23 Response Patterns of Great River Fish Assemblage Metrics to Outfall Effects from Point Source Discharges

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In: Simon,T.P., Ed. 2003. *Biological Response Signatures: Indicator Patterns Using Aquatic Communities*. CRC Press, Boca Raton, FL

23.1 INTRODUCTION

Human disturbance alters key attributes of aquatic ecosystems such as water quality, habitat structure, hydrological regime, energy flow, and biological interactions (Karr and Dudley 1981; Sparks 1995; Ward and Stanford 1989). In great rivers, this is particularly evident since they are disproportionately degraded (Karr et al. 1985a; Simon and Sanders 1999; Gammon and Simon

2000) by habitat alteration (Poff et al. 1997; Ward and Stanford 1995) and industrial and municipal discharges (Pearson and Krumholz 1984; Simon and Stahl 1998). Water quality degradation as a result of point and non-point source pollution further impacts the ecological integrity of large rivers such as the Ohio River (Sparks et al. 1990; Bayley 1995). By examining patterns in the response of fish assemblages to potential stressors associated with point-source discharges, it may be possible to assess the extent that pollution alters water quality and affects biotic integrity (Karr and Dudley, 1981; Bayley 1995; Yoder and Rankin 1995a).

The index of biological integrity (IBI) assesses the condition of water bodies by direct evaluation of biological attributes (Karr 1981; Karr et al. 1986). It integrates structural, ecological, trophic, and reproductive attributes of fish assemblages at multiple levels of organization (Fausch et al. 1990). The IBI was originally developed for assessment of Midwestern warmwater streams and has been modified for use in other regions and waters (Miller et al. 1988; Simon 1992; Simon and Lyons 1995; Hughes and Oberdorff 1999; Simon and Stahl 1998), including the upper Ohio River basin (Simon and Emery 1995; Emery et al. 1999; Simon and Sanders 1999; Emery et al., in review).

Emery and Thomas (Chapter 9) found that point source effects on biological communities of the Ohio River are limited to the immediate influence of the outfall. Typically, studies of the impacts of point source discharges to aquatic ecosystems have been limited to comparisons of the impacted area to an upstream, unimpaired “reference” condition. They described an approach of incrementally sampling outfalls that was intended to detect gradients of fish assemblage responses to effluents. This traveling zone (T-zone) approach was based on the computation of an IBI based on fish assemblage metrics from ten continuous 100 m segments. Data can be aggregated and metrics calculated to show incremental changes in response to the effects from point source discharges. These metrics can be evaluated individually or combined to form a multimetric index of biological integrity for the Ohio River. The purpose of this paper is to compare the responses of select metrics to three types of industrial and municipal wastewater discharges using data collected by the T-zone approach.

23.2 METHODS

23.2.1 Study Area

The Ohio River begins at the confluence of the Monongahela and Allegheny Rivers at Pittsburgh, PA (Rkm 0) and flows southwesterly to the confluence with the Mississippi River near Cairo, IL (1578.4 km) (Fig. 23.1). The Ohio River crosses four ecoregions (i.e., Western Allegheny Plateau, Interior Plateau, Interior River Lowland and Mississippi Alluvial Plain (Omernik 1987)). Nearly 10 percent of the nation's population, which is more than 25 million people, resides in the Ohio River basin. The Ohio River has over 600 permitted discharges to its waters including industrial, power generating facilities, and municipalities. Twenty navigational dams provide a 2.75 m minimum depth on the Ohio River for commercial navigation that transports approximately 250 million tons of cargo annually.

23.2.2 Sample Collection and Comparison of Outfall and Control Sites

Field collections were conducted at eleven outfall sites in 1999 by boat night electrofishing from early July until late October when the Ohio River is at stable low- to moderate-flow. We selected large, point source discharges with effluent plumes discharged at or near the surface.

These discharge locations were relatively unaffected by other anthropogenic disturbance. We measured habitat characteristics at each outfall site and selected upstream control sites with similar conditions. Control sites were chosen that were upstream of the discharge plume, were least disturbed by human activities, and possessed similar habitat type and composition. Boat night electrofishing was conducted at the outfall and control locations along a continuous 1000 m of shoreline, using the T-zone approach described by Emery and Thomas (Chapter 9). This approach provides a spatial resolution (at 100m increments) of the response of the fish assemblage to discharges and the equivalent of two contiguous 500 m electrofishing zones. Each outfall locations was broken into ten 100 m samples, which provides six 500 m T-zones (Table 23.1).

23.2.2 Data Analysis

We evaluated 13 metrics for each T-Zone for their response to disturbance (Table 23.2). We used the ANOVA GLM procedure in SAS (SAS Institute, Cary, NC) to calculate the least squares means differences of metric and index scores between control and outfall sites. We compared control and outfall sites (standard 500 m zones) and control vs. outfall sites for differences among T-zones. Only probabilities associated with pre-planned comparisons were used. Plots of mean scores for each metric in each T-zone were used to graphically depict differences between control and outfall sites.

23.3 RESULTS

23.3.1 Gradient Patterns Among the T-zones

Nine metrics show initial impairment closest to the outfall (i.e., within 700 m) followed by recovery to levels approximating those found at control sites (Figure 23.2). Four metrics (e.g., number of native species, number of sucker species, number of intolerant species, and number of deformities, eroded fins, lesions and tumors (DELT anomalies)) showed little or no response to discharges. Eight metrics exhibited a u-shaped response, indicating an immediate response at the discharge point with higher expectations immediately falling off and then recovering over the remainder of the zone.

23.3.2 Differentiating Between Control Condition and Outfall Effects

We found significant ($p<0.05$) differences between control and outfall sites for eight of the 13 metrics (Table 23.3). The metric scores were significantly higher ($p<0.0001$) at control sites. Two metrics did not respond as predicted (Table 23.3). The percent individuals as non-indigenous species and the percent individuals as tolerant species were greater at control sites with higher quality habitats. When comparing the first 500 m sample reach immediately below an outfall to the second contiguous 500m at the same location, no significant differences were observed between the two samples for any of the metrics.

23.3.3 Gradient Patterns Among Outfall Types

We were not able to make statistical comparisons across outfall types due to insufficient sample sizes. However, some metrics responded more strongly to particular types of outfalls than was indicated by the mean scores at outfalls. We used results from individual sampling events to graphically display these response ‘signatures’ and distinguish between summer and fall collections. At chemical outfall sites, the percent individuals as invertivore species declined between the first and second transect but then increased with distance away from the outfall (Figure 23.3), a pattern reflected in both the summer and fall samples. The percentage of individuals as lithophilous spawning species did not recover until the most downstream zone, and were not present at all during the summer sampling period. At sites with thermal discharges, the number of species and catch-per-unit-of-effort (CPUE) increased with distance from outfalls (Figure 23.3) in both the summer and fall samples, with summer expectations being much lower. Sites affected by wastewater effluent show either no change in values for CPUE or percent individuals as tolerant species or a decrease with distance from outfall (Figure 23.3).

Habitat quality in the vicinity of outfalls has an effect on biological integrity. For example, habitat quality may mitigate the deleterious effects of outfalls. Habitats with coarse substrates (good) tend to have greater diversity, even at outfalls, than shallow habitats (poor) with fine substrates (Figure 23.4).

23.4 DISCUSSION

23.4.1 Differentiating Between Control Condition and Outfall Effects

Outfalls on the Ohio River have a definable effect on the fish community present. Eight of the thirteen metrics detect significant differences between control sites and outfall sites. There are several reasons why some metrics did not respond as expected. The non-indigenous species metric was not intended to detect pollution but to track influence of invasive aquatic species on fish assemblages in the Ohio River. Less than 100 years ago, the common carp was the only species considered as exotic or as a non-native species (Fuller et al. 1999). Currently, there are 12 species that are considered as either exotic or non-indigenous in the Ohio River. As exotic and non-indigenous species increase at a site, the biological integrity decreases. The metric will be important for measuring improvements in the conservation of native species. Fish species classified as tolerant that are comprise the percent individuals as tolerant species metric are highly pollution tolerant and reflect water quality conditions that prevailed prior to the 1980s. As conditions in the Ohio River improved following the passage of the Clean Water Act of 1972, Emery et al (1999) reported that tolerant species have become increasingly scarce as impacts are becoming more localized. The number of sucker species, number of intolerant species, and number of deformities, eroded fins, lesions, and tumor (DELT) anomalies metrics all responded in a predictable manner, although not significantly so. In multi-metric indices not all of the metrics need to respond at the same time in order to distinguish between impacted and non-impacted conditions. The IBI was developed to respond to a number of environmental disturbances, point source impacts are just one of the many types of perturbations to which the index responds.

23.4.2 Gradient Patterns Among T-zones

The T-zone approach detected gradients at the outfalls that were not evident in the two sequential (upper vs. lower) 500 m zones. Most metrics showed distinct differences between control and outfall sites, even among sequential T-zones. The ability to detect a response gradient and indicate community recovery is essential to establishing cause and effect relationships, recommending future actions, and monitoring the success of pollution reduction efforts.

Most of the metrics indicate a community response within the first 700m. As compared to the area of impact seen on smaller streams or rivers this is a relatively short distance for community recovery (Karr et al. 1985b; Simon 1992; Simon et al., Chapter 22; Dufour et al., Chapter 24). Some metrics recover more quickly than others and some show little or no response. Seven of the metrics (Figure 23.2) display a u-shaped response, indicated by slightly inflated values at the point of discharge that rapidly decrease over the next 100 to 200m, then began to recover to background levels. This phenomenon may be due to transient individuals moving into the zone from upstream of the effluent, artificially inflating the values represented at the point of discharge. Similarly, in areas of poor habitat quality, the discharge structure itself may provide attractive fish cover for some species. Fish may be drawn to the area due to the increased flow or modified habitats typical of outfalls. Some type of bank stabilization usually in the form of rip-rap (cobble to boulder sized rock) or the outfall structure itself may offer some type of cover otherwise not found in the vicinity of the discharge.

23.4.3 Gradient Patterns Among Outfall Types

We examined the response of fish assemblage metrics at each of the three major types of discharges sampled (Figure 23.3). We found differences between summer and fall results from each type. Chemical facilities showed a slight u-shaped response with summer expectations being much lower than those observed in the fall months. Thermal effluents typically show a much stronger response during the summer months due to the increased thermal stress. Municipal wastewater treatment plants showed opposite effects during summer and fall periods. Summer samples show enrichment nearest the outfall with the observed effects diminishing with increased distance from the source. During the fall months, little or no effect is observed.

Outfall effects are sometimes masked by habitat quality so that response to disturbance is mitigated (Fig. 23.4). Higher quality outfall sites may have greater expectations than control sites with lower quality habitat. Figure 23.4 shows that thermal effects are equal across habitats, while chemical effects are similar across habitats but cause a greater response at the higher quality substrate sites. Wastewater effects are dramatically different between poor and good quality habitats probably as a result of soft sediments causing shifts in macroinvertebrate assemblage structure and function.

The response resolution of most fish assemblage metrics to discharge effects at finer scales suggests that any deleterious impacts are restricted to a few hundred meters. The use of the T-zone method diagnoses the response to the stressor, provides a more robust sampling approach, and identifies responses that may have otherwise been overlooked. We view this paper as a preliminary effort to initially test candidate Ohio River fish index metrics response to particular point source discharges. We do not have sufficient data to adequately test the statistical significance of each outfall type to individual IBI metrics.

23.5 CONCLUSIONS

The T-zone approach is similar to the Area Degradation Value (ADV) of Yoder and Rankin (1995b) since both are designed to measure the decline or recovery of the community immediately downstream of a discharge. Both approaches are successful in determining the extent and magnitude of impacts from point source discharges. However, the T-zone approach allows the dissection of specific impacts within large rivers. We developed a technique for evaluating fish community response, applicable for situations in which the zone of impairment is too small to be adequately represented by a standard sized boat-electrofishing zone. By collecting data in 100 m increments along a continuous 1000 m we are able to construct traveling zones, or T-zones, each 500 m in length and incrementally 100 m further from the point of impact. This technique requires the sampling effort of two standard sized boat-electrofishing zones, but provides the equivalent of six standard sized boat-electrofishing zones. This overlapping technique provides a 100 m resolution, increasing the researcher's ability to document community response usually missed by standard 500 m zones. We examined the responsiveness of select metrics to changes in water quality associated with point source discharges. We conducted night electrofishing at sites immediately downstream of point-source discharges and at upstream control sites, maintaining uniform habitat conditions between test and control locations. We employed an electrofishing method utilizing overlapping sampling zones to reveal indicator response along a gradient of human disturbance. Our results showed that eleven of the thirteen metrics responded to disturbance in a predictable manner. We were able to differentiate high-quality fish assemblages at control sites from ones with lower biotic integrity along disturbance gradients.

Acknowledgments

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REFERENCES

Bayley, P.B. 1995. Understanding large river-floodplain ecosystems. *BioScience* 45, 153-158.

Courtenay, W.R., Jr. and J.R. Stauffer, Jr. 1984. *Distribution, Biology, and Management of Exotic Fishes*. The Johns Hopkins Press, Baltimore, MD.

Emery, E.B. and J. Thomas. 2002. A method for assessing outfall effects on Great River fish populations: the traveling zone approach. In T.P. Simon (Ed.). *Biological Response Signatures: Patterns in Biological Indicators for assessing Freshwater Aquatic Assemblages*. CRC Press, Boca Raton, FL.

Emery, E.B., T.P. Simon, and R. Ovies. 1999. Influence of the family Catostomidae on the metrics developed for a great rivers index of biotic integrity. Pages 203-224 in T.P. Simon, editor. *Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities*. CRC Press, Boca Raton, FL.

Emery, E.B., T.P. Simon, F.H. McCormick, P.L. Angermeier, C.O. Yoder, J.E. DeShon, R.E. Sanders, W.D. Pearson, G.D. Hickman, R.J. Reash, M. Miller, and J.G. Shulte. In review. Development of the Ohio River Fish Index (ORFIn): an index of biotic integrity for a great river. *Transactions of the American Fisheries Society.*

Fausch, K.D., J. Lyons, J.R. Karr and P.L. Angermeier. 1990. Fish communities as indicators of environmental degradation. Pages 123-144 *in* S.M. Adams, editor. *Biological indicators of stress in fish*. American Fisheries Society, Symposium 8, Bethesda, MD.

Fuller, P.L., L.G. Nico, and J.D. Williams. 1999. *Non-indigenous fishes introduced into the inland waters of the United States*. American Fisheries Society, Special Publication 27, Bethesda, MD.

Gammon, J.R. and T.P. Simon. 2000. Variation in a great river index of biotic integrity over a 20-year period, *Hydrobiologia* 422/423: 291-304.

Hughes, R.M. and T. Oberdorff. 1999. Applications of IBI concepts and metrics to waters outside the United States and Canada. Pages 79-93 in T.P. Simon, editor. *Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities*. CRC Press, Boca Raton, FL.

Karr, J.R. 1981. Assessment of biological integrity using fish communities. *Fisheries* 6(6): 21-27.

Karr, J.R. and D.R. Dudley. 1981. Ecological perspective on water quality goals, *Environmental Management*, 5, 55 – 68.

Karr, J.R., L.A. Toth, and D.R. Dudley. 1985a. Fish communities of Midwestern rivers: a history of degradation. *Bioscience* 35, 90-95.

Karr, J.R., R.C. Heidinger, and E.H. Helmer. 1985b. Sensitivity of the index of biotic integrity to changes in chlorine and ammonia levels from wastewater treatment facilities. *Journal of the Water Pollution Control Federation* 57, 912-915.

Karr, J.R., K.D. Fausch, P.L. Angermeir, P.R. Yant, and I.J. Schlosser. 1986. *Assessing Biological Integrity in Running Waters: A Method and Its Rationale*. Illinois Natural History Survey Special Publication 5.

Miller, D.L., P.M. Leonard, R.M. Hughes, J.R. Karr, P.B. Moyle, L.H. Schrader, B.A> Thompson, R.A. Daniels, K.D. Fausch, G.A. Fitzhugh, J.R. Gammon, D.B. Halliwell, P.L. Angermeier, and D.J. Orth.. 1988. Regional applications of an index of biotic integrity for use in water resource management. *Fisheries* 13(5), 12-20.

Ohio River Valley Water Sanitation Commission (ORSANCO). 2000. *Quality assurance project plan for the collection of fish population samples as part of the fish community biocriteria development program*. ORSANCO, Cincinnati, OH. 27 pp.

ORSANCO and Ohio River Users Group. 1999. *Guidelines for Delineating Mixing Zones for Ohio River Discharges: Part I: Calculation of Mixing and Review of State Policies.* Limno-Tech, Inc., Ann Arbor Michigan. 27 pp.

Omernik, J.M. 1987. Ecoregions of the conterminous United States, *Annals of the Association of American Geographers* 77, 179-190.

Pearson, W.D. and L.A. Krumholz. 1984. *Distribution and Status of Ohio River fishes*, ORNL/Sub/79-7831/1. U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN.

Poff, N.L., J.D. Allen, M.B. Bain, J.R. Karr, K.L. Prestegaard, B.D. Richter, R.E. Sparks, and J.C. Stromberg. 1997. The natural flow regime: a paradigm for river conservation. *BioScience* 47, 769-784.

Statistical Application Software (SAS). 1996. PROC GLM module. SAS Institute, Cary, NC.

Simon, T.P. 1992. *Development of Biological Criteria for Large Rivers with an Emphasis on an Assessment of the White River Drainage, Indiana*, U.S. Environmental Protection Agency, Region 5, Chicago, IL. EPA 905/R-92/006.

Simon, T.P. and E.B. Emery. 1995. Modification and assessment of an index of biotic integrity to quantify water resource quality in great rivers, *Regulated Rivers: Research and Management*, 11, 283-298.

Simon, T.P. and J. Lyons. 1995. Application of the index of biotic integrity to evaluate water resource integrity in freshwater ecosystems. Pages 245-262 in W.S. Davis and T.P. Simon, editors. *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis Publishers, Boca Raton, FL.

Simon, T.P. and R.E. Sanders. 1999. Applying an index of biotic integrity based on great river fish communities: considerations in sampling and interpretation, Pp. 475-506, In T.P. Simon (ed.). *Assessing the Sustainability and Biological Integrity of Water Resources Using Fish Communities.* CRC Press, Boca Raton, FL.

Simon, T.P. and J.R. Stahl. 1998. *Development of index of biotic integrity expectations for the Wabash River*. EPA 905/R-96/026. USEPA, Water Division, Watershed and Non-Point Source Branch, Chicago, IL.

Sparks, R.E. 1995. Need for ecosystem management of large rivers and their floodplains. *BioScience* 45, 169-182.

Sparks, R.E., P.B. Bayley, S.L. Kohler and L.L. Osborne. 1990. Disturbance and recovery of large floodplain rivers. *Environmental Management* 14, 699-709.

Ward, J.V. and J.A. Stanford. 1989. Riverine ecosystems: the influence of man on catchment dynamics and fish ecology. *Canadian Special Publications in Fisheries and Aquatic Sciences*. 106, 56-64.

Ward, J.V. and J.A. Stanford. 1995. Ecological connectivity in alluvial river systems and its disruption by flow regulation. *Regulated Rivers*: *Research and Management* 11, 105-119.

Yoder, C.O. and E.T. Rankin. 1995a. Biological criteria program development and implementation in Ohio, in W.S. Davis and T.P. Simon (Eds.), *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis, Boca Raton, FL. 109-144.

Yoder, C.O. and E.T. Rankin. 1995b. Biological response signatures and the area of degradation value: New tools for interpreting multimetric data, in W.S. Davis and T.P

Simon (Eds.), *Biological Assessment and Criteria: Tools for Water Resource Planning and Decision Making*. Lewis, Boca Raton, FL. 263-286.

Table 23.1.

Outfall types, numbers of each type and number of samples collected. Control sites were paired with outfalls at each outfall location. Two control sites could not be sampled during one of the rounds of sampling.

Outfall Type	Number of Sites	Number of Events
Chemical	4	12
Thermal	4	12
Wastewater	3	9
Controls	11	31

Table 23.2.

Fish assemblage metrics tested for responsiveness to point source discharges and predicted responses to disturbance.

Metric	Expected response to disturbance
Native Species Richness	Decrease
Number of Sucker Species	Decrease
Number of Centrarchid Species	Decrease
Number of Great River Species	Decrease
Number of Intolerant Species	Decrease
Percentage of Tolerant Individuals	**Increase**
Percentage of Simple Lithophils	Decrease
Percentage of Invertivores	Decrease
Percentage of Detritivores	Increase
Percentage of Piscivores	Decrease
Percentage of Non-indigenous Species	**Increase**
Number of DELT Anomalies	Increase
CPUE	Decrease

Table 23.3.

Least square mean probability values based on comparisons of control and outfall data for point-source outfalls sampled during 1999 using the TZONE design and for non-overlapping 500m zones. Bold values indicate metric response values that are contrary to our *a priori* predictions (i.e., higher at control sites). Upper vs. lower outfall comparisons represent non-overlapping 500m zones at outfall sites.

Metric	Control vs. Outfall	Upper vs. Lower 500 m Outfall
Native Species Richness	0.01	0.30
Number of Sucker Species	0.36	0.55
Number of Centrarchid Species	0.007	0.52
Number of Great River Species	0.006	0.51
Number of Intolerant Species	0.42	0.64
Percentage of Tolerant Individuals	**0.0001**	0.76
Percentage of Simple Lithophils	0.0001	0.33
Percentage of Invertivores	0.004	0.79
Percentage of Detritivores	0.01	0.70
Percentage of Piscivores	0.0001	0.37
Percentage of Non-indigenous Species	**0.001**	0.68
Number of DELT Anomalies	0.62	0.42
CPUE	0.008	0.10

FIGURE CAPTIONS

Figure 1. Map of the Ohio River with outfall study locations.

Figure 2. Response of ORFIn metric and index values by traveling zone.

Figure 3. Responses of selected ORFIn metrics by traveling zone at a chemical, thermal and wastewater discharge.

Figure 4. Response of the number of native species at reference and outfall sites for three types of discharges. Sites with “poor” habitat quality are shallow with sandy substrates. Sites with “good” habitat quality are deep with coarse substrates.

Figure 1.

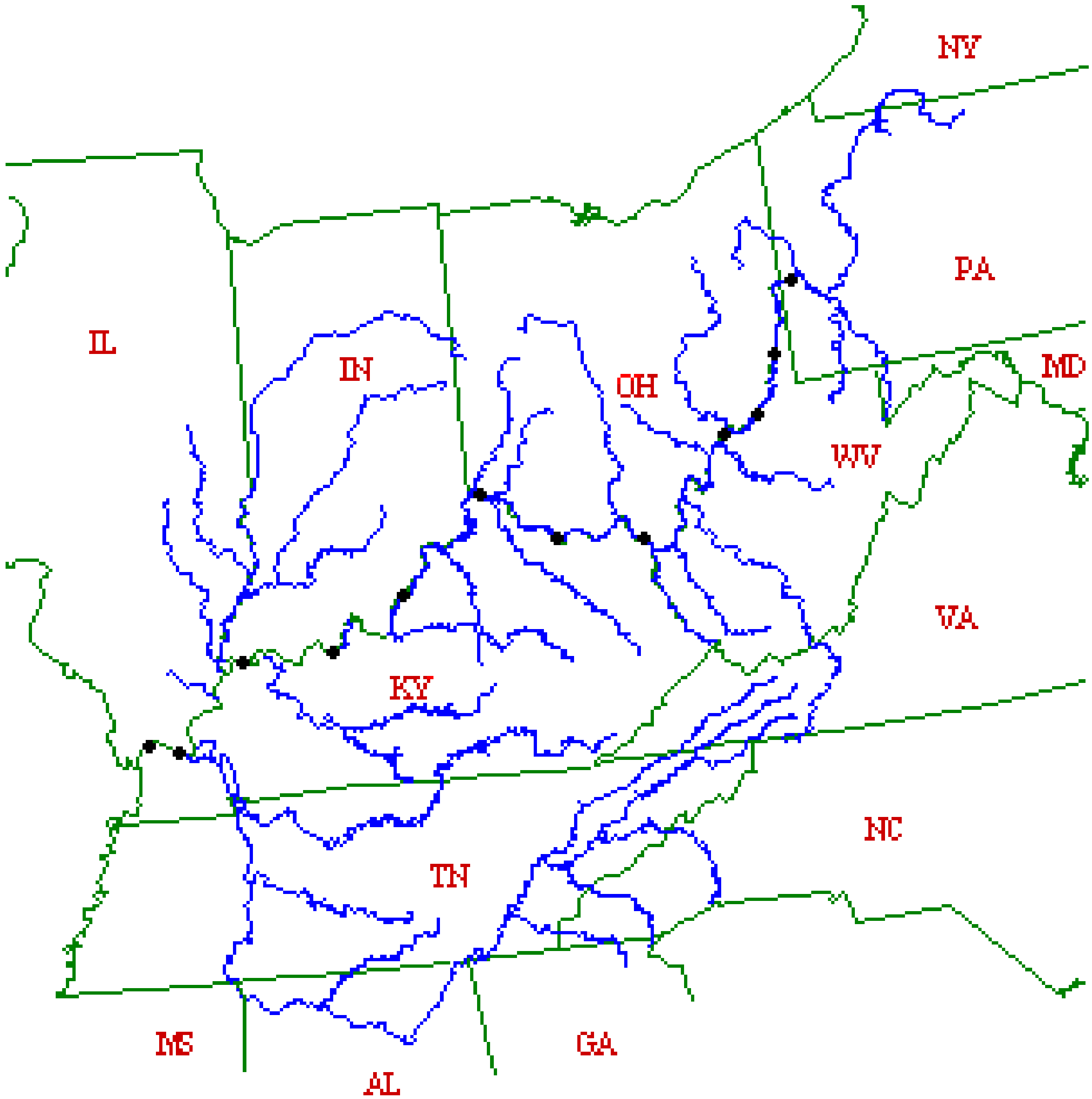
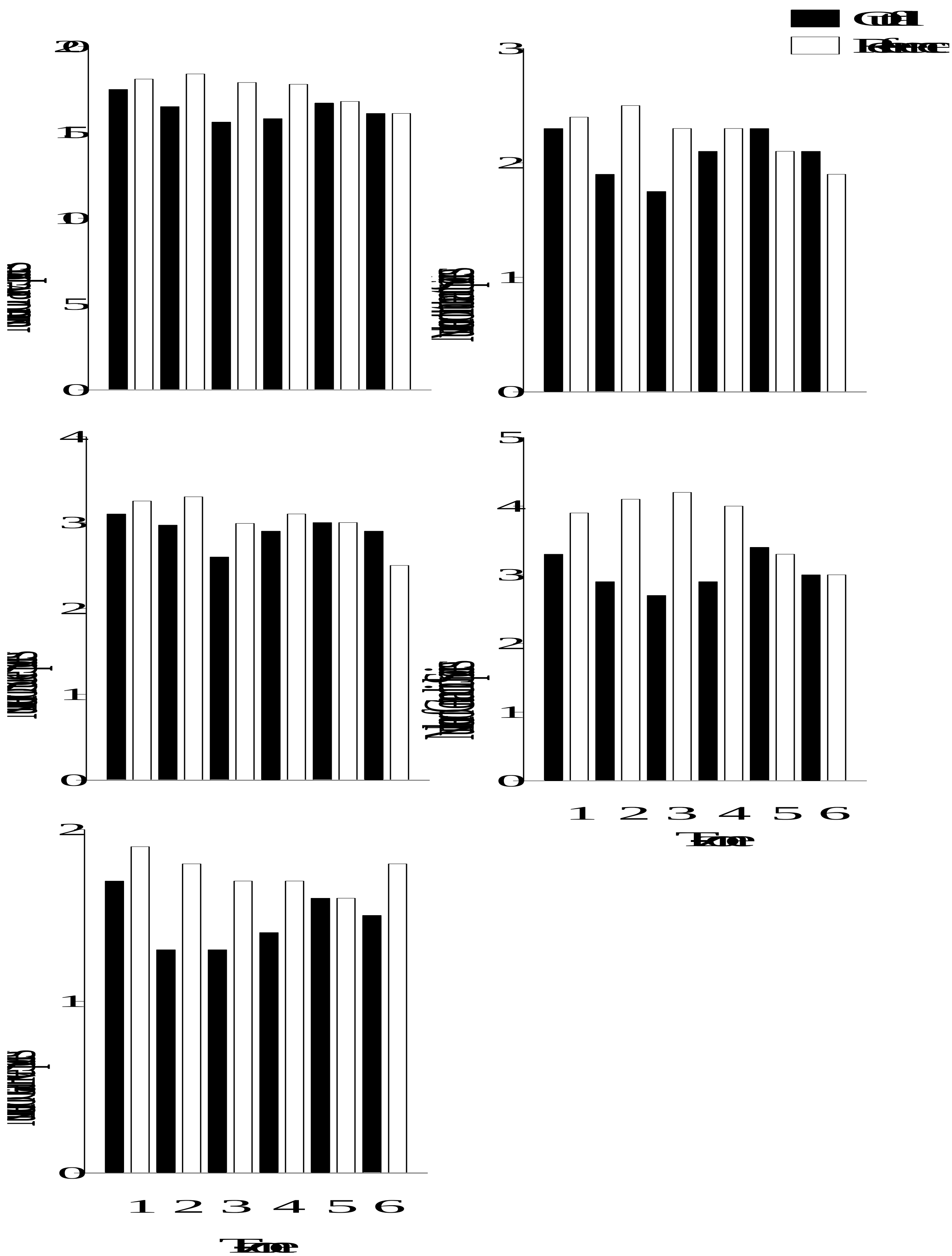


Figure 2.



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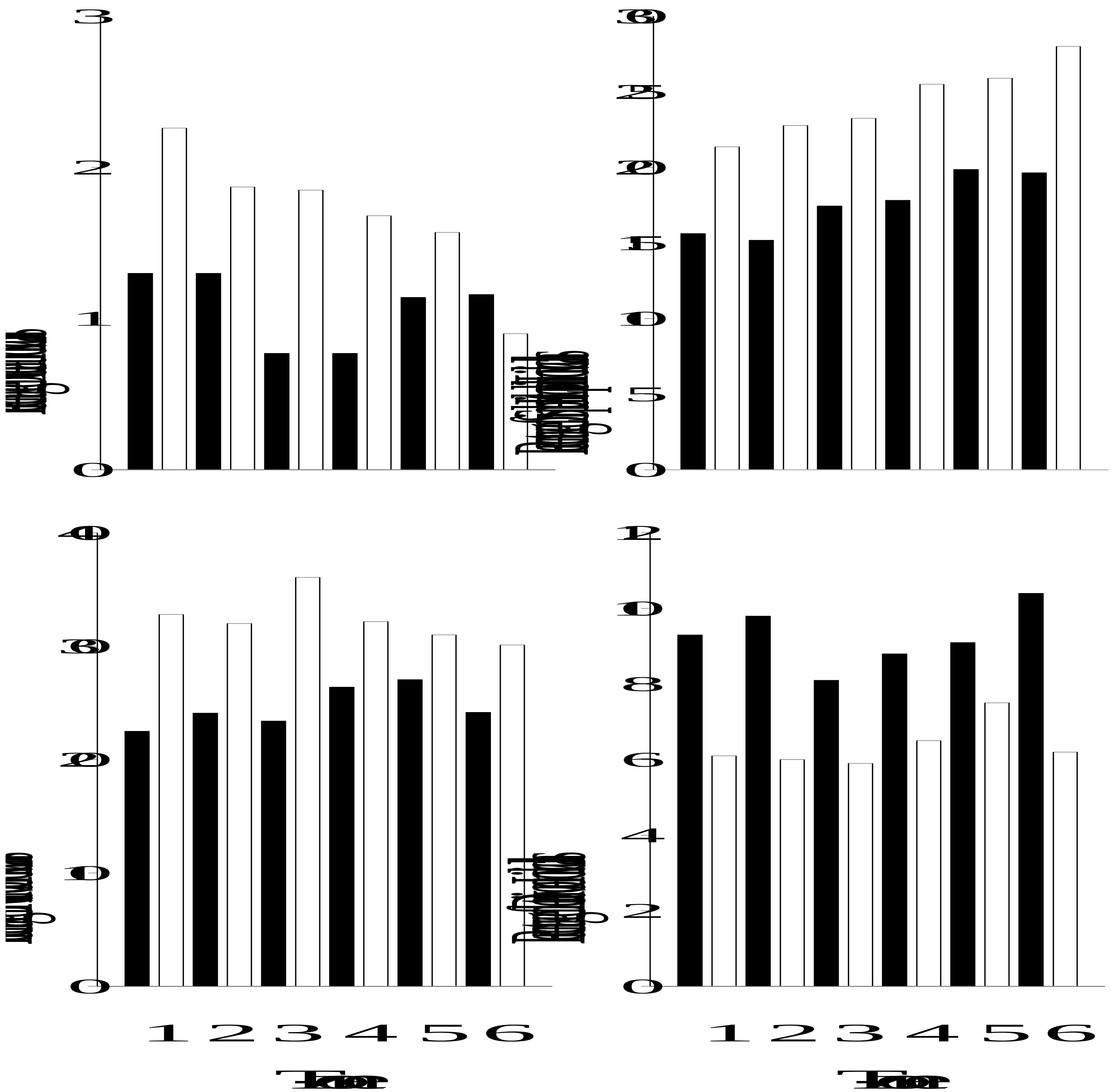

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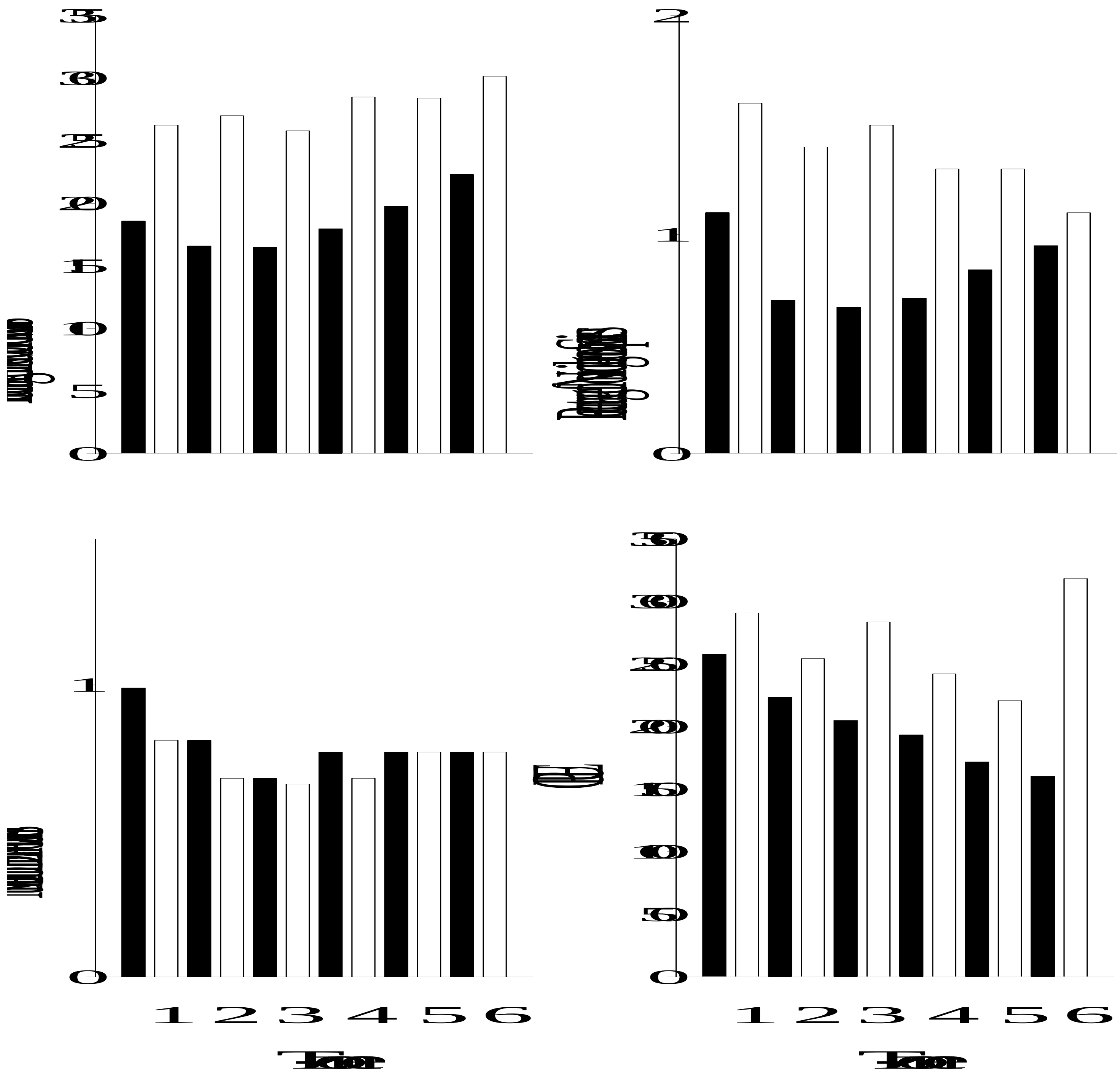

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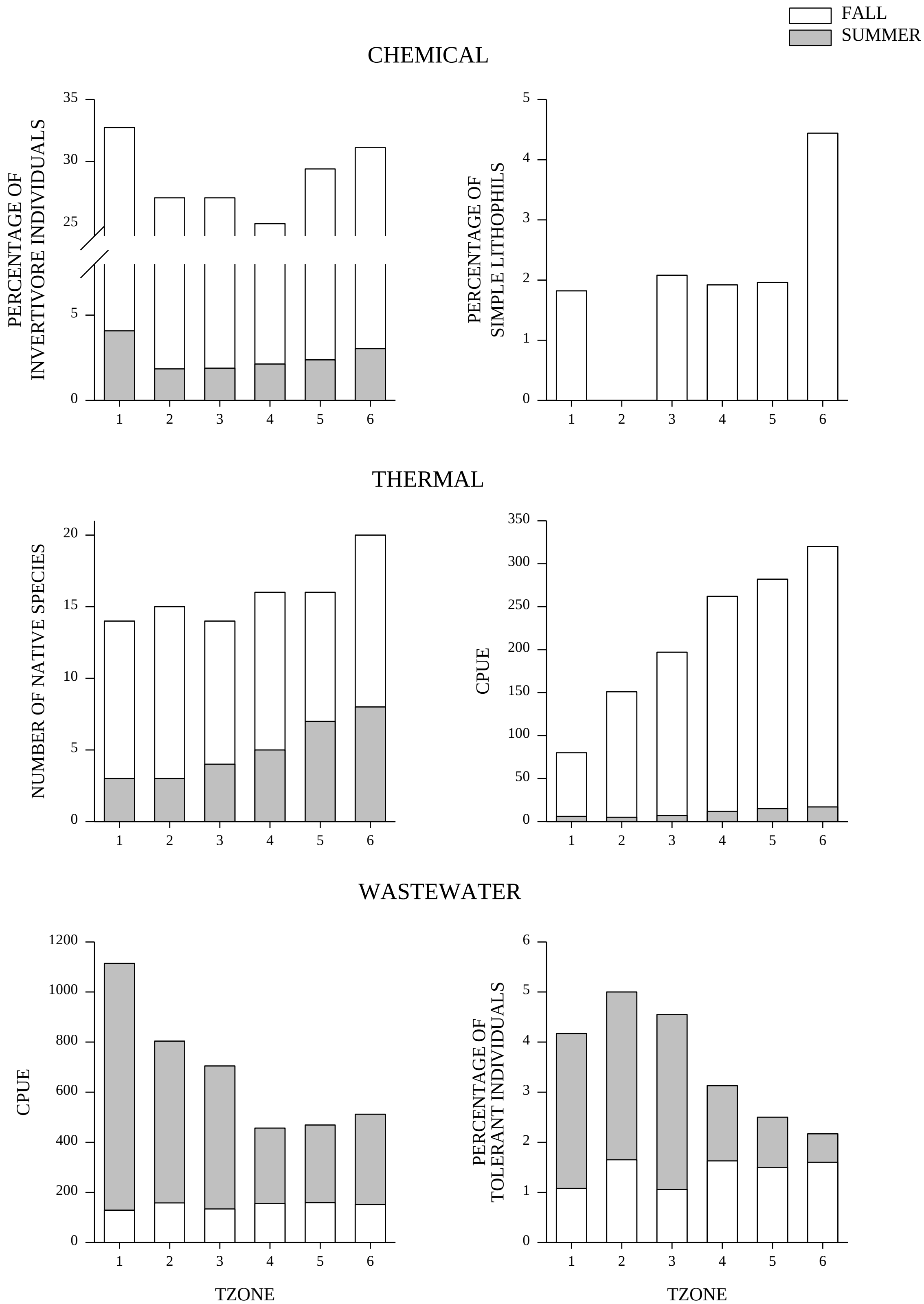
FALL
SUMMER
CHEMICAL
PERCENTAGE OF INVERTIVORE INDIVIDUALS
PERCENTAGE OF SIMPLE LITHOPHILS
THERMAL
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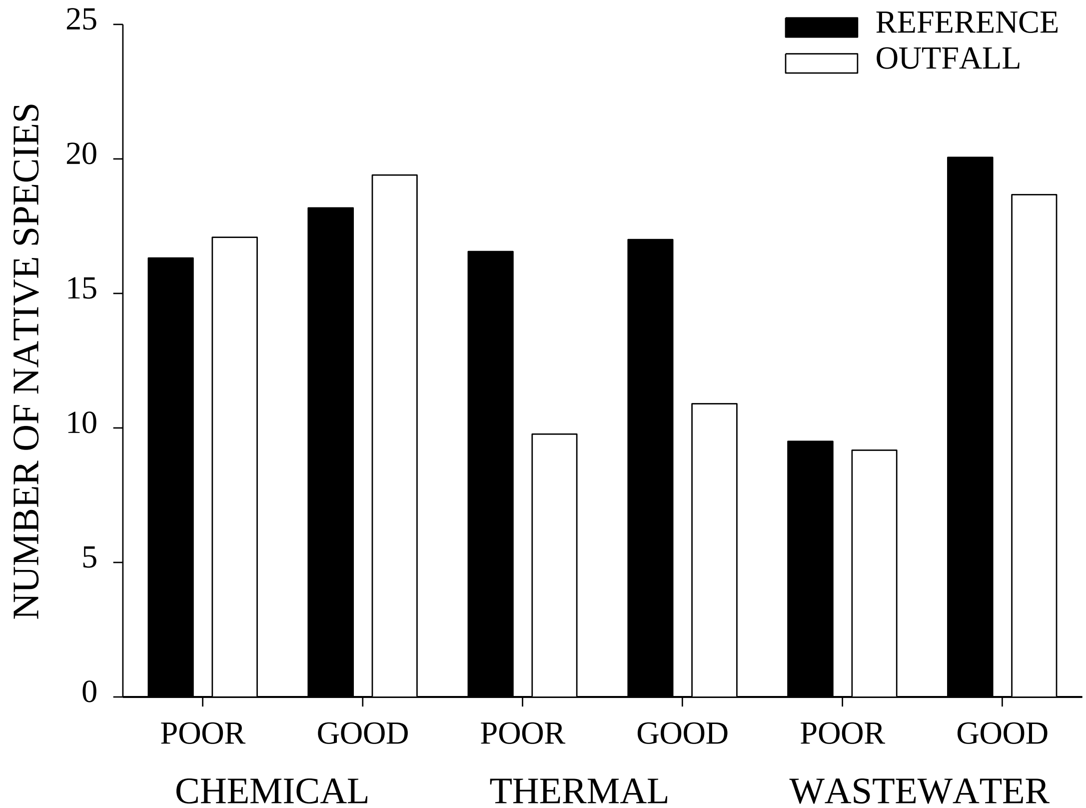
CPUE
WASTEWATER
CPUE
PERCENTAGE OF TOLERANT INDIVIDUALS
TZONE
TZONE

Figure 4.


REFERENCE
OUTFALL
NUMBER OF NATIVE SPECIES
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