrate assemblages at multiple spatial scales: The relative influence of sample size and spatial distribution. *Freshwater Biology* 46:87–97.

Moors, A. K. 1993. Towards an avian index of biotic integrity for lakes. Masters thesis. University of Maine. Department of Wildlife Management, Orono, Maine, 184 pp.

O'Connell, T. J., L. E. Jackson, and R. P. Brooks. 1998. A bird community index of biotic integrity for the mid-Atlantic highlands. *Environmental Monitoring and Assessment* 51(1–2): 145–156.

O'Connor, R. J., T. E. Walls, and R. M. Hughes. 2000. Using multiple taxonomic groups to index the ecological condition of lakes. *Environmental Monitoring and Assessment* 61: 207–229.

Odum, E. P. 1985. Trends expected in stressed ecosystems. *BioScience* 35(7):419–422.

Odum, E. P., J. T. Finn, and E. H. Franz. 1979. Perturbation theory and the subsidy-stress gradient. *BioScience* 29(6):349–352.

Omernik, J. M., and A. L. Gallant. 1986. Ecoregions of the Pacific Northwest. EPA/600/3-86/033. US Environmental Protection Agency Environmental Research Laboratory, Corvallis, Oregon.

Plafkin, J. L., M. T. Barbour, K. D. Porter, S. K. Gross, and R. M. Hughes. 1989. Rapid bioassessment protocols for use in streams and rivers: Benthic macroinvertebrates and fish. EPA/444/4-89-001. US Environmental Protection Agency, Washington, DC.

Root, R. B. 1967. The niche exploitation pattern of the blue-gray gnatcatcher. *Ecological Monographs* 37:317–350.

Severinghaus, W. D. 1981. Guild theory development as a mechanism for assessing environmental impact. *Environmental Management* 5:187–190.

Sibley, D. A. 2000. The Sibley guide to birds. Alfred A. Knopf, New York, New York, 544 pp.

Simon, T. P. (ed.). 1999. Assessing the sustainability and biological integrity of water resources using fish communities. CRC Press, Boca Raton, Florida, 671 pp.

Southerland, M. T., and J. B. Stribling. 1995. Status of biological criteria development and implementation. Pages 81–96 *in* W. S. Davis and T. P. Simon (eds.), Biological assessment and criteria: Tools for water resource planning and decision making. Lewis Publishers, Boca Raton, Florida.

Szaro, R. 1986. Guild management: An evaluation of avian guilds as a predictive tool. *Environmental Management* 10: 681–688.

Terborgh, J. W. 1989. Where have all the birds gone? Essays on the biology and conservation of birds that migrate to the American tropics. Princeton University Press, Princeton, New Jersey, 207 pp.

Terres, J. K. 1980. The Audubon Society encyclopedia of North American birds. Alfred A. Knopf, New York, 1110 pp.

USFWS (US Fish and Wildlife Service). 1990. Instructions for Breeding Bird Survey routes participants. Patuxent Research Laboratory, Patuxent, Maryland.

Verner, J. 1984. The guild concept applied to management of bird populations. *Environmental Management* 8:1–14.

Ward, J. V. 1989. The four-dimensional nature of lotic ecosystems. *Journal of the North American Benthological Society* 8:2–8.

Wilcove, D. S., and J. W. Terborgh. 1984. Patterns of population decline in birds. *American Birds* 38:10–13.

Wright, J. F. 1995. Development and use of a system for predicting the macroinvertebrate fauna in flowing waters. *Australian Journal of Ecology* 20:181–197.

Appendix. Bird species observed (ordered alphabetically, names follow Sibley 2000), number of individuals counted, and pertinent guild assignments (from Terres 1980, Ehrlich and others 1988, DeGraaf and others 1991).

| Species | Scientific name | Abundance | Neotropical migrant[a] | Tolerance[b] | Nest Type[c] | Diet[d] | Foraging Type[e] |
|---|---|---|---|---|---|---|---|
| American crow | *Corvus brachyrhynchos* | 69 | N | U | NA | OM | GG |
| American goldfinch | *Carduelis tristis* | 206 | N | T | NA | GR | FG |
| American kestrel | *Falco sparverius* | 4 | N | G | CAV | NA | NA |
| American robin | *Turdus migratorius* | 109 | N | U | NA | OM | GG |
| Band-tailed pigeon | *Columba fasciata* | 1 | Y | I | NA | GR | GG |
| Barn swallow | *Hirundo rustica* | 81 | Y | T | NA | IN | NA |
| Belted kingfisher | *Ceryle alcyon* | 3 | N | G | CAV | NA | NA |
| Bewick's wren | *Thryomanes bewickii* | 38 | N | T | CAV | IN | GG |
| Black-capped chickadee | *Poecile atricapilla* | 26 | N | G | CAV | IN | FG |
| Black-headed grosbeak | *Pheucticus melanocephalus* | 41 | Y | I | NA | OM | FG |
| Black-throated gray warbler | *Dendroica nigrescens* | 15 | Y | I | NA | IN | FG |
| Brewer's blackbird | *Euphagus cyanocephalus* | 64 | N | T | NA | IN | GG |
| Brown-headed cowbird | *Molothrus ater* | 30 | N | T | NA | OM | GG |
| Bullock's oriole | *Icterus bullockii* | 5 | Y | G | NA | IN | FG |
| Bushtit | *Psaltriparus minimus* | 16 | N | U | NA | IN | FG |
| California quail | *Callipepla californica* | 1 | N | G | GRND | GR | GG |
| Canada goose | *Branta canadensis* | 67 | N | G | GRND | NA | GG |
| Cassin's vireo | *Vireo cassinii* | 3 | Y | I | NA | IN | FG |
| Cedar waxwing | *Bombycilla cedrorum* | 134 | N | G | NA | NA | FG |
| Chipping sparrow | *Spizella passerina* | 1 | Y | I | NA | OM | GG |
| Cinnamon teal | *Anas cyanoptera* | 2 | Y | G | GRND | NA | GG |
| Cliff swallow | *Petrochelidon pyrrhonota* | 57 | Y | T | NA | IN | NA |
| Common raven | *Corvus corax* | 3 | N | U | NA | OM | GG |
| Common yellowthroat | *Geothlypis trichas* | 78 | Y | T | GRND | IN | FG |
| Dark-eyed junco | *Junco hyemalis* | 2 | N | U | GRND | GR | GG |
| Downy woodpecker | *Picoides pubescens* | 14 | N | U | CAV | IN | BG |
| European starling | *Sturnus vulgaris* | 296 | N | T | CAV | OM | GG |
| Great blue heron | *Ardea herodias* | 12 | N | G | NA | NA | NA |
| Green heron | *Butorides virescens* | 3 | N | G | NA | NA | NA |
| Golden-crowned kinglet | *Regulus satrapa* | 8 | N | I | NA | IN | FG |
| Greater yellowlegs | *Tringa melanoleuca* | 1 | N | G | GRND | NA | NA |
| Hairy woodpecker | *Picoides villosus* | 2 | N | I | CAV | IN | BG |
| Herring gull | *Larus argentatus* | 1 | N | G | GRND | OM | GG |
| House finch | *Carpodacus mexicanus* | 27 | N | T | NA | GR | GG |
| House sparrow | *Passer domesticus* | 28 | N | T | NA | OM | GG |
| House wren | *Troglodytes aedon* | 41 | Y | T | CAV | IN | GG |
| Hutton's vireo | *Vireo huttoni* | 1 | N | I | NA | IN | FG |
| Killdeer | *Charadrius vociferus* | 20 | N | T | GRND | IN | GG |
| MacGillivray's warbler | *Oporornis tolmiei* | 1 | Y | I | NA | IN | FG |
| Mallard | *Anas platyrhynchos* | 68 | N | G | GRND | OM | GG |
| Mourning dove | *Zenaida macroura* | 37 | N | T | NA | GR | GG |
| Northern flicker | *Colaptes auratus* | 8 | N | U | CAV | IN | GG |
| Northern harrier | *Circus cyaneus* | 1 | N | G | GRND | NA | NA |
| Orange-crowned warbler | *Vermivora celata* | 32 | Y | I | GRND | IN | FG |
| Pacific-slope flycatcher | *Empidonax difficilis* | 37 | Y | G | NA | IN | NA |
| Purple finch | *Carpodacus purpureus* | 32 | N | I | NA | NA | FG |
| Red-breasted nuthatch | *Sitta canadensis* | 11 | N | I | CAV | IN | BG |
| Red-breasted sapsucker | *Sphyrapicus ruber* | 4 | N | I | CAV | OM | BG |
| Red-tailed hawk | *Buteo jamaicensis* | 2 | N | U | NA | NA | NA |
| Red-winged blackbird | *Agelaius phoeniceus* | 144 | N | G | NA | OM | GG |
| Ring-necked pheasant | *Phasianus colchicus* | 11 | N | T | GRND | OM | GG |
| Rock dove | *Columba livia* | 29 | N | T | NA | GR | GG |
| Ruby-crowned kinglet | *Regulus calendula* | 2 | N | I | NA | IN | FG |
| Rufous hummingbird | *Selasphorus rufus* | 13 | Y | G | NA | NA | NA |
| Savannah sparrow | *Passerculus sandwichensis* | 40 | N | G | GRND | OM | GG |

Appendix. (*Continued*)

| Species | Scientific name | Abundance | Neotropical migrant[a] | Tolerance[b] | Nest Type[c] | Diet[d] | Foraging Type[e] |
|---|---|---|---|---|---|---|---|
| Scrub jay | *Aphelocoma californica* | 34 | N | T | NA | OM | GG |
| Song sparrow | *Melospiza melodia* | 217 | N | U | GRND | OM | GG |
| Spotted towhee | *Pipilo maculatus* | 60 | N | G | GRND | OM | GG |
| Swainson's thrush | *Catharus ustulatus* | 88 | Y | I | NA | IN | FG |
| Tree swallow | *Tachycineta bicolor* | 50 | Y | I | CAV | IN | NA |
| Turkey vulture | *Cathartes aura* | 6 | N | G | GRND | NA | NA |
| Vaux's swift | *Chaetura vauxi* | 2 | Y | G | CAV | IN | NA |
| Violet-green swallow | *Tachycineta thalassina* | 67 | Y | G | CAV | IN | NA |
| Warbling vireo | *Vireo gilvus* | 16 | Y | I | NA | IN | FG |
| Western wood peewee | *Contopus sordidulus* | 94 | Y | G | NA | IN | NA |
| White-breasted nuthatch | *Sitta carolinensis* | 5 | N | I | CAV | IN | BG |
| White-crowned sparrow | *Zonotrichia leucophrys* | 6 | N | G | GRND | OM | GG |
| Willow flycatcher | *Empidonax traillii* | 24 | Y | I | NA | IN | NA |
| Wilson's warbler | *Wilsonia pusilla* | 12 | Y | I | GRND | IN | FG |
| Winter wren | *Troglodytes troglodytes* | 3 | N | I | GRND | IN | GG |
| Wood duck | *Aix sponsa* | 1 | N | G | CAV | GR | GG |

[a] Neotropical migrant: N, no; Y, yes

[b] Tolerance: G, generalist; I, intolerant; T, tolerant; U, ubiquitous.

[c] Nest type: CAV, cavity nester; NCAV, native cavity nester; GRD, ground nester; NA, nest type not used in final index; WGR, woodland ground nester

[d] Diet: GR, granivore; IN, insectivore; NA, diet type not used in final index; OM, omnivore

[e] Foraging type: BG, bark gleaner; FG, foliage gleaner; GG, ground gleaner