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A proof-of-concept index for operational domain in floodplain lakes

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The purpose of the Biological Technical Publication series is to provide a streamlined and accessible platform for employees of the U.S. Fish and Wildlife Service and their collaborators to technical documents such as (but not limited to) preliminary reports, guides, assessments, management approaches, and project syntheses. The report series provides immediate access to science by the USFWS to the broader conservation community. The Biological Technical Publication report series was initiated in 1999 and relaunched in 2025 with a focus on sharing USFWS authored reports. It is published by the USFWS Conservation Library at the National Conservation Training Center in Shepherdstown, West Virginia. Previous report numbering systems (1999-2021) for the series referenced the USFWS region. The reports beginning in 2025 are numbered sequentially, starting with 101, with the year included for reference. Reports undergo technical review only. The findings and conclusions in this article are those of the author(s) and do not necessarily represent the views of the U.S. Fish and Wildlife Service.

Executive Summary

Floodplain lakes expand and contract as river stage, local precipitation, groundwater exchange, evapotranspiration, sedimentation, and connection pathways change. These dynamics alter not only the physical waterbody but also the portion available for boat-based field operations. Most monitoring programs record nominal effort, such as sampling time, number of stations, or crew days, without documenting the spatial domain over which that effort was applied.

Natural fluctuations in lake area and volume create three problems when developing monitoring efforts. First, variation in depth and extent affect where vessels and equipment can be deployed safely and effectively. Second, fixed effort applied over a changing operational domain can alter sampling intensity, encounter rates, and the bias or precision of catch-per-unit-effort (CPUE) and other relative-abundance indices. Third, changes in area and volume alter the spatial support of ecological observations, complicating comparisons among years, lakes, hydrologic states, and flood regimes. These problems are connected but distinct: access is an operational constraint, CPUE is an observation-process problem, and ecological comparability is an interpretive problem.

We developed the Index of Relative Sampleable Domain (IRSD) and Relative Sampleable-Domain Area (RSDA) as a low-data geometric workflow for describing expansion or contraction of the boat-accessible operational domain. The method uses a reference polygon, a centerline coordinate system, and paired distal and lateral landmarks to estimate relative geometric change between a reference condition and each field occasion. RSDA places that change on the scale of the reference polygon. It is a reference-scaled index, not a direct estimate of wetted area, water volume, navigable area, swept area, fish density, or detection probability.

Simulation results showed that the workflow was most reliable when landmarks deliberately represented the operational limits the method was designed to capture. Targeted placement improved agreement with known polygon-area ratios under simple and moderately complex conditions. Performance declined when contraction was localized or strongly asymmetric, revealing the limitations of a single global affine transformation.

We applied the workflow to repeated sampling occasions at Desoto Lake and Lake Whittington. RSDA varied substantially within both lakes and closely tracked mean river gage height, indicating that it captured broad hydrologic expansion and contraction. Species-specific CPUE models for six fish species produced mixed results. RSDA was most informative for smallmouth buffalo, whereas base or gage-height models were better supported by other species. Including RSDA did not materially change conclusions about sampling-method performance.

RSDA is best viewed as a proof-of-concept operational and spatial-support index. It makes changing field area explicit, supports planning and documentation, and provides a way to test whether spatial-domain variation affects biological inference. It is not a universal CPUE correction and does not replace bathymetry, depth mapping, water-surface mapping, vessel tracking, or independent abundance estimation.

Keywords: hydrologic variability; spatial support; sampling effort; relative abundance; observation process; affine transformation

Introduction

Hydrologic variability in floodplain lakes

River floodplains are dynamic ecosystems in which hydrologic and hydraulic processes continually reshape aquatic and terrestrial habitats (Junk et al 1989; Baker et al 1991; Bayley 1995; Tockner and Stanford 2002; Ward et al 2002). Oxbows and other floodplain lakes connect to primary river channels through tie channels, backwater inundation, or overbank flooding, then may become progressively isolated as water is lost through drainage, evapotranspiration, seepage, and groundwater exchange. The relation between river stage and adjacent lake conditions varies with geomorphic age, sill elevation, channel configuration, local inflows, and internal storage (Amoros and Bornette 2002; Hudson et al 2012).

Flood pulses therefore change more than shoreline configuration, they alter lake depth, volume, connectivity, shoreline complexity, vegetation exposure, and access for field vessels. In shallow, elongated oxbows, modest changes in water elevation can expose broad flats, isolate lake segments, restrict navigation, or open access to vegetated and formerly terrestrial margins. Sampling occasions may consequently represent different operational and ecological conditions within and among years.

Consequences of changing lake area and volume

Boat-based sampling, assessment, and treatment require adequate depth and unobstructed passage for vessels, crews, and equipment. Changes in area, depth, and shoreline configuration affect launch access, navigation, gear deployment, safety, travel time, and the number and placement of feasible sampling stations. Despite the statistical and inferential advantages, standardizing nominal effort does not standardize the operational setting in which that effort is applied.

Vessel and gear configuration can materially affect sampling coverage due to method-specific (Chick et al 1999) limitations. Shallow-draft airboats, conventional electrofishing boats, electrified dozer trawls, water-quality skiffs, and vegetation-treatment vessels differ in draft, turning radius, obstruction tolerance, and effective working margin. Therefore, operational boundaries should be defined for the focal vessel and activity rather than assumed to equal total surface area or invariable among methods.

Changing surface area can also complicate inference from catch or detection data. Catch per unit of effort (CPUE) is widely used as an index of relative abundance, but it depends on availability, encounter rate, capture efficiency, crew experience, and environmental conditions (Harley et al 2001; Maunder and Punt 2004; Guy and Brown 2007; Bonar et al 2009; Hoyle et al 2024). Standardized freshwater protocols reduce variation in effort duration, power transfer, station allocation, and field procedures (Burkhardt and Gutreuter 1995; Bonar et al 2009, 2017; Miranda 2009; Miranda and Boxrucker 2009), but fixed time or station counts do not ensure comparable spatial allocation of effort. Spatial effort metrics can reduce bias when time alone poorly represents sampling extent, yet they are seldom recorded or analyzed (Marcy-Quay et al 2019). The result is that expansion of surface area with higher river stages may dilute effort and the density of organisms, but it can also increase access to occupied habitat, alter fish-gear overlap, or improve gear operation. Contraction on the other hand concentrates organisms and effort, increasing encounter rates even when abundance is in fact unchanged (Boston et al 2016; DeBoer et al 2016). Changes in volume further affect vertical distribution and the portion of the water column exposed to sampling. Because the net effect can differ in magnitude and direction, area-based terms should be estimated and evaluated rather than imposed as proportional corrections.

Every ecological observation is tied to a geographic location. Sites are the spatial support for the observation—i.e., the area or volume over which counts, concentrations, occupancy estimates, treatment outcomes, or habitat measurements are interpreted. When lake area, volume, or morphology changes, the spatial support also changes. Counts, density, species richness, water-quality measurements, vegetation

coverage, biomass, and effort may not be directly comparable when the represented spatial domain is left implicit. This challenge is one of domain and scale. Ecological patterns depend on the grain, extent, and domain of measurement (Wiens 1989; Levin 1992; Dungan et al 2002), and combining observations from different supports can confound environmental change with measurement geometry (Gotway and Young 2002). Comparisons among years, waterbodies, connectivity states, restoration treatments, or flood regimes remain possible, but they require the spatial domain to be measured, standardized, or explicitly acknowledged.

A low-data geometric approach

Direct approaches to measuring changes in floodplain-lake area and volume include bathymetric or sonar surveys, water-level loggers paired with hypsographic curves, remotely sensed water extent, and vessel-track or shoreline-distance records (Pekel et al 2016; Jones 2019). These methods are preferable when it is feasible to collect or when suitable data are available, but they may be impractical for historical datasets, obscured by vegetation or cloud cover, costly to repeat, or poorly aligned with vessel-specific operational boundaries. We therefore developed a landmark-based workflow for settings in which a reference polygon and field-location data are available but direct measurements of operational area are not.

The workflow produces two related quantities. The Index of Relative Sampleable Domain (IRSD) is a dimensionless area-scaling factor derived from an affine transformation. The Relative Sampleable-Domain Area (RSDA) multiplies IRSD by the reference-polygon area to express the result in reference-scaled area units. Here, the spatial domain is the portion of an oxbow in which the focal vessel and equipment can feasibly operate during a field occasion.

The objectives of this proof-of-concept report were to (1) describe a reproducible IRSD/RSDA workflow; (2) evaluate its geometric behavior through simulation; (3) apply it across repeated occasions at Desoto Lake and Lake Whittington; (4) illustrate its use in CPUE models for common oxbow fishes; and (5) identify assumptions, limitations, and priorities for validation and improvement. The intended contribution is a practical framework for planning, documentation, and empirical evaluation, not a validated replacement for direct area or volume measurements.

Materials and Methods

Definitions and scope

The IRSD/RSDA procedure has six steps: (1) define a reference operational domain and delineate its polygon; (2) construct a centerline coordinate system; (3) identify paired landmarks for the reference and field-occasion configurations; (4) fit an affine transformation between the landmark sets; (5) calculate IRSD from the transformation; and (6) multiply IRSD by reference-polygon area to obtain RSDA. Section 2.2 describes the general workflow while Sections 2.3 and 2.4 describe the simulation and case-study implementation, respectively.

The operational domain is defined for a particular vessel, activity, and set of field conditions. For boat-based work, it approximates the portion of a waterbody with sufficient depth, connectivity, and freedom from vegetation or obstructions for the activity (e.g., electrified dozer trawl) to be conducted. The workflow represents relative planar change. For clarity, it does not estimate volume and should not be interpreted as total wetted area, navigable area, swept area, effective sampled area, spatial coverage, organismal availability, catchability, abundance, or density. Depth, discharge, connectivity, and other physical conditions remain separate measurements that can be analyzed in conjunction with RSDA.

Table 1 defines the principal quantities used in the workflow. The definitions are operational because the same waterbody may have different domains for different vessels, gears, seasons, safety constraints, or management activities.

Table 1 Working definitions for IRSD/RSDA workflow.

Term	Definition
Reference polygon	User-defined baseline boundary representing the operational domain under a selected reference condition.
Operational domain	Portion of the waterbody in which the focal vessel and activity can be deployed during a field occasion.
Wetted area	Total surface area, including water that may be too shallow, obstructed, vegetated, or disconnected for the focal activity.
Water volume	Three-dimensional quantity determined by area and depth; not estimated by the planar IRSD/RSDA workflow.
Spatial support	Spatial extent to which an observation or summary applies; changing support can complicate comparisons among occasions or waterbodies.
Effective sampled area	Area actually exposed to a sampling method during an operation; not estimated by RSDA.
IRSD	(Index of Relative Sampleable Domain) Dimensionless absolute determinant of the affine transformation's linear component; an index of relative area scaling.
RSDA	(Relative Sampleable-Domain Area) Reference-polygon area multiplied by IRSD; an area-scaled proxy expressed in reference-scaled units.
Effort	Recorded effort associated with an activity, such as electrofishing time, number of operations, distance traveled, or crew time.
Relative operational intensity	Nominal effort divided by RSDA; a descriptive index of effort per reference-scaled area, not actual spatial coverage.

IRSD/RSDA workflow

Reference operational domain and reference polygon

The workflow begins by defining the operational question: the vessel or platform, the field activity, the conditions under which deployment is feasible, and the limits of the relevant domain. The boundary may be determined by water depth, emergent vegetation, woody shrubs, sediment bars, access channels, obstructions, safe operating limits, or other constraints. Because the spatial domain is activity-specific, it need not coincide with the terrestrial shoreline or full wetted perimeter.

A reference polygon represents the baseline configuration against which field occasions are compared. It may correspond to a common operating condition, a mapped shoreline margin, a management benchmark, or another reproducible state; it does not have to represent the maximum water extent or high-water condition. The reference condition should be documented and applied consistently within a sampling method or program.

The polygon may be derived from field mapping, geographic information system layers, aerial or satellite imagery, or other defensible spatial sources. Calculations should use an appropriate projected coordinate reference system so that distances and areas are expressed in linear units. Geometry preparation includes removing irrelevant dimensions, repairing invalid features, extracting polygons from mixed geometries, and selecting the relevant component of multipart features. The area of the cleaned reference polygon is denoted A_{ref} (Eq. 1). Separate reference polygons and RSDA series may be needed when access differs materially among vessels or activities.

$$A_{\mathrm{ref}} = \mathrm{area}(\Omega_{\mathrm{ref}}) \tag{1}$$

Centerline coordinate system

Curved floodplain lakes (e.g., oxbows) cannot be summarized adequately by a single Cartesian length and width. Direct comparison of map coordinates can therefore confound position and orientation with changes in the longitudinal and lateral dimensions of the operational domain. The workflow addresses this problem by constructing an internal centerline and expressing landmarks in a curvilinear coordinate system.

The centerline is defined as a longitudinal path through the reference polygon. It may be generated from a medial axis or skeleton, digitized manually as a thalweg, or defined by another suitable, reproducible method. Each landmark is represented by s, the distance along the centerline from a fixed origin, and n, the signed perpendicular distance from the centerline. This representation preserves distance units while aligning points by their longitudinal and lateral positions within an oxbow.

The centerline transformation is a pragmatic normalization for landmark-based transformations (Bookstein 1991), not a complete referencing of morphometric landmarks. It provides a common frame for comparing dominant longitudinal and lateral limits and is most appropriate when one centerline captures the primary geometry. Highly branched or strongly segmented domains may require separate components, piecewise transformations, or a different spatial representation. Using s and n allows the analyst to separate position and orientation from shape change (Bookstein 1991).

Paired reference and field-occasion landmarks

IRSD requires paired landmarks that represent corresponding limits of the reference and field-occasion domains. The minimum configuration used here contains four reference landmarks: two distal landmarks at the longitudinal ends of the reference centerline and two lateral landmarks on opposite sides near its midpoint (Figure 1). Together, they describe the dominant longitudinal and lateral dimensions of the reference domain. Additional lateral pairs can be placed at proportional positions along the centerline when greater detail is needed.

Field-occasion landmarks represent the same conceptual limits under conditions observed during a sampling occasion. They may be measured directly as access-limit locations or reconstructed from operation coordinates, vessel tracks, field notes, maps, imagery, or other spatial records. They should represent the limits of the occasion-level operational domain, not the activity center, the vessel route, or the area sampled. Reference and occasion landmarks must be paired consistently—i.e., the number of occasion-level distal landmarks and occasion-level lateral landmarks must equal the same number of each type of reference landmarks.

Targeted landmark collection is preferable to retrospective inference from routine sampling points. A minimal field protocol records both distal limits and both lateral margins, together with notes on depth, obstructions, connectivity, vessel type, and why each point represented an operational limit. Routine samples may not reach those limits because of randomized station selection, habitat targeting, safety decisions, or incomplete coverage. When routine locations are used, selections should be reviewed and changes documented.

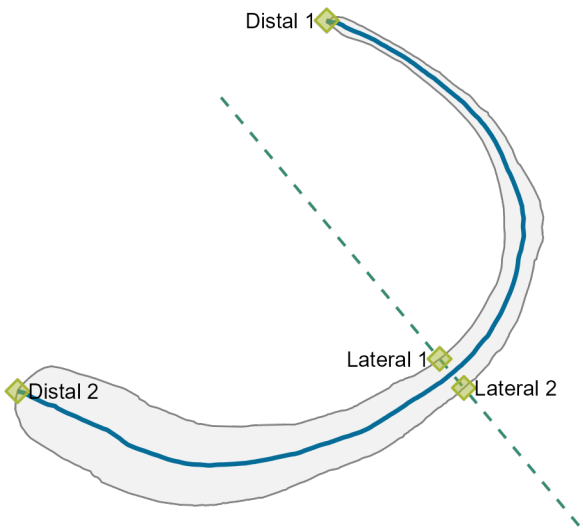


Figure 1 Example oxbow lake showing the centerline (solid line) and midpoint perpendicular (dashed line). The longitudinal endpoints are labeled as distal landmarks, and the intersections of the midpoint perpendicular with the perimeter are labeled as lateral landmarks; these constitute reference landmarks. Field-occasion landmarks are represented using a centerline coordinate system with s as the distance along the centerline from Distal 1 and n as the signed perpendicular distance from the centerline (Lateral 1 negative and Lateral 2 positive).

Affine transformation, IRSD, and RSDA

For field occasion j, an affine transformation maps paired reference landmarks to occasion landmarks in centerline coordinates. Let (s, n) denote a reference landmark and (s', n') the corresponding occasion landmark:

$$s' = a \cdot s + b \cdot n + c, \tag{2}$$

$$n' = d \cdot s + e \cdot n + f, \tag{3}$$

The six parameters (a-f) are estimated by least squares. Translation parameters c and f change position but not area scaling; scaling is determined by the linear component:

$$\mathbf{M} = \begin{bmatrix} a & b \\ d & e \end{bmatrix}. \tag{4}$$

The determinant of $\mathbf{M}$ is the signed area-scaling factor. Because orientation reversal has no substantive meaning here, IRSD is defined as the absolute determinant:

$$\text{ISRD} = |\det(\mathbf{M})|. \tag{5}$$

Therefore, IRSD is dimensionless. Values greater than 1 indicate net expansion relative to the reference, values less than 1 indicate contraction, and values near 1 indicate little net area scaling. RSDA places the index on the scale of the reference polygon:

$$\text{RSDA} = A_{\text{ref}} \cdot \text{IRSD}. \tag{6}$$

RSDA has area units because it is multiplied by A_{ref}, but those units are reference-scaled and not direct measurements of accessible or wetted area. The affine transformation can represent translation, rotation, shear, and global scaling, but the determinant reduces that change to one area factor. RSDA therefore does not: show where change occurred, preserve local shoreline complexity, distinguish connected from disconnected pockets, or quantify water volume.

Quality assurance, interpretation, and implementation options

Each occasion should be evaluated geometrically before its IRSD or RSDA value is used. Quality assurance should include mapped overlays of reference and occasion landmarks, verification of landmark identity and ordering, checks for side reversals or implausible distal assignments, and confirmation that the transformation represents the intended operational limits. Affine residuals and root-mean-square error describe agreement between observed landmarks and the fitted global transformation, but low residual error does not establish that the landmarks captured the true operational boundary.

The landmark configuration should match the geometry and objective. Four landmarks provide a parsimonious first-order representation, but additional landmarks may better describe variable width. More landmarks also require more stable correspondences and do not resolve violations of the global affine assumption. Strongly nonuniform change may require piecewise affine transformations, centerline width profiles, segmented domains, explicit depth surfaces, or direct mapping of occasion-specific operational polygons.

RSDA should generally be treated as a measured descriptor or estimated covariate unless a proportional relation with an outcome has been independently justified. Using log RSDA as an offset in a catch model would force expected catch to change in direct proportion to the indexed domain. That assumption is likely to be too strong because expansion may dilute fish, increase access to occupied habitat, alter fish-gear overlap, or have little net effect. The direction and functional form of any association should be evaluated empirically; an assessment needed for RSDA.

Simulation-based sensitivity analysis

We evaluated the geometric behavior of the IRSD/RSDA workflow by comparing point-derived IRSD estimates with known polygon-area ratios. Four example polygons represented two shoreline-complexity classes and two water conditions: simple normal-water, simple low-water, complex normal-water, and complex low-water. Within each complexity class, the normal-water polygon was the reference. The benchmark was the condition-polygon area divided by the corresponding reference-polygon area. This benchmark tested recovery of geometric scaling only; it did not represent navigable area, effective sampled area, fish exposure, abundance, or density (quantities also not represented by IRSD/RSDA).

The primary simulation generated 10 points per polygon and compared untargeted with targeted placement. Untargeted points were selected randomly near the boundary and displaced normal to it. Targeted designs placed four points near the expected distal and lateral landmark locations and allocated the remaining six randomly. Specifically, boundary-normal displacement followed an asymmetric truncated distribution with a mean of 20 m inward, a standard deviation of 30 m, and bounds of 40 m outside and 100 m inside the polygon. Targeted points also received along-boundary displacement with a standard deviation of 25 m. Each polygon-by-placement combination was replicated 100 times.

Each point set was processed through the four-landmark centerline and affine workflow. Performance was summarized by mean percent difference, mean absolute percent difference, empirical 5th–95th percentile intervals, and the proportions of estimates within ±10% and ±20% of the polygon-area ratio. Secondary checks were examined—20 points, six landmarks, systematic placement, and targeted-systematic placement—but produced similar results and were not included here for brevity.

Case-study illustration

Study lakes and field sampling

The case application used two Lower Mississippi Alluvial Valley oxbows that we electrofished from 2023 through 2025. The dataset contained 13 sampling occasions: seven at Desoto Lake and six at Lake Whittington. Both oxbows undergo substantial hydrologic expansion and contraction annually and

therefore provided suitable examples for deriving RSDA from routine field locations and comparing it with an external river-stage series.

We sampled fish assemblages using an electrified dozer trawl and modified electrofishing methods. The electrified dozer trawl pushes a framed conical net ahead of the vessel, whereas modified electrofishing combines controlled boat maneuvering, electrical power, and dip-net capture (Bouska et al 2017; Hammen et al 2019). Their different deployment and encounter mechanisms provided a useful setting for testing whether an occasion-level spatial-domain descriptor contributes to CPUE models.

Operation-level records included date, lake, sampling method, geographic coordinates, effort (time), mean water depth, and gage height. Fish were identified and enumerated following regional taxonomic guidance (Ross 2001). We selected six species for the CPUE illustration presented here which included gizzard shad (*Dorosoma cepedianum*), bluegill (*Lepomis macrochirus*), smallmouth buffalo (*Ictiobus bubalus*), freshwater drum (*Aplodinotus grunniens*), shortnose gar (*Lepisosteus platostomus*), and largemouth bass (*Micropterus nigricans*). These species differed in catch frequency, aggregation, habitat association, and sampling-method response. They were chosen based on their assumed contrasting observation processes, not to define ecological guilds or universal responses to changing operational area.

Case-specific implementation of the IRSD/RSDA workflow

For each lake, the reference polygon was delineated manually in Google Earth Pro along the shoreline margin associated with emergent vegetation, woody shrubs, shallow water, and other apparent constraints on the two electrofishing methods, and checked against field notes and crew observations. These polygons represented an operational reference condition for both sampling methods, not total surface area. The polygons were exported as Keyhole Markup Language files, imported into R, transformed to North American Datum of 1983, Universal Transverse Mercator Zone 15N (EPSG:26915), and cleaned by removing Z/M dimensions, repairing invalid geometries, extracting polygon features, and retaining the relevant polygon component. Spatial processing used the sf package in R (Pebesma 2018; R Core Team 2024).

A Voronoi-based skeleton was generated from each polygon, and the dominant path was retained as the lake centerline. Reference landmarks comprised two distal points at the centerline ends and two lateral points on opposite sides near the midpoint. Reference and field coordinates were transformed into centerline coordinates before affine fitting.

Field operations were grouped by lake, year, and month. Locations from both electrofishing methods were pooled within an occasion because the methods were assumed to share the same operational domain. Candidate occasion landmarks represented the distal and lateral limits reached during that occasion. Lake-specific quality-assurance maps were reviewed, and overrides were applied when an operation did not plausibly represent an access limit or when the initial configuration was implausible.

For each occasion, paired reference and occasion landmarks were used to fit the affine transformation. IRSD was calculated as the absolute determinant of the fitted linear component, and RSDA was obtained by multiplying IRSD by the lake's reference-polygon area. The occasion-level value was assigned to all operations in that group. These choices were specific to the case study and other applications may use slightly different methods which can accommodate local conditions.

Occasion-level hydrologic comparison

Mean gage height (GH) at the Mississippi River—U.S. Geological Survey gage number 07047870 at Helena, Arkansas (river mile 663.1)—was calculated for each sampling occasion from distinct operation records. Minimum and maximum GH described stage variation during the occasion. GH and RSDA were therefore represented at the same occasion level, avoiding pseudo-replication from repeated operations.

Within each lake, Pearson correlation summarized linear correspondence between GH and RSDA, and Spearman correlation summarized monotonic correspondence. Scatterplots with lake-specific linear fits were used descriptively to assess direction, consistency, and possible nonlinearity. With only 13 independent lake-occasion observations, these analyses were not interpreted as validated prediction models or true boat-accessible area.

CPUE model comparison

For each focal species, we fit three Bayesian negative-binomial models with a log link (Eqs. 7-9). All models included lake (L), year (Y), sampling method (M), standardized operation-level water depth (WD), a method-by-depth interaction, a random intercept for sampling occasion, and log effort (E) as an offset. The models differed only in the occasion-level term: none (BASE), standardized GH, or standardized log RSDA (LOGRSDA). GH and LOGRSDA were evaluated separately because they represented alternative descriptions of the same hydrologic gradient and were strongly correlated in the case dataset.

$$C_i \sim \text{NegBin}\left(\lambda_{ig}, \phi\right), \tag{7}$$

$$\log\left(\lambda_{ig}\right) = \alpha + \text{L} + \text{Y} + \text{M} \cdot \text{WD} + X + \gamma_g + \log\left(E_{ig}\right), \tag{8}$$

$$\gamma_g = \text{Normal}\left(0, \sigma_g\right), \tag{9}$$

In these equations, α is the intercept, X is the candidate occasion-level term, and the remaining terms are defined above. RSDA was evaluated as a covariate rather than an offset because proportionality between expected catch and operational area was unknown. GH was calculated from distinct operations and standardized within the common GH series. LOGRSDA was assigned by occasion and standardized across the complete dataset; operation-level water depth was also standardized. Priors were Normal(0, 2) for the intercept and fixed effects and Exponential(1) for the occasion-level standard deviation and negative-binomial shape parameter. Models were fit in brms with four chains, 4,000 iterations per chain, 1,000 warmup iterations, a target sampler acceptance probability (the adapt_delta argument) of 0.99, and a maximum tree depth of 15 (Bürkner 2017). Each species used the same complete-case dataset of 250 operations.

Model support was summarized with the widely applicable information criterion (WAIC) model weights and differences in expected log predictive density (ELPD). Bayesian R^2 values were used as a supporting measure of within-sample fit (Vehtari et al 2017). The primary comparison contrasted the LOGRSDA model with the highest-ranked model that did not include LOGRSDA (i.e., BASE and GH). Posterior predictive checks assessed the distribution of counts, zero catches, and high-catch observations for visual assessment of model plausibility.

Population-level CPUE was standardized to 300 s of effort, excluding occasion-specific random deviations and averaging over the empirical distribution of other covariates. Because abundance was not independently estimated, predicted CPUE was interpreted as a standardized relative catch rate. Associations with RSDA were treated as observation-process relationships, not direct estimates of abundance, density, availability, catchability, or sampling efficiency as noted previously.

Results

Geometric performance in the sensitivity analysis

Across the primary simulation, recovery of known polygon-area ratios depended mainly on landmark placement and geometric condition. Targeted designs produced narrower IRSD distributions than untargeted designs, indicating that points deliberately located near distal and lateral limits yielded more stable estimates of global area scaling (Figure 2). Untargeted placement produced broader distributions and longer tails, especially for the complex normal-water polygon.

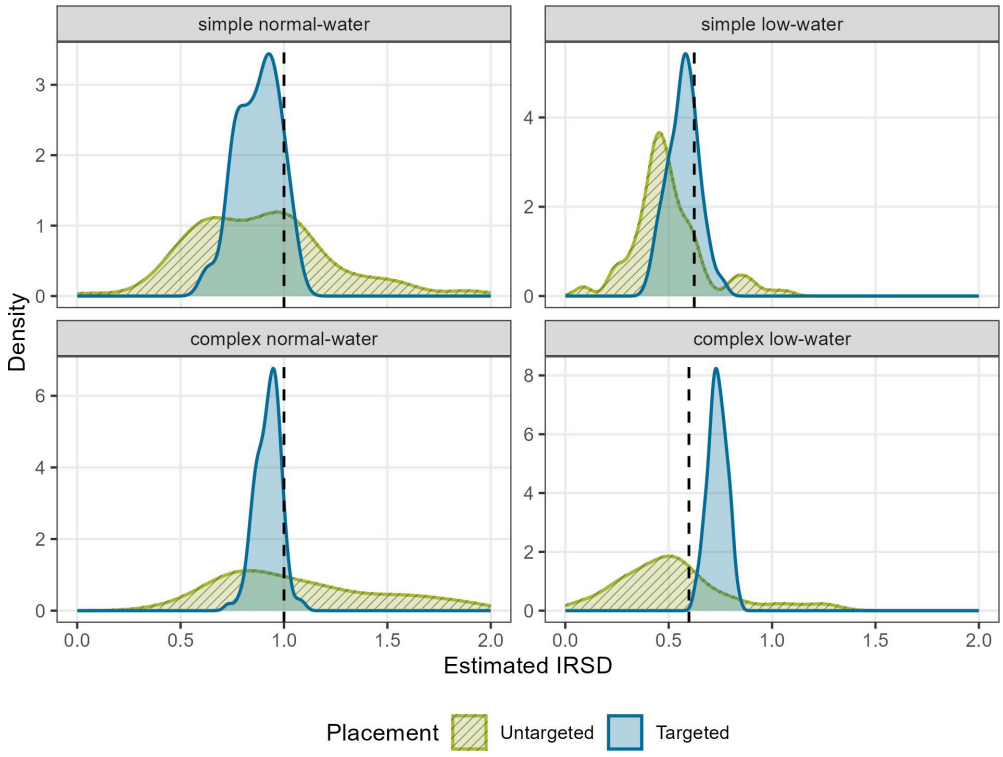


Figure 2 Estimated IRSD distributions for four polygon conditions. Dashed lines show polygon-area ratios. Targeted designs included distal and lateral points; untargeted designs used random boundary-offset points (100 replicates per condition and design). Untargeted distributions are hatched; targeted distributions are unhatched.

For the simple normal-water, simple low-water, and complex normal-water polygons, targeted placement reduced the mean absolute percent difference and increased the proportions of estimates within ±10% and ±20% of the polygon-area ratio (Figure 3). The main benefit was reduced dispersion and greater practical agreement, not the uniform removal of directional bias.

The complex low-water condition was the main exception. Targeted estimates were relatively precise but centered above the polygon-area ratio, with mean percent difference and mean absolute percent difference of approximately 23%. Only about 35% of estimates from either design fell within ±20% of the benchmark. This pattern indicates structural error: a four-landmark global affine transformation could not fully represent localized, asymmetric contraction. Secondary checks with more points, additional landmarks, or systematic placement did not contradict that interpretation.

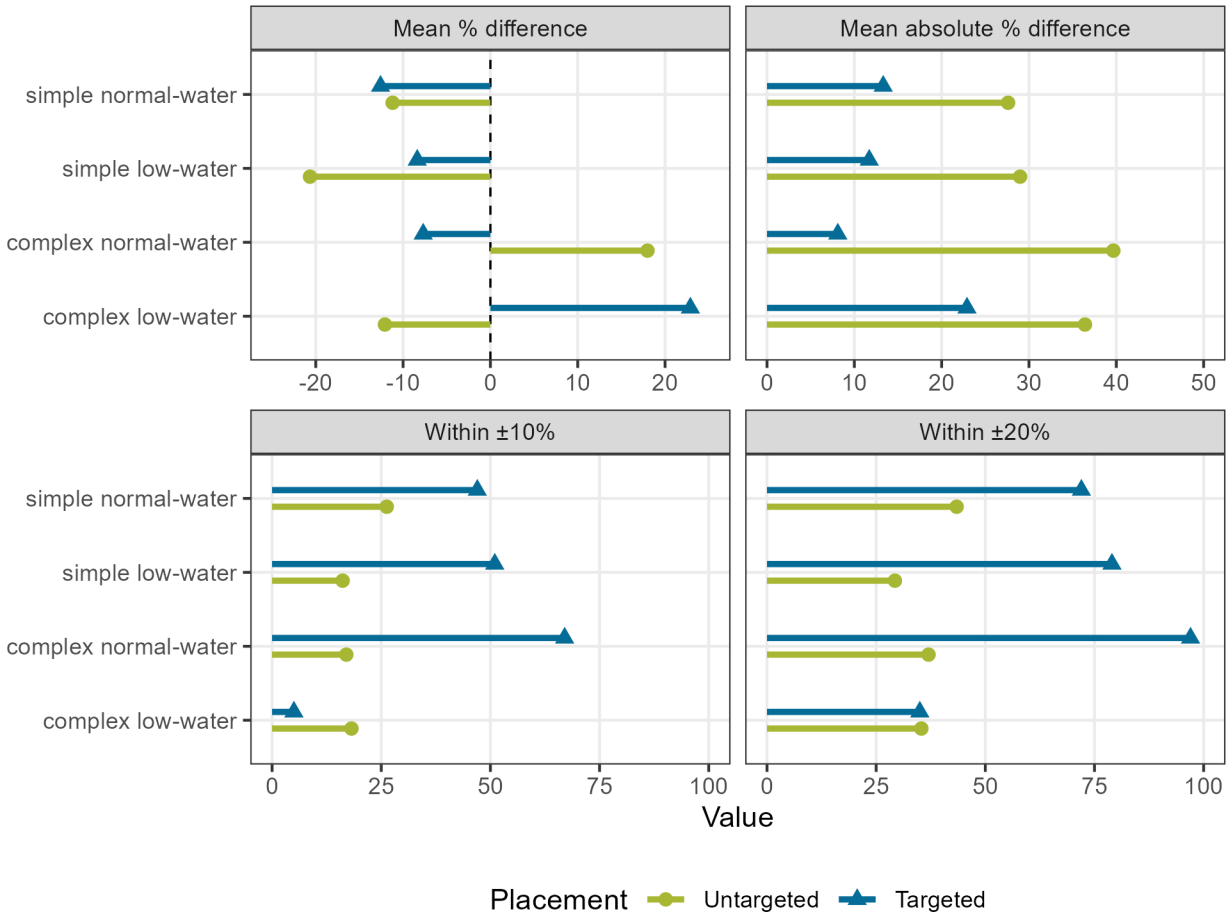


Figure 3 Performance of targeted and untargeted placement in the sensitivity analysis. Metrics are mean percent difference, mean absolute percent difference, and the percentages of estimates within ±10% and ±20% of the polygon-area ratio.

Case-study RSDA variation

Grouping operations by lake, year, and month produced 13 field occasions: seven at Desoto Lake and six at Lake Whittington. The workflow yielded one four-landmark affine estimate and one RSDA value per occasion. Initial landmark assignments were reviewed on lake-specific quality-assurance maps, and documented overrides were applied before final values were retained. Assigning each occasion-level value to all operations in its group produced a common complete-case dataset of 250 operations per species for the CPUE analysis.

RSDA varied substantially within both lakes. Desoto Lake ranged from 194 to 620 reference-scaled ha, a 3.2-fold range, whereas Lake Whittington ranged from 86 to 1,092 ha, a 12.7-fold range. Equal numbers of operations or equal electrofishing time were therefore applied across markedly different indexed operational domains, especially at Lake Whittington.

Within-lake contrasts are the primary interpretation because absolute RSDA values reflect both the user-defined reference-polygon area and the estimated scaling. The values should not be interpreted as surveyed water-surface or boat-accessible area. All correlations used one observation per sampling occasion.

Occasion-level correspondence with river stage

RSDA closely tracked GH in both lakes (Figure 4). Pearson correlations were 0.958 for Desoto Lake and 0.953 for Lake Whittington; Spearman correlations were 0.964 and 0.943, respectively. Lake Whittington showed the wider RSDA range, suggesting a larger geometric response over the observed hydrologic conditions. The limited number of occasions precluded estimation of nonlinear thresholds or filling-versus-draining hysteresis. These results demonstrate hydrologic responsiveness, not validation of RSDA as a direct measure or predictor of boat-accessible area. They also show that river stage and RSDA carried highly redundant information in this dataset, a relation that may differ in other systems.

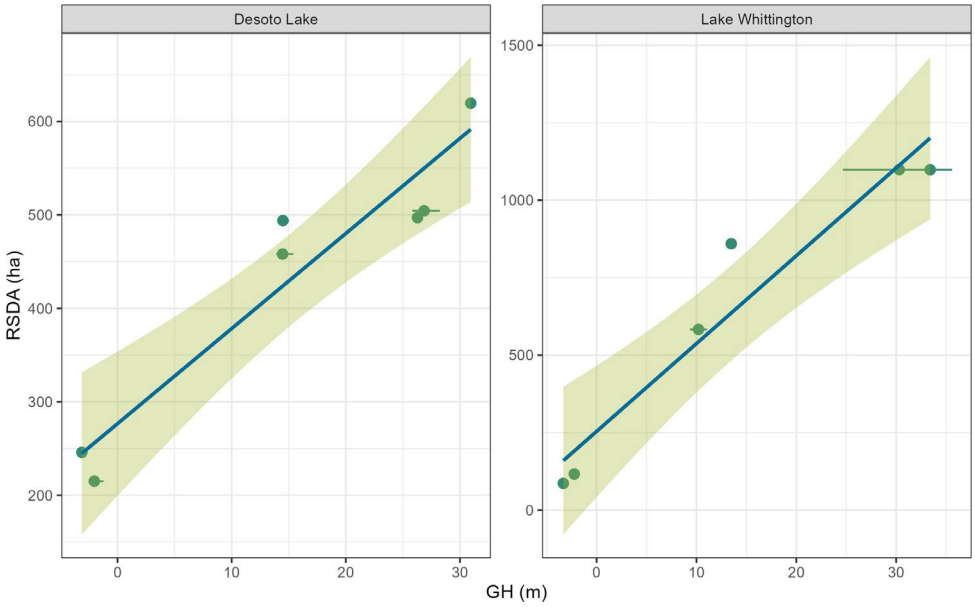


Figure 4. RSDA (ha) and mean gage height (m; GH) at the Mississippi River at Helena, Arkansas (river mile 663.1), for seven Desoto Lake and six Lake Whittington occasions. Horizontal segments show the minimum-to-maximum GH recorded during each occasion. Lines are lake-specific linear fits shown for description, not validated access-prediction models.

CPUE model comparison

The six focal species differed markedly in replication, aggregation, and response to sampling method, providing contrasting tests of an occasion-level RSDA covariate. Catch support is summarized in Table 2, candidate-model results in Table 3, and standardized method-specific CPUE in Figure 5.

Data support and candidate-model ranking

Catch support varied widely among species (Table 2). Gizzard shad were captured during all 13 occasions and totaled 14,744 fish, whereas bluegill and largemouth bass were detected infrequently and were strongly concentrated during a few occasions.

Table 2. Operation- and occasion-level catch support for the six focal species. A total of 250 operations and 13 occasions were possible.

Species	Positive operations	Occasions detected	Catch in largest occasion
Gizzard shad	135	13	40.6%
Shortnose gar	153	13	14.0%
Smallmouth buffalo	97	12	18.8%
Freshwater drum	28	10	33.3%
Bluegill	23	5	71.4%
Largemouth bass	24	7	65.6%

All 18 models converged satisfactorily: split-chain R-hat values were no greater than 1.003 (target < 1.1), minimum bulk effective sample sizes exceeded 1,498 (target > 100 × no. of chains = 400), and no divergent transitions or maximum-tree-depth events occurred (target = 0). Posterior predictive checks reproduced the broad count distributions and zero frequencies, although fitted means smoothed the largest catches, especially for gizzard shad. Sparse catches of bluegill, freshwater drum, and largemouth bass produced wide predictive uncertainty. The diagnostics therefore supported the general negative-binomial formulation but did not imply complete representation of episodic aggregation or rare-catch processes.

The BASE model ranked first for gizzard shad (WAIC weight = 0.47), bluegill (0.41), and shortnose gar (0.41; Table 3). The GH model ranked first for freshwater drum (0.58) and largemouth bass (0.73), whereas the LOGRSDA model ranked first only for smallmouth buffalo (0.53). No occasion-level formulation was favored consistently across species.

Compared with the highest-ranked non-LOGRSDA model, the LOGRSDA model changed ELPD by -2.16 for largemouth bass to +0.61 for smallmouth buffalo. Changes in Bayesian R^2 ranged from -0.0035 to +0.0111. Smallmouth buffalo was the only species for which LOGRSDA ranked first and increased point-estimated ELPD, but the gain was small relative to its standard error. The LOGRSDA model was clearly less supported than GH for largemouth bass; differences for the other species were weak or equivocal.

Table 3. Candidate-model comparison for six focal species. Within each species, ΔELPD is reported relative to the top-ranked model. ELPD = expected log predictive density.

Species	Model	WAIC weight	ΔELPD (SE)	R^2	Interpretation
Gizzard shad	BASE	0.47	0.00 (–)	0.19	BASE ranked first; LOGRSDA had the least support.
	GH	0.37	-0.25 (0.75)	0.19	
	LOGRSDA	0.16	-1.06 (0.97)	0.20	
Bluegill	BASE	0.41	0.00 (–)	0.36	Models were similarly supported; evidence was inconclusive.
	LOGRSDA	0.30	-0.32 (0.64)	0.36	
	GH	0.29	-0.35 (0.44)	0.36	
Smallmouth buffalo	LOGRSDA	0.53	0.00 (–)	0.30	LOGRSDA ranked first, but its advantage over GH was small relative to uncertainty.
	GH	0.29	-0.61 (1.13)	0.29	
	BASE	0.18	-1.11 (1.38)	0.29	
Freshwater drum	GH	0.58	0.00 (–)	0.23	GH ranked first; LOGRSDA provided no clear predictive gain.
	LOGRSDA	0.25	-0.85 (1.42)	0.24	
	BASE	0.18	-1.18 (1.89)	0.21	
Shortnose gar	BASE	0.41	0.00 (–)	0.35	BASE and LOGRSDA were nearly tied; predictive differences were negligible.
	LOGRSDA	0.38	-0.06 (1.41)	0.36	
	GH	0.21	-0.65 (1.15)	0.36	
Largemouth bass	GH	0.73	0.00 (–)	0.37	GH ranked first; LOGRSDA was substantially less supported.
	BASE	0.19	-1.37 (0.50)	0.35	
	LOGRSDA	0.08	-2.16 (0.77)	0.36	

The strength of inference depended on replication across occasions. Species detected broadly and without one dominant event supported more stable comparisons than sparse or highly aggregated species. Overall, the results show that LOGRSDA may describe relevant occasion-level variation for some taxa, but they do not support a common spatial-domain correction. Stronger or different patterns may emerge in lakes whose hydrology is less tightly coupled to a major river.

Occasion-level gage height and RSDA associations

Smallmouth buffalo showed the clearest hydrologic association. Catch declined with standardized mean GH (-0.95; 95% credible interval = -1.82 to -0.13) and standardized LOGRSDA (-0.83; -1.50 to -0.23). Because the predictors were evaluated in separate models, these coefficients are alternative descriptions of the same hydrologic gradient, not independent effects. The negative LOGRSDA association is

consistent with greater encounter rates under a contracted domain, but it cannot distinguish spatial concentration from changes in habitat use, availability, abundance, or sampling efficiency.

Freshwater drum and shortnose gar also had negative point estimates under both hydrologic formulations, but their credible intervals overlapped zero. For freshwater drum, coefficients were -0.89 (-1.87 to 0.07) for GH and -0.45 (-1.22 to 0.24) for LOGRSDA; GH ranked first. For shortnose gar, coefficients were -0.25 (-0.75 to 0.27) and -0.32 (-0.69 to 0.05), respectively, and BASE and LOGRSDA were nearly tied. These results suggest possible increases in encounter rate during contraction, but neither species clearly distinguished LOGRSDA from the alternatives.

The remaining species showed no coherent hydrologic pattern. Gizzard shad coefficients were -0.33 (-1.35 to 0.64) for GH and +0.45 (-0.39 to 1.21) for LOGRSDA. Bluegill coefficients were positive but imprecise (+0.68, -1.30 to 2.62; +1.37, -0.20 to 3.05), and largemouth bass estimates were -0.91 (-3.03 to 0.96) for GH and +0.19 (-1.56 to 1.40) for LOGRSDA. Wide intervals for bluegill and largemouth bass reflected sparse detections and concentration of catch on few occasions; inference for gizzard shad was limited by schooling and upper-tail aggregation.

Standardized CPUE and sampling-method contrasts

Including LOGRSDA changed population-level standardized CPUE estimates only modestly. The electrified dozer trawl retained a pronounced advantage for gizzard shad and shortnose gar, and it also produced higher CPUE for smallmouth buffalo (Figure 5).

Method contrasts were less certain for bluegill, freshwater drum, and largemouth bass. Point estimates favored the electrified dozer trawl for bluegill and modified electrofishing for freshwater drum and largemouth bass, but credible intervals overlapped broadly. Across all six species, the LOGRSDA model produced no qualitative reversal in method interpretation and only minor changes in posterior medians and intervals.

In Table 3, ΔELPD is reported relative to the top-ranked model for each species; values closer to zero indicate similar expected predictive performance. Bayesian R^2 describes within-sample fit and should not be interpreted as independent evidence of out-of-sample improvement.

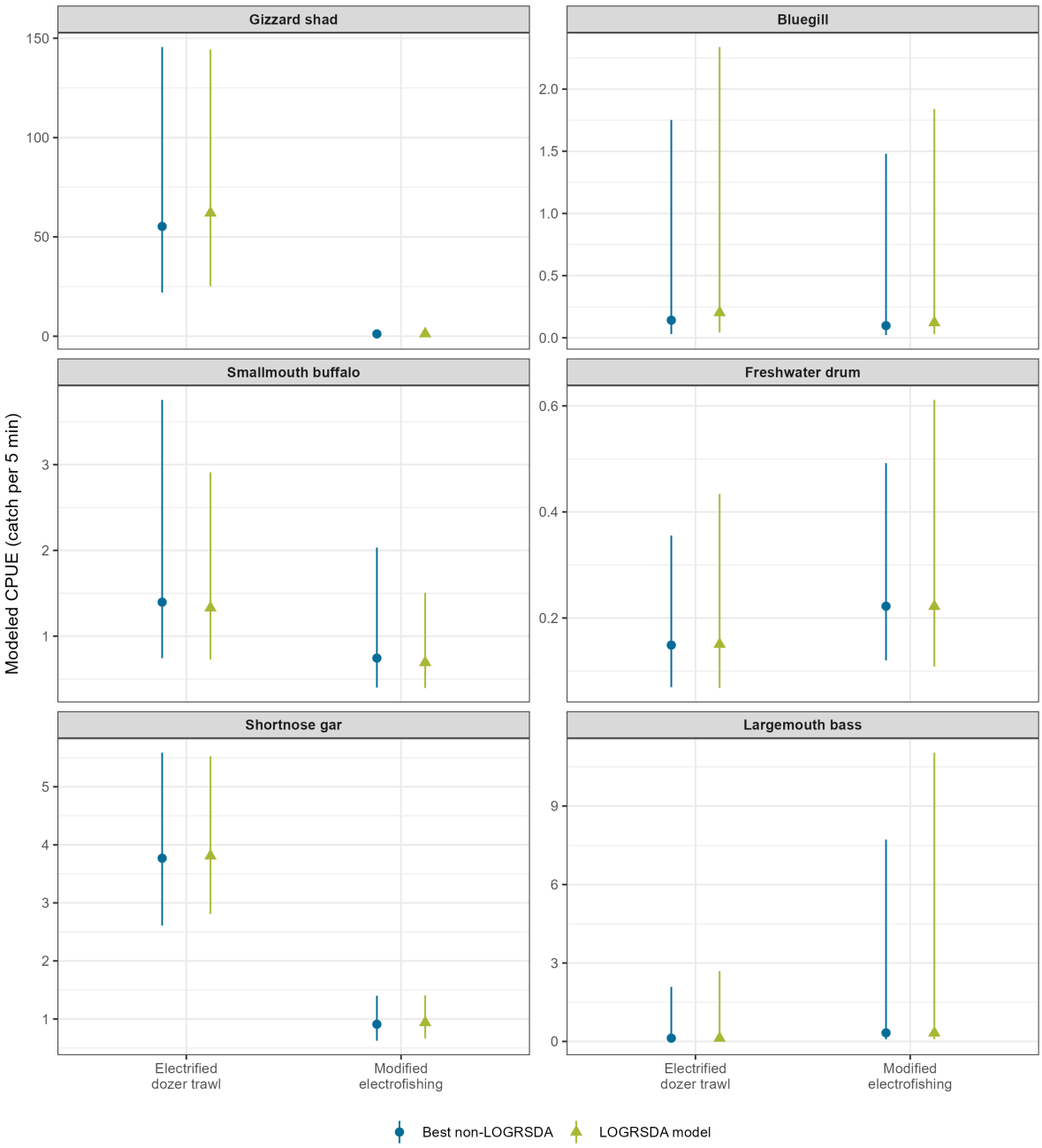


Figure 5. Population-level standardized CPUE for six focal species under the highest-ranked non-LOGRSDA model and the LOGRSDA model. Points are posterior medians and bars are 95% credible intervals. Panels use species-specific y-axis scales. Predictions exclude occasion-specific random deviations and average over the empirical distribution of other covariates.

Discussion

Proof-of-concept: making the changing operational domain explicit

Based on the results of the case study, RSDA's principal contribution is not a universal correction to CPUE. It converts an often-implicit field condition, the spatial domain available to a boat and activity, into occasion-level metadata that can be mapped, reported, and tested. The simulations show that a small set of well-placed landmarks can recover dominant area scaling under several geometric conditions. The field application shows substantial variation among occasions and close correspondence with river stage. The six-species analysis demonstrates how RSDA can be evaluated without assuming that its effect is proportional or has a common direction.

The evidence establishes geometric plausibility and hydrologic responsiveness, not criterion validity for true boat-accessible area. The LOGRSDA model ranked first only for smallmouth buffalo, and its predictive advantage over GH remained uncertain. For the other species, BASE or GH models ranked first or the alternatives were nearly indistinguishable. These results do not invalidate the index; they show that its biological relevance depends on species, system, and observation process and may be weaker than effects of sampling method, depth, aggregation, or unmeasured occasion conditions.

Addressing operational access and deployment

For field planning, RSDA can document how the operational domain expands or contracts relative to a reference condition. That information can be linked to launch feasibility, crew-day requirements, expected travel distance, station number and spacing, gear constraints, and safety. The 12.7-fold range at Lake Whittington illustrates why a fixed number of operations can imply very different field burdens and coverage among visits, as observed complex in-lake habitats altered operational feasibility.

Where the river-stage–RSDA relation is stable, a nearby gage may also support advance planning. Forecast or observed stage could indicate whether the operational domain is likely to be contracted or expanded, while RSDA translates that external stage into a lake-specific geometric response. Lakes sharing a gage may differ in thresholds, slopes, lags, and response shapes because of sill elevation, tie-channel geometry, sediment bars, vegetation, drainage, or groundwater. Departures from an expected river-stage–RSDA relation may therefore be operationally informative.

A descriptive relative operational-intensity index, effort divided by RSDA, could complement reporting and design review. For example, the same number of five-minute operations represents greater nominal effort per reference-scaled area when the domain is contracted. The ratio is not actual coverage and, under fixed effort, contains no information beyond the inverse of RSDA; it should not be entered with effort and RSDA as a separate model predictor. Such an index would prove more useful when time of effort is not fixed. Nonetheless, direct measures such as vessel speed, path length, effective width, overlap, and inaccessible area may ultimately provide better calibration.

Addressing CPUE bias and precision

RSDA provides a direct way to test whether changing operational area contributes to relative catch rates after accounting for known capture covariates. It should generally enter a CPUE model as an estimated covariate rather than an offset. An offset would impose a coefficient of 1 on log RSDA and assume proportional scaling between expected catch and operational area. Expansion could instead decrease CPUE through dilution, increase it through access to occupied habitat, or have little net effect when redistribution and sampling opportunity offset one another.

The case study illustrated both the value and the limits of that test. Smallmouth buffalo provided the strongest evidence of an RSDA association: the LOGRSDA model ranked first and catch declined as the

indexed domain expanded. The pattern is consistent with concentration during contraction, but changes in habitat use, availability, population exchange, or gear efficiency are equally plausible. GH ranked first for freshwater drum and largemouth bass, whereas BASE ranked first for gizzard shad, bluegill, and shortnose gar. Coefficient signs and precision differed among species, and the sparsest or most aggregated datasets supported the weakest inference.

RSDA was also useful as a sensitivity analysis. Adding it did not materially change the sampling-method conclusions for any species. The electrified dozer trawl retained clear advantages for gizzard shad, smallmouth buffalo, and shortnose gar, while contrasts for bluegill, freshwater drum, and largemouth bass remained uncertain. Different results are plausible where river-stage is not as tightly coupled to local geometry or where taxa differ in schooling, habitat position, mobility, life stage, or seasonal behavior.

Changes in operational area could also contribute to nonlinear relationships between CPUE and abundance. Contraction, schooling, or aggregation within the remaining accessible domain could produce hyperstability, whereby CPUE declines more slowly than abundance. Conversely, expansion, redistribution into inaccessible habitat, or reduced fish–gear overlap could produce hyperdepletion, whereby CPUE declines more rapidly than abundance. At high local concentrations, gear saturation or handling constraints could further flatten the catch response. These mechanisms were not distinguishable in the present analysis because independent abundance estimates were unavailable. They nevertheless reinforce why RSDA should be evaluated as an empirical covariate rather than imposed as a proportional correction.

Addressing spatial support and ecological comparison

Ecological observations are values attached to a spatial support. RSDA documents that the domain available for boat-based observation differed among occasions, which matters for interpreting counts, station density, species richness, water-quality measurements, vegetation treatments, invasive-species surveillance, contaminant response, and restoration monitoring. The same number of stations or detections may represent a different sampling context when the operational domain differs threefold or thirteenfold.

RSDA does not resolve every change-of-support problem. Ecological processes may scale with total wetted area, water volume, littoral length, habitat-specific area, connected area, or an effective detection domain rather than boat-accessible area. Even so, an explicit relative descriptor is preferable to assuming constant support. RSDA can be reported as metadata, used to stratify hydrologic conditions, evaluated as a covariate, used to describe station density, or combined with depth and habitat measures to build more relevant support metrics.

Water volume is an important extension. Two occasions can have similar surface area but different depth distributions, volume, and vertical habitat. RSDA cannot distinguish those states. Where bathymetry or repeated depth transects are available, it could be paired with mean depth, a stage-volume curve, or a three-dimensional accessibility model. Until such data are available, RSDA should be described explicitly as a planar index.

Transferability, assumptions, and limitations

The strong river-stage–RSDA correlations observed here should not be assumed elsewhere. Stage-area relations in shallow basins may be nonlinear, with thresholds when water overtops sills, reconnects segments, or enters vegetated margins. Filling and draining can follow different paths because of storage, channel restriction, evapotranspiration, and groundwater exchange. The temporal resolution of our data may also obscure within-occasion change or capture true stage-area dynamics. Applications across

broader hydrologic settings should therefore test nonlinear terms, thresholds, lags, and hysteresis when the data permit.

Where aerial or satellite imagery resolves open water and vegetation boundaries, remotely sensed extent can provide independent validation or a direct alternative (Pekel et al 2016; Jones 2019). Water extent, however, is not synonymous with boat access. Shallow water, vegetation, woody debris, sediment bars, or disconnected pockets may be wet but operationally unavailable. The best validation data should match the vessel and activity used to define the operational domain.

The IRSD/RSDA workflow assumes that the reference polygon represents a documented baseline operational boundary. Because the reference is user-defined, results depend on how it is delineated. Absolute RSDA values should therefore not be compared across lakes unless reference conditions and vessel criteria are demonstrably equivalent. Within-lake comparisons are more defensible.

The method also assumes that field locations or manual overrides reach meaningful operational limits and that paired landmarks remain conceptually comparable across occasions. Routine samples may reflect study design rather than access limits, and pooling methods assume that they share an operational domain. Method-specific domains should be used when vessels or gear constraints differ materially.

A global affine transformation assumes that dominant expansion and contraction can be represented by one linear map. It can accommodate translation, rotation, shear, and overall scaling but not localized shoreline retreat, branching, isolated pockets, internal barriers, or topological change. Affine residual error measures landmark fit, not error in the underlying operational boundary. The two-lake, 13-occasion case study is too limited to characterize broader error rates or infer hydrologic thresholds.

GH and RSDA were strongly correlated in this study, so they were treated as alternative occasion-level predictors rather than partitioned in a joint model. That choice avoids unstable coefficients but does not identify which variable is causally closer to encounter rate. The sampling-occasion random effect appropriately accounts for clustering, yet it can also absorb variation that RSDA might explain when the number of occasions is small.

The sensitivity analysis illustrates the main geometric caveat: targeted landmarks can yield precise estimates around the wrong value when change is strongly non-affine. Precision is not a substitute for validation. RSDA should be presented as a reference-scaled index unless independent boundary, bathymetric, or navigability data establish a stronger interpretation.

Priority next steps

The highest priority is direct field validation. Crews should deliberately navigate and record operational boundaries at selected sites, emphasizing distal endpoints, lateral margins, shallow bars, vegetated edges, obstructions, and disconnected areas. Repeated observations across filling and draining phases would allow RSDA to be compared with mapped accessible polygons, vessel tracks, remotely sensed water extent, and gage height.

Observer and reference uncertainty should also be quantified. Multiple analysts could delineate reference polygons and select landmarks, with that variation propagated into IRSD and RSDA. Method-specific operational domains should be evaluated when vessel drafts, turning radius, electrical fields, or deployment requirements differ. Simulation work should be expanded to include localized contraction, branching, internal islands, disconnected pockets, and topology changes, with piecewise or segmented alternatives compared with the global affine approach.

Extensions to volume and habitat support will require bathymetry, depth distributions, littoral-zone area, vegetation, and connectivity data. Biological testing should include more lakes, more occasions,

seasonal contrasts, resident and mobile taxa, multiple gears, and independent abundance or density estimates. The key question is not whether RSDA always improves a model, but when operational-domain variation is large enough, and sufficiently distinct from stage, to change inference or management decisions.

Conclusion

Changing floodplain-lake area and volume create operational, statistical, and ecological-comparability problems that are widely recognized but seldom quantified in field datasets. The IRSD/RSDA workflow offers a transparent, low-data way to describe dominant changes in the boat-accessible operational domain. Simulations supported the value of targeted landmarks under approximately affine change and exposed clear limitations under localized, asymmetric contraction. The two-lake application showed large within-lake variation and strong correspondence with river stage. Across six species, RSDA ranked first only for smallmouth buffalo and did not materially alter sampling-method conclusions. RSDA should therefore be used as operational metadata and a testable spatial-domain covariate, not as a direct area measurement or universal CPUE correction. Its practical value will depend on direct validation, explicit field protocols, broader hydrologic testing, and integration with depth, volume, habitat, and vessel-specific access data.

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CAA conceived the study question and objectives. ECB and CAA contributed to study design, sampling, and analysis. ECB collected or curated the data. CAA conducted the analysis. CAA and ECB interpreted the results. CAA drafted the manuscript. Both authors provided substantive review and revision, approved the submitted version, consented to submission, and agreed to the accuracy and integrity of the work.

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The findings and conclusions in this report are those of the authors and do not necessarily represent the views of the U.S. Fish and Wildlife Service. Any use of trade, firm, or product names is for descriptive purposes only and does not imply endorsement by the U.S. Government. The authors are employed by the U.S. Fish and Wildlife Service and, as part of their official duties, participate in the review and recommendation of financial assistance for external projects related to the subject matter of this manuscript. The authors do not receive personal financial benefit from the approval, funding, outcome, or publication of such projects, nor from the conclusions of this manuscript.

Data and code used for this report are available from the corresponding author subject to agency review and applicable data-release requirements.

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