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A Comparison Between South Dakota and North American Standard Sampling Gears in Lakes and Reservoirs

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A COMPARISON BETWEEN SOUTH DAKOTA AND NORTH AMERICAN STANDARD SAMPLING GEARS IN LAKES AND RESERVOIRS

BY

BRADLEY J. SMITH

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A COMPARISON BETWEEN SOUTH DAKOTA AND NORTH AMERICAN STANDARD SAMPLING GEARS IN LAKES AND RESERVOIRS

This thesis is approved as a creditable and independent investigation by a candidate for the Master of Science in Fisheries and Wildlife degree and is acceptable for meeting the thesis requirements for this degree. Acceptance of this does not imply that the conclusions reached by the candidates are necessarily the conclusions of the major department.

Brian Blackwell, Ph.D. Thesis Advisor	Date
Nels Troelstrup, Ph.D. Interim Head, Department of Natural Resource Management	Date
Dean, Graduate School	Date

This thesis is dedicated in memory of Dave Willis. As one of the last students to be advised by Dave I stand at the tail-end of the academic and professional lineage known collectively as “Willis Nation.” In writing this thesis I hope to honor his legacy by providing the level of work to which he would have aspired.

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My family has tolerated my obsession with fish for a long time and for that I am thankful. I could always count on them to support my endeavor to make a career out of fisheries science, even if they didn't always understand what I was doing☺. Most of all I thank my Mom, Dad, and grandparents for taking me fishing and my brother Danny for being my fishing buddy through the years.

CONTENTS

ABBREVIATIONS

AFS	American Fisheries Society
ANCOVA	Analysis of Covariance
ANOVA	Analysis of Variance
CPUE	Catch Per Unit Effort
df	degrees of freedom
ha	hectares
hr	hour
KS	Kolmogorov-Smirnov Test
mm	millimeter
MR	Missouri River
Non-MR	non-Missouri River
PPR	Prairie Pothole Region
PSD	Proportional Size Distribution
PSD-P	Proportional Size Distribution-Preferred
R	R statistical software package
$R^2_{adj.}$	Adjusted R-squared value
SDGFP	South Dakota (Department of) Game, Fish and Parks
SELECT	Share Each LEngth’s Catch Total
Standard	North American Standard
TL	Total Length

ABSTRACT

A COMPARISON BETWEEN SOUTH DAKOTA AND NORTH AMERICAN STANDARD SAMPLING GEARS IN LAKES AND RESERVOIRS

BRADLEY J. SMITH

2015

A statewide gear comparison was performed in South Dakota during 2013 and 2014 between current South Dakota Department of Game, Fish and Parks (SDGFP) sampling gears (i.e., gill nets and modified fyke nets) and their equivalents described in *Standard Methods for Sampling North American Freshwater Fishes* (Standard). Adopting Standard gears would provide uniform gear specifications for annual sampling statewide, facilitate data sharing within South Dakota and beyond, and allow for large-scale spatial and temporal analyses relevant to researchers and managers. Sampling was divided between non-Missouri River (non-MR) and Missouri River (MR) systems because gill nets used by SDGFP to sample Missouri River reservoirs were double the length of gill nets used elsewhere in the state and were constructed of multifilament twine instead of monofilament twine. In non-MR systems, SDGFP gill nets had higher catch per unit effort for most species commonly indexed with gill nets including Walleye and Yellow Perch while Standard gill nets selected for larger individuals of most species. In MR systems, gill net CPUE was higher for almost all species captured using SDGFP multifilament reservoir gill nets because SDGFP nets were over three times longer than Standard nets. Standard gill nets with additional large bar-mesh panels selected for larger individuals of most species, including Walleye, than did SDGFP reservoir nets. Monofilament was more efficient than multifilament for almost all species investigated. Modified fyke net catches were similar for many species between net types though

Standard nets captured more Black Crappies and SDGFP nets captured more Black Bullheads. Standard modified fyke nets tended to select for larger Black Crappie and Bluegills. In both MR and non-MR systems, conversion factors for lakewide catch per unit effort were developed for each gear type using regression analysis to allow for conversion of historic catch data into equivalent Standard CPUE. Estimates of species diversity and evenness did not differ between SDGFP or Standard gears. Indirect estimates of gill net selectivity were performed for 18 species sampled using Standard gill nets to identify shape of species and mesh-specific selectivity curves, approximate peak modal efficiency for each mesh, and identify overall shape of selectivity curves for all meshes combined. Comparisons of modified fyke nets with restricted and unrestricted throat configurations revealed that catch per unit effort was higher for nets with restricted throats. Subsequent escapement trials confirmed that most Black Crappie and Bluegill escaped from modified fyke nets with unrestricted throats. Together, the paired gear comparisons between SDGFP and Standard gears and additional investigations of Standard gears provided the necessary information to allow for a potential statewide transition to North American Standard sampling gears.

CHAPTER 1.

GENERAL INTRODUCTION

Standardization of gears and methods allows for efficient transfer of reliable and universally understood information and is fundamental in scientific inquiry, business, and governance (U.S. Environmental Protection Agency 1996; Eaton and Franson 2005; European Committee for Standardization 2005). Standardization reduces extraneous variability and increases replicability of results (Maunder and Punt 2004) allowing for acquisition of reliable knowledge. Fisheries science is a relatively new branch of science (Nielsen 1999) and efforts to standardize gears and methods used to sample fish are not fully established in research and management paradigms (Bonar and Hubert 2002). Voluntary standards for sampling fish have been developed independently in both Europe and North America in the last decade (European Committee for Standardization 2005; Bonar et al. 2009b). North American standards were published by the American Fisheries Society in 2009 under the title *Standard Methods for Sampling North American Freshwater Fishes*. In this publication, authors identified the appropriate gears and sampling methods to use by water type and specify exact dimensions of North American standard gears, hereafter referred to as Standard (Bonar et al. 2009b). Unfortunately, adoption of these standards has been a slow process because gears and methods are traditionally standardized at local, state, or provincial levels (Bonar and Hubert 2002) and there has been resistance within agencies to adopt new standards that would require managers and researchers to purchase new equipment, reduce sampling flexibility, and potentially compromise historic datasets (Hayes et al. 2003).

Concerns about cost and the potential loss of historic data resulting from adoption of new gears has been central in the debate over whether the South Dakota Department of Game, Fish, and Parks (SDGFP) should adopt North American standard gears for sampling lakes and reservoirs (B. G. Blackwell, personal communication). Current sampling gears used by SDGFP to sample lakes and reservoirs are not standardized within the state and do not conform to North American standards but have been used to develop water-specific long-term data sets. Switching to North American standards would help promote standardization regionally and beyond (Bonar et al. 2009a) but this change should not be made at the expense of long-term monitoring data that are critical for detecting changes in populations and ecosystems (Likens 1992). A gear comparison that also encompasses the diversity of fishes and lentic habitats of South Dakota is necessary to understand potential biases between SDGFP and North American Standard sampling gears (Speas et al. 2004; Peterson and Paukert 2009).

South Dakotas lakes and reservoirs can be loosely organized into several distinct habitat regions including: eastern glacial lakes and prairie reservoirs that tend to be shallow and eutrophic (Stukel 2003), Missouri River impoundments (i.e., Lewis and Clark, Francis Case, Sharpe, and Oahe) that were created by the Army Corps of Engineers during the 1950's to 1970's as part of the Flood Control Act of 1944, and Black Hills reservoirs that are generally deeper and less productive than lakes in eastern South Dakota. Gill nets are used to sample benthic species (Hubert 1996) in all aforementioned water types while modified fyke nets are used to sample littoral fishes (Hubert et al. 2012) in eastern lakes and prairie reservoirs.

North American standard gill nets and fyke nets are similar to their respective SDGFP gears but differ in several key ways. For instance, Standard gill nets are 24.4-m long by 1.8-m deep and include 8 randomly ordered bar mesh panels (i.e., 19, 25, 32, 38, 44, 51, 57, and 64-mm bar-mesh) each 3.0-m long while SDGFP gill nets are much longer at 45.7-m by 1.8-m deep for non-Missouri River gill nets and 91.4-m long by 1.8-m deep for Missouri River gill nets. All SDGFP gill nets include 13, 19, 25, 32, 38, and 51-mm sequentially ordered bar-mesh panels that are 7.6-m long on non-Missouri River nets and 15.2-m long on Missouri River nets. An additional caveat is that twine material used for SDGFP gill nets is not standardized; nets used on the Missouri River are constructed of multifilament twine while nets used outside the Missouri River system are made with monofilament that is generally more efficient at capturing fish (Pycha 1962; Collins 1979). The primary difference between Standard and SDGFP modified fyke nets is bar-mesh size; Standard nets have 13-mm knotless bar-mesh while SDGFP nets use knotted 19-mm bar-mesh. Both modified fyke net types incorporated restricted throats, though inclusion and specifications for such an apparatus are not provided in *Standard Methods for Sampling North American Freshwater Fishes*.

To understand how gear differences would influence estimates of commonly calculated population parameters should SDGFP switch to North American standard gears, I performed a statewide gear comparison between differing gill net and fyke net types to gain a better understand of potential biases of Standard sampling gears. The specific objectives were to:

1.) quantify bias in estimates of CPUE, size structure, and diversity between SDGFP and Standard gill nets and modified fyke nets used to sample eastern glacial lakes, prairie impoundments, and Black Hills reservoirs and develop conversion factors for CPUE between gear types to allow continued usage of historic data;

2.) quantify bias in estimates of CPUE, size structure, and diversity between multifilament SDGFP reservoir and monofilament Standard gill nets used to sample Missouri River reservoirs, develop conversion factors for CPUE between gear types to allow continued usage of historic data, perform indirect estimates of selectivity for both gill net types, and investigate potential differences in efficiency between monofilament and multifilament twines;

3.) perform indirect estimates of selectivity for 18 species commonly collected using Standard gill nets in South Dakota to identify shape of species and mesh-specific selectivity curves, calculate peak modal efficiencies of capture for each bar-mesh and species, and identify shape of overall selectivity curves for each species collected;

4.) investigate differences in CPUE, size structure, and escapement of fishes from Standard modified fyke nets with differing throat configurations to optimize recommended gear specifications outlined in *Standard Methods for Sampling North American Freshwater Fishes*; and

5.) make recommendations about the feasibility of converting to North American standard gears that would take into account management concerns.

Despite the many benefits of using of standardized gears, they may not be appropriate in all situations. Research and management activities that target specific organisms at irregular spatial or temporal intervals (e.g., Muskellunge) often demand high resolution at small scales making use of standard methods impractical (Peterson and Dunham 2010). Switching to Standard gears may also require more sampling effort if precision of CPUE estimates and sample sizes are inadequate as Koch et al. (2014) discovered when Kansas Department of Wildlife, Parks and Tourism transitioned to smaller Standard gill nets for reservoir sampling. Standardizing gears provides the most benefit at larger scales by allowing data sharing leading to identification of long-term changes at large spatial scales (Bonar et al. 2009a). Standardization is especially relevant to research and management as questions about the influence of land conversion (Dodds and Oakes 2006), climate change (Ficke et al. 2007), and human use of fisheries resources (Schramm et al. 1991) continue to grow in importance, requiring use of data sets generated using similar gears and methods (e.g., fisheriesstandardsampling.org). The ultimate goal of this project is to provide South Dakota Department of Game, Fish and Parks with the analysis and interpretation necessary to facilitate a transition to North American standard gears, if they so desire. Should such a transition be made, it would benefit not only South Dakota but add momentum to the on-going effort to standardize sampling programs across North America.

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CHAPTER 2. COMPARISON OF SOUTH DAKOTA AND NORTH AMERICAN STANDARD GILL NETS AND FYKE NETS

Abstract

A paired gear comparison was performed throughout South Dakota to investigate the feasibility of switching from South Dakota Department of Game, Fish and Parks (SDGFP) standardized gill nets and fyke nets to North American standard (hereafter, referred to as “Standard”) gill nets and fyke nets. Differences in catch per unit effort (CPUE), size structure, and diversity were quantified and conversions for CPUE between Standard and SDGFP gears were developed using regression analyses. Longer SDGFP gill nets (i.e., 45.7 meter; 13, 19, 25, 32, 38, and 51 mm bar-mesh) yielded higher CPUE for bullheads, Northern Pike *Esox lucius*, Rock Bass *Ambloplites rupestris*, Walleye *Sander vitreus*, and Yellow Perch *Perca flavescens* though similar catch rates were found between gears for nine commonly collected species. Standard gill nets (i.e., 24.4 meter; 19, 25, 32, 38, 44, 51, 57, and 64 mm bar-mesh) generally selected for larger fish due to the presence of larger bar-mesh panels and absence of the smallest size bar-mesh panel used in SDGFP gill nets. Black Crappies *Pomoxis nigromaculatus* were consistently sampled in greater numbers by Standard fyke nets while bullhead, Rock Bass, Smallmouth Bass *Micropterus dolomieu*, and Walleye CPUE was higher for SDGFP fyke nets. Size selectivity bias between fyke net types for commonly sampled species took one of several forms: Standard nets selected for larger fish (i.e., Black Crappie), SDGFP selected for larger fish (i.e., bullheads, White Bass, and Yellow Perch), no difference (i.e. Channel Catfish, Common Carp, Rock Bass, and White Sucker), or Standard nets simultaneously selected for smaller and larger fish (i.e., Bluegill, Northern Pike, Smallmouth Bass, and Walleye). No differences in species diversity or evenness were

detected between gill net or fyke net types. Regression equations with high strength of fit will be useful for converting CPUE data from SDGFP to Standard, allowing for continued use of historic data and easing a potential transition to Standard sampling gears.

Introduction

Standardization in data collection has become common in many scientific fields (e.g., meteorology, geology, and medicine) and has facilitated the sharing and understanding of information among professionals across spatiotemporal boundaries (Bonar and Hubert 2002). However, no standard methods for sampling fishes have been universally implemented in the study and management of inland freshwater fisheries in North America. Resistance to standardization in fisheries sampling is driven by concerns of cost, reduced creativity in sampling, an inability to use historic data sets, as well as perceived infringement on the ability of field biologists to define best sampling practices (Bonar and Hubert 2002). Currently, inland fisheries biologists at the local, state, tribal, and federal levels determine their own standard sampling protocols that often vary by location, gear used, and sampling design (Gritters 1997; Bonar et al. 2009b). Sampling methods also vary based on type of system being sampled (e.g., pond, lake, reservoir, stream, large river) and species targeted for capture (Schreck and Moyle 1990; Murphy and Willis 1996). Differences in methods used to collect fisheries data can inhibit data comparison and make data comparisons across large spatial and temporal scales difficult (Bonar et al 2009a).

In 2009, the Fisheries Management Section of the American Fisheries Society, with assistance from fisheries professionals across North America, developed standardized fish sampling protocols and published them in the book *Standard Methods for Sampling North American Freshwater Fishes* (Bonar et al. 2009b). Standard sampling protocols incorporate commonly used gears and define standard computation of effort by gear (Bonar et al. 2009b). Fish collection methods were standardized by water type (e.g., large standing water, warmwater) and targeted fish assemblages.

South Dakota Department of Game, Fish and Parks (SDGFP) standardized lake sampling protocols and gear specifications differ from those outlined in *Standard Methods for Sampling North American Freshwater Fishes* (Bonar et al. 2009b). Understanding biases in CPUE, size structure, and diversity between gear types typically requires a paired gear comparison whereby two gear types (e.g., standard and nonstandard) are simultaneously fished alongside one another. Regression analyses can then be used to compare data between those two gears allowing for development of correction factors (Peterson and Paukert 2009).

Developing standardized fish sampling protocols and a centralized database have been identified as objectives for the South Dakota statewide fisheries and aquatic resources 2014-2018 strategic plan (Statewide Components Work Group 2014). Aligning SDGFP and North American standard (Standard) sampling methodology will allow for improved large scale analyses, easier data sharing between fisheries professionals in South Dakota and beyond, and will be a necessary component in the development of a future statewide fisheries database. Because of the long-term data sets that SDGFP has developed there is reluctance to change to the North American standard.

Development of potential correction factors would allow for continued use of historic data sets and should reduce this reluctance to change. To help facilitate a potential transition from current SDGFP methods to Standard sampling methods, the objectives of this study were to 1) compare catch rates, size structure, and species composition of fishes collected in Standard gill nets and fyke nets to SDGFP gill nets and fyke nets; and 2) develop conversions for commonly collected species that will allow historic South Dakota gill net and fyke net data to be converted to North American standard.

Methods

Study area- Twenty-six lakes were sampled during 2013-2014 including 19 natural lakes and four prairie stream impoundments in the Prairie Pothole Region (PPR) of eastern South Dakota and three Black Hills reservoirs; one reservoir (i.e., Pactola) was sampled during both study years. Natural lakes in eastern South Dakota tend to be shallow, wind-swept, turbid, eutrophic to hypereutrophic, have small watersheds, and widely fluctuating lake levels (Steuven and Stewart 1996; Table 2). However, some of the lakes included in this research can be classified as mesotrophic and are well drained with extensive connections to aquifers, resulting in fairly stable lake levels. Natural lakes in eastern South Dakota rarely stratify, are susceptible to intense algae blooms (Stueven and Stewart 1996; Stukel 2003), and host low diversity fish communities dominated by percids, moronids, esocids, centrarchids, ictalurids, and cyprinids (Stukel 2003). Impoundments of small prairie streams of eastern South Dakota are similar to natural lakes of the region and can be described as shallow, turbid, and eutrophic to hypereutrophic though they are generally smaller (< 400 ha) and have less fetch than most natural lakes included in this study (Table 2). Fish communities in impoundments are also more likely to include riverine species including Channel Catfish *Ictalurus punctatus*, Freshwater Drum *Aplodinotus grunniens*, and River Carpsucker *Carpiodes carpio*. Black Hills reservoirs sampled for this project were located at approximately 1,396 – 1,800 meters above sea level and were formed by impounding coldwater streams. These reservoirs have popular coldwater fisheries that have resulted from stocking efforts for Lake Trout *Salvelinus namaycush* in Pactola Reservoir, Rainbow Trout *Onchorynchus mykiss* in all three reservoirs studied, Brook Trout *Salvelinus fontinalis* and Splake Trout *Salvelinus namaycush x Salvelinus fontinalis* in Deerfield Reservoir. These reservoirs also have a mixture of coolwater fishes including Bluegill *Lepomis macrochirus*, Northern Pike, *Esox lucius* and Rock Bass *Ambloplites rupestris*.

Description of gear types- One lake was sampled each week during June-August of 2013 and 2014 in conjunction with SDGFP summer fish community surveys. South Dakota Game, Fish and Parks gill nets were set perpendicular to shore in their established fixed locations by SDGFP personnel and were paired with a Standard gill net. Each Standard gill net was randomly assigned to the left or right, approximately 100-m away from and parallel to a SDGFP gill net. All nets were set during the morning and retrieved the following morning. Standard gill nets were 24.8-m long and contain eight randomly ordered panels of mesh (19, 25, 32, 38, 44, 51, 57, 64-mm bar mesh) while SDGFP gill nets were 47.5-m long with six fixed-order panels (13, 19, 25, 32, 38, 51-mm bar mesh). During 2014 sampling, all Standard gill nets included an additional “mini-mesh” add-on comprised of three randomly ordered panels (i.e., 10, 13, 19 mm bar mesh) to investigate catches of sub-stock fish, primarily Yellow Perch *Perca flavescens*. All fish captured in “mini-mesh” add-ons were treated and were not included in subsequent analyses for the first objective.

Fyke netting was completed concurrent with gill netting during June-August of 2013 and 2014. Standard fyke nets were randomly assigned to be fished approximately 100-m to the right or left of SDGFP fyke nets that were set at fixed sampling sites. All nets were set during the morning and retrieved the following morning. Standard fyke nets (0.9 m x 1.8 m frames) were constructed using 10-mm rolled steel bar and 13-mm bar mesh and possessed a single throat stretched between the second and fourth hoops that tapered to a 203-mm opening at the cod end with a restriction to reduce escapement as described by Sullivan and Gale (1999). In contrast, SDGFP fyke nets (0.9 m x 1.5 m frames) were constructed using 25-mm steel tubing and 19-mm bar mesh and possessed a single constricted throat stretched between the second and fourth hoops that tapered to a 152-mm opening at the cod end. Leads for both fyke net types were 15.2-m long.

Statistical Analysis- Collected fish were measured for total length (TL; mm), weighed (g), and released. Only widespread and relatively abundant species were included for analysis with the exception of two coldwater species found only in the Black Hills. Black Bullhead *Ameiurus melas* (N=29,006 from all gears) and Yellow Bullhead *Ameiurus natalis* (N=453 from all gears) are sometimes treated collectively for management purposes, so data for these two species were combined and will be referred to hereafter as “bullheads.” Fish used in analysis of catch per unit effort (CPUE) were at least stock length as identified by Gabelhouse (1984) and Bister et al. (2000). Replicate units for CPUE comparisons were the species-specific arithmetic mean number of stock-length fish captured per net/night/lake. For coldwater species abundant enough to be included in this analysis (i.e., Lake Trout and Rainbow Trout), the individual net was the replicate unit due to low sample size of populations where these species are found. Assumptions of normality and homoscedasticity were tested using the Shapiro-Wilk and Levene tests, respectively, and CPUE data was $LOG_{10}(x + 1)$ transformed when necessary to normalize data.

Analysis of covariance (ANCOVA) was used to identify whether slopes or intercepts differed between the observed regression of Standard (i.e., independent variable) against SDGFP (i.e., dependent variable) CPUE and a hypothetical 1:1 regression line that would imply no difference in CPUE between gears across lakes. A difference in intercept indicated that one gear has a higher CPUE relative to the other gear while differing slopes indicate higher capture efficiency for one gear as lake-wide relative density of fish increases.

Gill nets received additional statistical attention due the large difference in overall length between gill net types and concern over a possible "leading" effect whereby fish are more likely to encounter a longer net (Rudstam et al. 1984) and less likely to swim around the net before trying to pass through. This phenomenon is suspected to inflate CPUE of longer nets (Hamley 1975; Davis and Schupp 1987). A higher catch per area would be expected in the longer net if leading effects existed because the surface area of the net is directly correlated with the panel length. We converted CPUE data into bar mesh panel-specific catch per m^2 data to correct for the difference in panel surface area between gears then. These corrected values were then compared between gear types by species for each bar mesh size shared in common between both gears (i.e., 19, 25, 32, 38, and 51-mm bar mesh) using the Kruskal-Wallis Test (Conover 1999). Mini-mesh add-ons were assessed qualitatively due to limited and highly variable data applicable only to Yellow Perch.

Size-related bias was investigated between gears by comparing length frequencies and commonly calculated population indices. Species-specific length-frequency distributions of total fish sampled were compared between gear types using the Kolmogorov-Smirnov test with individual fish as replicate units (Conover 1999). Proportional size distribution of quality (PSD) and preferred-length fish (PSD-P) were calculated by gear and species as outlined in Neumann and Allen (2007) and compared using a Chi-Square test.

Species diversity and evenness were calculated and compared by gear type. Species diversity was calculated using the Shannon-Wiener index (i.e., Shannon's *H*') and is calculated as

$$H^{'} = -\sum_{i=1}^{S}(p_i)\,(log_e p_i)$$

where S = number of species and p_i = proportion of total sample represented by *i*th species (Kwak and Peterson 2007). An evenness score (i.e., Shannon's *J*') was calculated as

$$J^{'} = \frac{H'}{H'_{max}} = \frac{H'}{log_e s}$$

where H'_{max} = $\log_e s$ = maximum Shannon's index score and s = number of species sampled (Kwak and Peterson 2007). Comparisons of species diversity and evenness between gears types were performed using analysis of variance (ANOVA) with Shannon's H' or J' scores as response variables, gear as a class variable, and lake as a blocking factor (Eggleton et al. 2010).

Correction factors- To address the second objective, regression analysis was used to develop species-specific conversions for lake-wide $LOG_{10}(X + 1)$ transformed mean stock CPUE between gears by species. Standard CPUE (i.e., independent variable) was regressed against SDGFP catch per unit effort (i.e., dependent variable) with associated 95% confidence intervals. Regression equations were constructed for each species captured in each gear type (i.e., gill net and fyke net). The utility of the correction factors was determined by the precision of the estimates (i.e., adjusted R^2 values or $R^2_{adj.}$). A higher $R^2_{adj.}$ indicated that variation in CPUE resulted from gear differences while lower $R^2_{adj.}$ values indicated that little of the variation in CPUE between gears could be explained by differences in gear type. All calculations were performed using R version 3.0.2 “Frisbee Sailing” (The R Foundation for Statistical Computing 2013) and $\alpha = 0.05$ was assumed for all tests.

Results

A total of 14,997 fish of 34 species were collected using Standard and SDGFP gill nets (Table 3). The SDGFP gill nets produced significantly higher CPUE for bullhead, Northern Pike, Rock Bass, Walleye *Sander vitreus*, and Yellow Perch, but no difference in CPUE was detected for Black Crappie *Pomoxis nigromaculatus*, Bluegill, Channel Catfish *Ictalurus punctatus*, Common Carp *Cyprinus carpio*, Lake Trout, Rainbow Trout, Smallmouth Bass *Micropterus dolomieu*, White Bass *Morone chrysops*, and White Sucker *Catostomus commersonii* between gill net types (Figure 1). No “leading” effect was detected for any species or bar mesh panel size with the exception of Common Carp captured in the 51-mm panel where SDGFP gill nets produced higher total catch/m^2 than Standard nets (χ^2=5.663, p=0.017). Mini-mesh add-ons seldom caught fish, but sub-stock Yellow Perch were caught in great abundance in Bullhead Lake and Lake Cochrane (Table 4). Length-frequency distributions were similar between gill net types for Black Crappie, Bluegill, Northern Pike, Rainbow Trout, and Rock Bass while Standard gill nets selected for larger bullhead, Channel Catfish, Common Carp, Lake Trout, Walleye, Smallmouth Bass, White Bass, White Sucker and Yellow Perch (Figure 2). Standard gill nets produced significantly higher values of PSD for bullhead, Northern Pike, Smallmouth Bass and Walleye and higher values of PSD-P for bullhead, Common Carp, Smallmouth Bass, Walleye, and Yellow Perch (Table 5). Measures of species diversity and evenness were similar between gill net types (Figure 3).

Standard and SDGFP fyke nets collected a total of 39,710 fish of 26 species during this study (Table 3). Comparisons between fyke net types revealed that similar values of CPUE were observed for almost all species sampled (i.e., Bluegill, Channel Catfish, Common Carp, Northern Pike, White Sucker, White Bass, and Yellow Perch) although Standard nets yielded higher CPUE for Black Crappie and SDGFP fyke nets produced higher CPUE for bullhead, Rock Bass, Smallmouth Bass, and Walleye (Figure 4). Length frequencies were similar between fyke net types for Channel Catfish, Common Carp, Rock Bass, and White Sucker. Standard fyke nets selected for larger Black Crappie, Bluegill, Northern Pike, Smallmouth Bass and Walleye while SDGFP fyke nets selected for larger bullhead, White Bass, and Yellow Perch (Figure 5). Standard fyke nets yielded significantly higher PSD values for Black Crappie, Bluegill, bullhead, Northern Pike, and Smallmouth Bass while PSD values for Channel Catfish were higher in SDGFP fyke nets (Table 5). Standard fyke nets had higher PSD-P values for Bluegill, Northern Pike, and Smallmouth Bass (Table 1). No significant difference in species diversity or evenness was detected between fyke net types (Figure 3).

Equations to convert $LOG_{10}(X + 1)$ transformed CPUE data between SDGFP and Standard gears were developed for 14 species collected from gill nets and 12 species collected from fyke nets (Table 6). Strength of fit as determined by $R^2_{adj.}$ was high for most gill net comparisons with 29.2% to 95.7% of the variation in CPUE being explained by gear differences except for Lake Trout and Rainbow Trout where only 1.0% and 5.7% of variation was explained by gear type, respectively. No detectible difference in slope between the actual regression and hypothetical 1:1 line was found for any species sampled except for White Sucker. Intercept values were significantly greater than zero for all comparisons except those for White Bass (Figure 6). Regression analysis of CPUE data for fyke nets generated conversions equally useful as those found for gill nets and resulting strength of fit for these models interpreted from $R^2_{adj.}$ was variable though over half the variation in CPUE was explained by gear type for all fyke net models fitted (Figure 7).

Discussion

This project demonstrated the feasibility of converting from current South Dakota Game, Fish and Parks lake and small impoundment sampling gears to voluntary standards outlined by Bonar et al. (2009b). Biases in CPUE, size structure, and species composition were quantified and reliable conversion factors for CPUE were developed. Taken together, these comparisons provide the information necessary to pursue a transition in sampling gears.

Gill Net Interpretation – Surprisingly, 7 of 14 species effectively sampled by gill nets had similar CPUE between Standard and SDGFP gears but, as expected, all significantly higher catches were produced by longer SDGFP gill nets. Analogous catches for seven species between gill net types likely resulted from the presence of 44, 57, and 64-mm meshes on Standard gill nets that compensated for differences in net length by broadening selectivity of the net, particularly for Channel Catfish, Common Carp, Smallmouth Bass, and White Bass that were more vulnerable to larger bar mesh sizes. Higher CPUE of bullhead, Northern Pike, Rock Bass, Walleye and Yellow Perch in SDGFP gill nets resulted primarily from the greater length of SDGFP gill nets but for small-bodied species may also be attributable to lower vulnerability to unique larger bar mesh sizes of Standard gill nets. Lake Trout and Rainbow Trout comparisons were hampered by high variability resulting from use of individual nets as replicate units. For both trout species, but especially for Rainbow Trout, it is difficult to interpret what relationship exists between gear types without further sampling that would allow lakes or lake-years to be used as replicates instead of individual nets.

Additional metrics investigated for gill net CPUE including comparisons of catch/m^2 and utility of “mini-mesh” add-ons improved the understanding of gill net selectivity. Failure to detect a “leading effect” was consistent with previous research that found either no difference or decreasing CPUE with increasing net length (Minns and Hurley 1988; Acosta 1994). The implication of this finding was that analogous CPUE between gill net types were attributable to mesh sizes not shared by both nets because catch/m^2 was similar between gear types when correcting for bar-mesh size. Addition of “mini-mesh” add-ons may be useful in sampling strong year classes of sub-stock Yellow

Perch and requires little additional labor to check because few fish are susceptible to the smallest mesh sizes and has the added benefit of broadening the total selectivity of the gill net.

Consistent size selective bias with Standard nets selecting for larger fish was attributable to presence of 44, 57, and 64 mm bar-mesh panels and simultaneous absence of the 13 mm bar mesh that shifted size structure towards larger fish. Selectivity for smaller Yellow Perch by SDGFP gill nets was attributable to a few high catches of sub-stock fish in the 13 mm bar-mesh panel that was present on SDGFP gill nets but absent from Standard nets. Standard gill nets did not select for larger Northern Pike even with three larger mesh sizes not shared by SDGFP nets. This result may be explained in part by observations during this study that Northern Pike are often captured by tangling after attacking a prey fish (i.e., Yellow Perch) already captured in a smaller mesh of the gill net potentially distorting gear selectivity for this species and violating the assumption of geometric similarity whereby selectivity of the mesh is explained by the girth of the fish alone (Baranov 1914). Failure to detect differences in species diversity or evenness indicates that both gill net types are sampling fish communities in a similar manner.

Fyke Net Interpretation - Directionality of bias for CPUE between fyke net types was inconsistent. Higher catches of Black Crappie in Standard fyke nets are consistent with the findings of Fischer et al. (2010) who found smaller mesh sizes in fyke nets correspond to higher catches of centrarchids. Higher catches of bullhead by SDGFP nets may result from more constricted throat dimensions leading to reduced escapement as demonstrated by Porath et al. (2011) who found increased escapement rates of ictalurids between restricted and unrestricted nets with increasing density. Channel Catfish catches appear to follow a similar trend though small sample size and comparatively high variability preclude detection of a significant difference. Failure to detect differences in CPUE between fyke net types for Northern Pike is consistent with results of Clark and Willis (1989) that found similar CPUE for Northern Pike between varying fyke net types in glacial lakes.

Size selectivity varied between gears and species primarily due to bar-mesh size and behavioral attributes of targeted species. Standard fyke nets with smaller mesh size selected for larger Black Crappie unlike results of a Nebraska study where larger mesh sizes caught larger Black Crappie (Jackson and Bauer 2000). There were three species where SDGFP nets sampled larger fish (i.e., bullhead, White Bass and Yellow Perch) and for all three the major difference was in retention of sub-stock fish; Standard nets retained many sub-stock fish of the three species due to a smaller 13-mm bar-mesh size while most sub-stock fish swam through the larger 19-mm bar mesh of SDGFP nets. One caveat is that PSD was significantly higher for bullhead in Standard nets while there was no difference for PSD-P. Failure to detect differences in size structure between nets for Channel Catfish, Common Carp, Rock Bass, or White Sucker may be an artifact of low sample size though for Channel Catfish PSD was significantly higher for SDGFP nets while PSD-P and KS tests indicated that size structure was similar. My finding that Standard nets selected for larger and smaller individuals of four species (i.e., Bluegill, Northern Pike, Smallmouth Bass, and Walleye) was unanticipated and both observations may be explained by the same factor, smaller bar mesh size of Standard fyke nets; the smallest fish are physically retained by smaller bar mesh, and because Standard nets have more net material in the water, larger fish may perceive Standard nets as thicker cover to use for shelter or ambush purposes (Hansen 1944). Jackson and Bauer (2000) found that smaller 13-mm mesh selected for smaller Bluegill compared to 16-mm mesh and Latta (1959) speculated that larger panfish may be more active in finding cover. Other researchers have noted that fyke nets rarely sample fish as small as the minimum size imposed by the dimensions of the gear (Latta 1959; Shoup et al 2003) though Standard nets began retaining bluegill at approximately 65 mm. Larger panfish in the net may also exclude smaller ones that selectively escape when in the presence of larger conspecifics (Patriarche 1968). Hansen (1944) found that up to 86% of Bluegills can escape from passive entrapment gear. Regardless of the explanation this phenomenon of broadened selectivity is clearly ideal for standardized sampling purposes. My observation for Northern Pike size structure was not found by previous researchers who reported no difference in size structure between fyke nets of differing mesh size (Clark and Willis 1989). The observation that fyke nets produce similar estimates of diversity and evenness should ease concerns that switching sampling gears would result in biased estimates of fish community composition (Figure 3).

Conversion Factors - Regression analyses of CPUE between SDGFP and Standard gears for both gill nets and fyke nets yielded reliable conversion factors for most species with a few exceptions making comparisons by regression techniques appropriate (Table 6). Regression models with poor strength of fit leave much variability unaccounted for and these regression models should be used with caution. Poor strength of fit for several species in either gill or fyke nets may be of limited concern because not all species included in these analyses are primarily indexed for CPUE and size structure using these gears in South Dakota. For instance, Smallmouth Bass are included in both gill and fyke net comparisons because they are commonly sampled with these gears, but for management purposes, they are more effectively sampled by boat electrofishing (Milewski and Willis 1991; Bacula et al. 2011).

Additional caveats of this study include methods used to analyze size structure and the usage of data for conversions. Kolmogorov-Smirnov tests using individual fish as the experimental unit to compare length frequencies were likely influenced by the large sample sizes for several species used in this analysis (Neumann and Allen 2007) but comparisons of PSD and PSD-P helped corroborate or clarify results of the Kolmogorov-Smirnov tests. The benefit of the Kolmogorov-Smirnov test was the ability to compare whole length frequencies instead of only stock-length fish. Both methods collectively provided an understanding of size structure bias between gears. Regression analyses yielded equations useful for converting Standard CPUE of stock-length fish to their equivalent lake-wide SDGFP catch per unit effort thus facilitating the use of historic CPUE data collected by SDGFP. Conversions of data between sampling gears should be done with caution due to increased bias from making interpolations based on an index of abundance, and Peterson and Paukert (2009) suggested that converted data should be identified as such in any long-term database where the data are contained.

This study and similar gear comparisons in Iowa (Fischer et al. 2010) and Kansas (Koch et al. 2014) have demonstrated benefits and shortcomings of proposed standard sampling gears. By providing a thorough analysis of biases between SDGFP and Standard gears there is little doubt that switching to Standard gears would continue to provide managers and researchers in South Dakota with reliable fisheries data. Converting to Standard sampling gears would not only benefit South Dakota but, as

Bonar et al. (2009a) noted, would allow for larger scale analyses facilitated by open-source databases (i.e. fisheriesstandardsampling.org) that allow researchers to compare their data to continent-wide averages and potentially tackle broader questions in fisheries science.

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Table 1.- Selected references for usage of gill nets and fyke nets when sampling select North American freshwater fish species.

	Common Name	Scientific Name	Selected References
Gill Nets	bullheads	*Ameiurus spp.*	Hanchin et al. 2002, Pope et al. 2009
	Channel Catfish	*Ictalurus punctatus*	Elrod 1974
	crappies	*Pomoxis spp.*	Guy et al. 1996
	Freshwater Drum	*Aplodinotus grunniens*	Minns and Hurley 1988
	Lake Trout	*Salvelinus namaycush*	Hansen et al. 1997, Hansen et al. 1998
	Northern Pike	*Esox lucius*	Pierce et al. 1994
	Rainbow Trout	*Oncorhynchus mykiss*	Losanes 1992
	Walleye	*Sander vitreus*	Willis et al. 1985, Willis 1987, Henderson and Nepszy 1992
	White Bass	*Morone chrysops*	Willis et al. 1985, Henderson and Nepszy 1992
	White Sucker	*Catostomus commersoni*	Minns and Hurley 1988, Henderson and Nepszy 1992
	Yellow Perch	*Perca flavescens*	Kraft and Johnson 1992
Fyke Nets	Bluegill	*Lepomis macrochirus*	Cross et al. 1995, McInerny and Cross 2004, Schultz and Haines 2005, Fischer 2010
	bullheads	*Ameiurus spp.*	Hanchin et al. 2002, McInerny and Cross 2004, Fischer 2010
	crappies	*Pomoxis spp.*	Willis 1984, Guy and Willis 1991, Gritters 1997, Shoup et al. 2003
	Northern Pike	*Esox lucius*	Guy and Willis 1991, McInerny and Cross 2004
	Pumkinseed	*Lepomis gibbosus*	Gritters 1997, Shoup et al. 2003, McInerny and Cross 2004
	Rock Bass	*Ambloplites rupestris*	Laarman and Ryckman 1982, Hoffman et al. 1990
	Smallmouth Bass	*Micropterus dolomieu*	Milewski and Willis 1991, McInerny and Cross 2004
	Walleye	*Sander vitreus*	Guy and Willis 1991, Rogers et al. 2003
	Yellow Perch	*Perca flavescens*	Guy and Willis 1991, Kraft and Johnson 1992, McInerny and Cross 2004

Table 2.- Characteristics of lakes sampled during June-August 2013 and 2014 including effort used by both sampling regimes (i.e. Standard and SDGFP) in each lake. Fyke nets were not used in all lakes. Trophic state was determined based on Trophic State Index outlined by Carlson (1977). Several water bodies including all Black hills impoundments were sampled with gill nets only.

Lake	Lake Type	Surface Area (ha)	Max depth (m)	Trophic State	Gill Nets	Fyke Nets
Alvin	Prairie Stream Impoundment	42	7.9	Eutrophic	3	10
Bitter	Glacial lake	6070	8.5	Eutrophic	8	18
Blue Dog	Glacial lake	251	2.7	Eutrophic	6	18
Bullhead	Glacial lake	66	4.6	Eutrophic-Hypereutrophic	3	12
Clear	Glacial lake	192	6.7	Mesotrophic-Eutrophic	6	18
Cochrane	Glacial lake	58	7.3	Eutrophic	3	12
Deerfield	Black Hills Impoundment	176	29.0	Mesotrophic	4	
East Krause	Glacial lake	70	6.1	Eutrophic	3	12
Enemy Swim	Glacial lake	868	7.9	Mesotrophic-Eutrophic	6	24
Kampeska	Glacial lake	2125	4.9	Eutrophic	6	21
Madison	Glacial lake	1069	4.9	Eutrophic	5	10
Mina	Prairie Stream Impoundment	326	8.2	Eutrophic	6	18
Mitchell	Prairie Stream Impoundment	271	8.8	Eutrophic	4	12
North Rush	Glacial lake	1133	3.7	Eutrophic-Hypereutrophic	6	
Pactola	Black Hills Impoundment	318	50.6	Oligotrophic	12	
Pickerel	Glacial lake	397	12.5	Eutrophic	6	12
Richmond	Prairie Stream Impoundment	335	8.8	Eutrophic	6	18
Roy	Glacial lake	831	6.4	Eutrophic	6	24
Scott	Glacial lake	43	3.4	Eutrophic	3	5
Sheridan	Black Hills Impoundment	155	29.3	Mesotrophic	2	
Sinai	Glacial lake	735	10.1	Eutrophic	4	10
South Buffalo	Glacial lake	724	4.3	Eutrophic	6	
Thompson	Glacial lake	5041	7.9	Eutrophic	5	10
Wall	Glacial lake	84	7.3	Eutrophic	3	5
Waubay	Glacial lake	6289	9.4	Hypereutrophic	8	32
West 81	Glacial lake	554	6.7	Hypereutrophic	5	10

Table 3.- Total catch of Standard and SDGFP gill nets and fyke nets used to sample 26 lakes across South Dakota during June-August of 2013 and 2014.

Species		Gill Net		Fyke Net		
Common Name	Scientific Name	Standard	SDGFP	Standard	SDGFP	Total
Bigmouth Buffalo	*Ictiobus cyprinellus*	4	3	22	43	72
Black Bullhead	*Ameiurus melas*	1567	2889	8451	15289	28196
Black Crappie	*Pomoxis nigromaculatus*	91	147	1014	798	2050
Bluegill	*Lepomis macrochirus*	96	207	2084	2012	4399
Bluegill Hybrid	*Lepomis macrochirus x Lepomis spp.*	1		179	491	671
Brook Trout	*Salvelinus fontinalis*	3	23			26
Brown Trout	*Salmo trutta*	3	13			16
Channnel Catfish	*Ictalurus punctatus*	123	163	74	119	479
Cisco	*Coregonus artedi*	5	3			8
Common Carp	*Cyprinus carpio*	82	122	2044	1437	3685
Emerald Shiner	*Notropis atherinoides*		1	1		2
Eurasian Rudd	*Scardinius erythrophthalamus*		1			1
Flathead Catfish	*Pylodictis olivaris*				1	1
Freshwater Drum	*Aplodinotus grunniens*	48	58	11	15	132
Golden Shiner	*Notemigonus crysoleucas*	1		1		2
Green Sunfish	*Lepomis cyanellus*		1	59	47	107
Green Sunfish Hybrid	*Lepomis cyanellus x Lepomis spp.*	1	2			3
Lake Trout	*Salvelinus namaycush*	29	87			116
Largemouth Bass	*Micropterus salmoides*	3	3	28	9	43
Northern Pike	*Esox lucius*	181	402	215	214	1012
Orangespotted Sunfish	*Lepomis humilis*			1	1	2
Pumkinseed	*Lepomis gibbosus*		1	7	10	18
Rainbow Smelt	*Osmerus mordax*		29			29
Rainbow Trout	*Oncorhynchus mykiss*	38	49			87
River Carpsucker	*Carpiodes carpio*	3	4	3	3	13
Rock Bass	*Ambloplites rupestris*	31	79	51	273	434
Shorthead Redhorse	*Moxostoma macrolepidotum*	1	2	3		6
Smallmouth Bass	*Micropterus dolomieu*	76	100	180	484	840
Splake Trout	*Salvelinus fontinalis x Salvelinus namaycush*	1	10			11
Spottail Shiner	*Notropis hudsonius*		5			5
Walleye	*Sander vitreus*	534	1199	176	446	2355
White Bass	*Morone chrysops*	142	251	710	382	1485
White Crappie	*Pomoxis annularis*	18	33	18	33	102
White Sucker	*Catostomus commersonii*	228	224	102	94	648
Yellow Bullhead	*Ameiurus natalis*	6	13	50	384	453
Yellow Perch	*Perca flavescens*	1195	4362	1114	527	7198
Grand Total		4511	10486	16598	23112	54707

Table 4.- Total catch of "mini-mesh" panels used in conjunction with Standard "core-mesh" gill nets in nine eastern South Dakota lakes during June-August 2014.

Species		Bar Mesh Size			
Common Name	Scientific Name	10 mm	13 mm	16 mm	Total
Black Bullhead	*Ameiurus melas*		2	3	5
Black Crappie	*Pomoxis nigromaculatus*		2	1	3
Bluegill	*Lepomis macrochirus*	1			1
Channnel Catfish	*Ictalurus punctatus*			1	1
Common Carp	*Cyprinus carpio*	1	3	3	7
Northern Pike	*Esox lucius*	1			1
Smallmouth Bass	*Micropterus dolomieu*		4	1	5
Spottail Shiner	*Notropis hudsonius*	9	2		11
Walleye	*Sander vitreus*		1	5	6
White Bass	*Morone chrysops*	4	6	3	13
Yellow Perch	*Perca flavescens*	72	282	71	425
Grand Total		88	302	88	478

Table 5. Calculated values of proportional size distribution (PSD) and proportional size distribution of preferred length fish (PSD-P) for Standard and SDGFP gill nets and fyke nets collected in South Dakota lakes during June-August 2013-2014 shown with results of Chi-Square Test where $\alpha = 0.05$ for all comparisons.

		PSD					PSD-P				
Gear	Species	Standard	SDGFP	χ^2	p-value		Standard	SDGFP	χ^2	p-value	
Fyke nets	Black Crappie	89	85	6.365	0.015	*	53	48	3.224	0.073	
	Bluegill	75	55	167.404	< 0.001	*	31	17	102.61	< 0.001	*
	Bullhead	73	62	51.077	< 0.001	*	14	15	1.209	0.272	
	Channel Catfish	59	76	5.036	0.025	*	21	14	0.785	0.376	
	Common Carp	94	89	1.826	0.177		61	56	0.658	0.417	
	Northern Pike	79	64	10.110	0.001	*	23	14	4.98	0.026	*
	Rock Bass	74	61	2.336	0.126		14	13	0.002	0.966	
	Smallmouth Bass	57	40	10.942	< 0.001	*	33	18	14.576	< 0.001	*
	Walleye	42	33	3.632	0.057		15	11	1.301	0.254	
	White Bass	99	100	0.306	0.580		89	93	3.522	0.061	
	White Sucker	94	91	0.211	0.646		89	82	1.665	0.197	
	Yellow Perch	20	26	3.378	0.066		2	2	0	1.000	
Gill nets	Black Crappie	95	93	0.231	0.631		70	77	0.987	0.321	
	Bluegill	72	82	3.061	0.080		28	23	0.543	0.461	
	Bullhead	63	50	50.010	< 0.001	*	8	5	11.943	< 0.001	*
	Channel Catfish	70	60	2.517	0.113		10	8	0.262	0.607	
	Common Carp	91	90	0	1.000		70	45	4.344	0.037	*
	Lake Trout	67	49	1.880	0.170		19	16	0	1.000	
	Northern Pike	74	64	4.975	0.026	*	15	10	2.261	0.133	
	Rainbow Trout	8	0	1.659	0.198		3	0	0.004	0.950	
	Rock Bass	37	34	< 0.001	0.981		7	3	0.233	0.629	
	Smallmouth Bass	73	53	6.242	0.012	*	46	29	4.600	0.032	*
	Walleye	36	29	8.039	0.005	*	13	5	36.493	< 0.001	*
	White Bass	100	99	0.128	0.720		96	92	2.648	0.104	
	White Sucker	98	95	1.690	0.194		96	91	3.831	0.050	
	Yellow Perch	40	40	0.041	0.839		13	10	4.757	0.029	*

Table 6. Species-specific regression equations useful as conversion factors for lake-wide $LOG_{10}(X + 1)$ transformed Catch Per Unit Effort (CPUE) data between North American Standard and South Dakota Game, Fish and Parks gill nets and fyke nets. For Lake Trout and Rainbow trout net set was the replicate unit.

Gear	Species	Standard to SDGFP	SDGFP to Standard
Gill nets	Black Crappie	SDGFP = 0.827 * (Standard) + 0.085	Standard = (SDGFP - 0.085)/0.827
	Bluegill	SDGFP = 0.730 * (Standard) + 0.230	Standard = (SDGFP - 0.230)/0.730
	Bullhead	SDGFP = 1.053 * (Standard) + 0.155	Standard = (SDGFP - 0.155)/1.053
	Channel Catfish	SDGFP = 0.983 * (Standard) + 0.084	Standard = (SDGFP - 0.084)/0.983
	Common Carp	SDGFP = 0.664 * (Standard) + 0.050	Standard = (SDGFP - 0.050)/0.664
	Lake Trout	SDGFP = 0.360 * (Standard) + 0.448	Standard = (SDGFP - 0.448)/0.360
	Northern Pike	SDGFP = 1.187 * (Standard) + 0.135	Standard = (SDGFP - 0.135)/1.187
	Rainbow Trout	SDGFP = 0.099 * (Standard) + 0.402	Standard = (SDGFP - 0.402)/0.099
	Rock Bass	SDGFP = 1.139 * (Standard) + 0.114	Standard = (SDGFP - 0.114)/1.139
	Smallmouth Bass	SDGFP = 0.858 * (Standard) + 0.097	Standard = (SDGFP - 0.097)/0.858
	Walleye	SDGFP = 0.798 * (Standard) + 0.424	Standard = (SDGFP - 0.424)/0.798
	White Bass	SDGFP = 1.175 * (Standard) + 0.005	Standard = (SDGFP - 0.005)/1.175
	White Sucker	SDGFP = 0.892 * (Standard) + 0.041	Standard = (SDGFP - 0.041)/0.892
	Yellow Perch	SDGFP = 0.940 * (Standard) + 0.420	Standard = (SDGFP - 0.420)/0.940
Fyke nets	Black Crappie	SDGFP = 0.632 * (Standard) + 0.130	Standard = (SDGFP - 0.130)/0.632
	Bluegill	SDGFP = 0.891 * (Standard) + 0.166	Standard = (SDGFP - 0.166)/0.891
	Bullhead	SDGFP = 1.063 * (Standard) + 0.229	Standard = (SDGFP - 0.229)/1.063
	Channel Catfish	SDGFP = 1.077 * (Standard) + 0.141	Standard = (SDGFP - 0.141)/1.077
	Common Carp	SDGFP = 0.938 * (Standard) - 0.036	Standard = (SDGFP + 0.036)/0.938
	Northern Pike	SDGFP = 0.950 * (Standard) - 0.006	Standard = (SDGFP + 0.006)/0.950
	Rock Bass	SDGFP = 2.589 * (Standard) + 0.048	Standard = (SDGFP - 0.048)/2.589
	Smallmouth Bass	SDGFP = 1.597 * (Standard) - 0.007	Standard = (SDGFP + 0.007)/1.597
	Walleye	SDGFP = 1.225 * (Standard) + 0.087	Standard = (SDGFP - 0.087)/1.225
	White Bass	SDGFP = 1.010 * (Standard) - 0.032	Standard = (SDGFP + 0.032)/1.010
	White Sucker	SDGFP = 0.907 * (Standard) + 0.009	Standard = (SDGFP - 0.009)/0.907
	Yellow Perch	SDGFP = 0.892 * (Standard) + 0.121	Standard = (SDGFP - 0.121)/0.892

List of Figures

1.) Regressions of Standard against SDGFP gill net catch per unit effort plotted against a 1:1 line for 14 species with results of analysis of covariance (ANCOVA) shown where β_0 and β_1 indicate results for differences in slope and intercept, respectively. All fish sampled across South Dakota during June-August 2013-2014. Solid lines indicate actual regressions and dotted lines indicate 1:1 regressions.

2.) Length frequency distributions for 14 species sampled using Standard and SDGFP gill nets in South Dakota during June-August 2013-2014 shown with results of Kolmogorov-Smirnov Test.

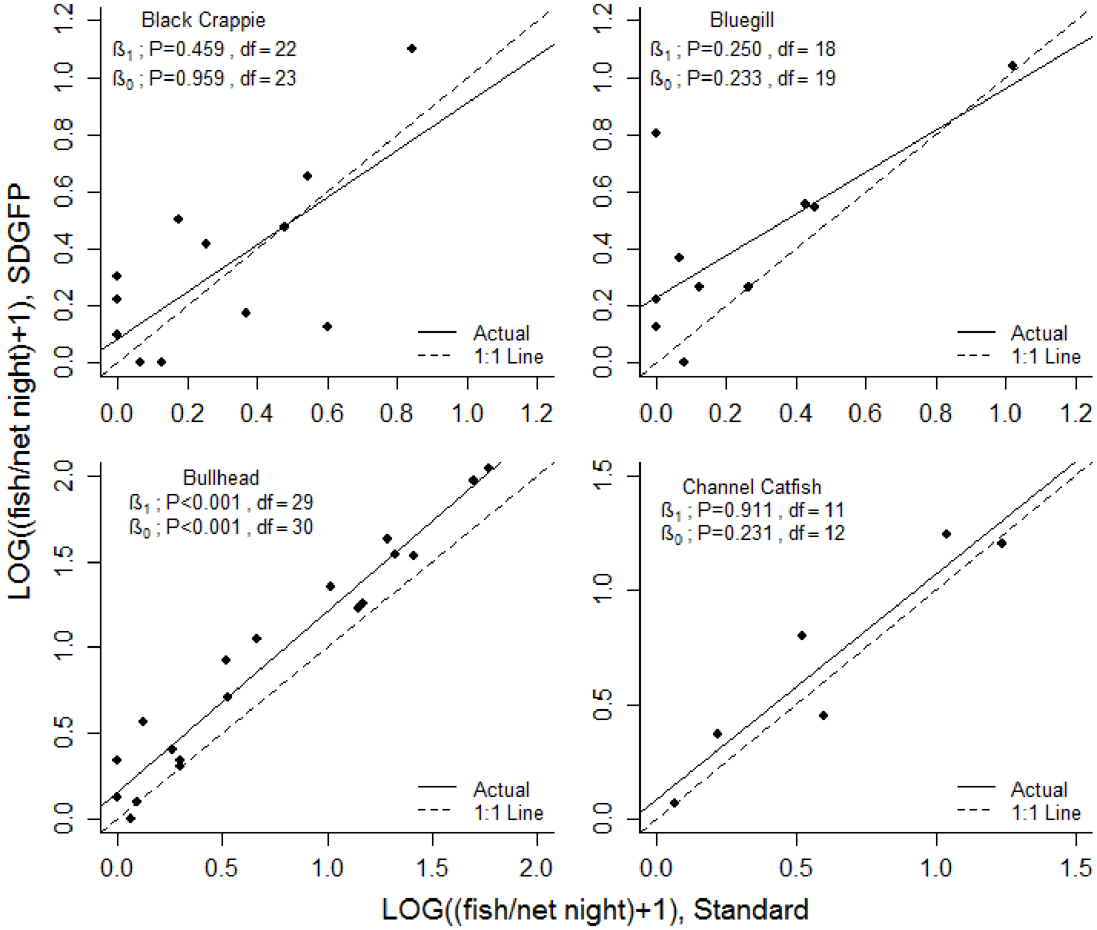
3.) Box plots of Shannon's diversity and evenness for Standard and SDGFP gill nets shown with results of blocked analysis of variance (ANOVA). Fish collected using gill nets (N=26 lakes) and fyke nets (N=21 lakes) across South Dakota during June-August 2013-2014.

4.) Regressions of Standard against SDGFP fyke net catch per unit effort plotted against a 1:1 line for 12 species with results of analysis of covariance (ANCOVA) shown where β_0 and β_1 indicate results for differences in slope and intercept, respectively. All fish sampled across South Dakota during June-August 2013-2014. Solid lines indicate actual regressions and dotted lines indicate 1:1 regressions.

5.) Length frequency distributions for 12 species sampled using Standard and SDGFP fyke nets in South Dakota during June-August 2013-2014 shown with results of Kolmogorov-Smirnov Test.

6.) Regressions of Standard against SDGFP gill net catch per unit effort shown with associated 95% confidence intervals, regression equation and adjusted R^2 value for 14 species sampled across South Dakota during June-August 2013-2014.

7.) Regressions of Standard against SDGFP fyke net catch per unit effort shown with associated 95% confidence intervals, regression equation and adjusted R^2 value for 12 species sampled across South Dakota during June-August 2013-2014.



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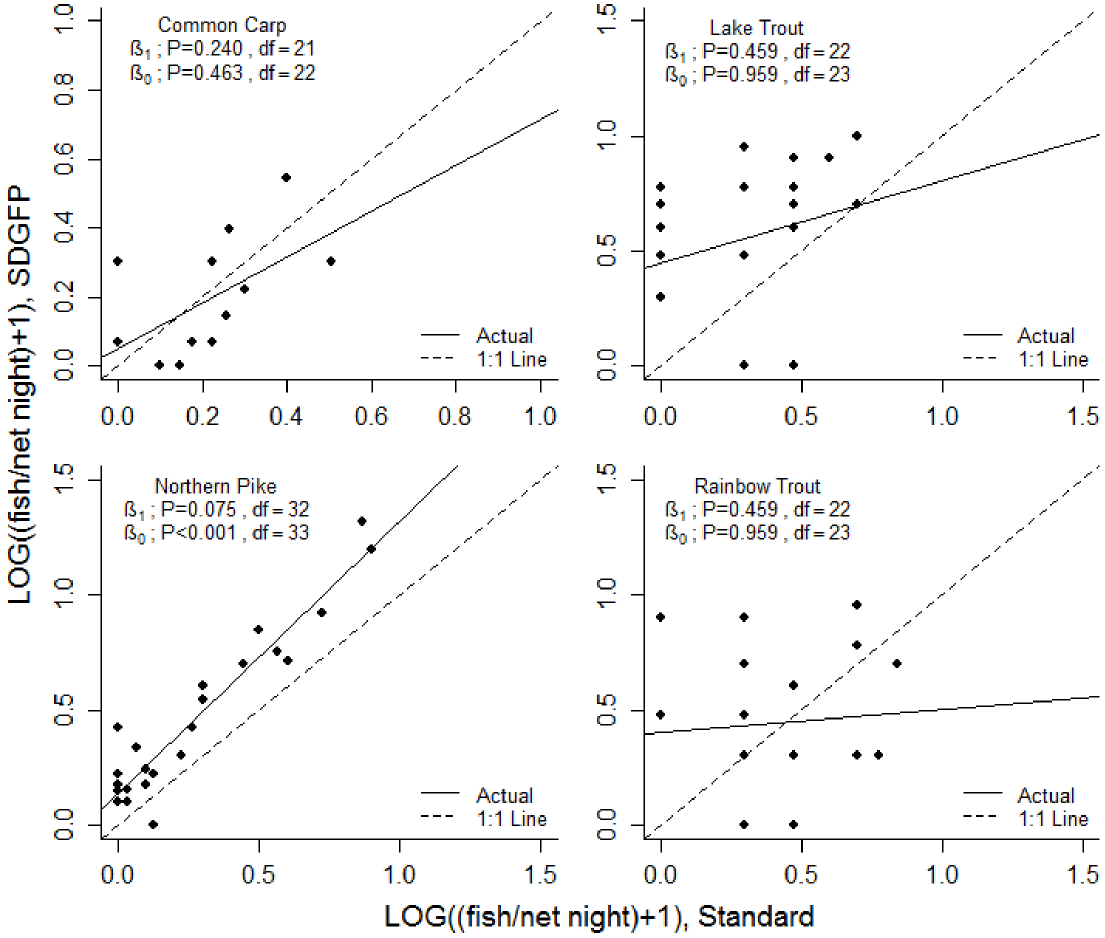

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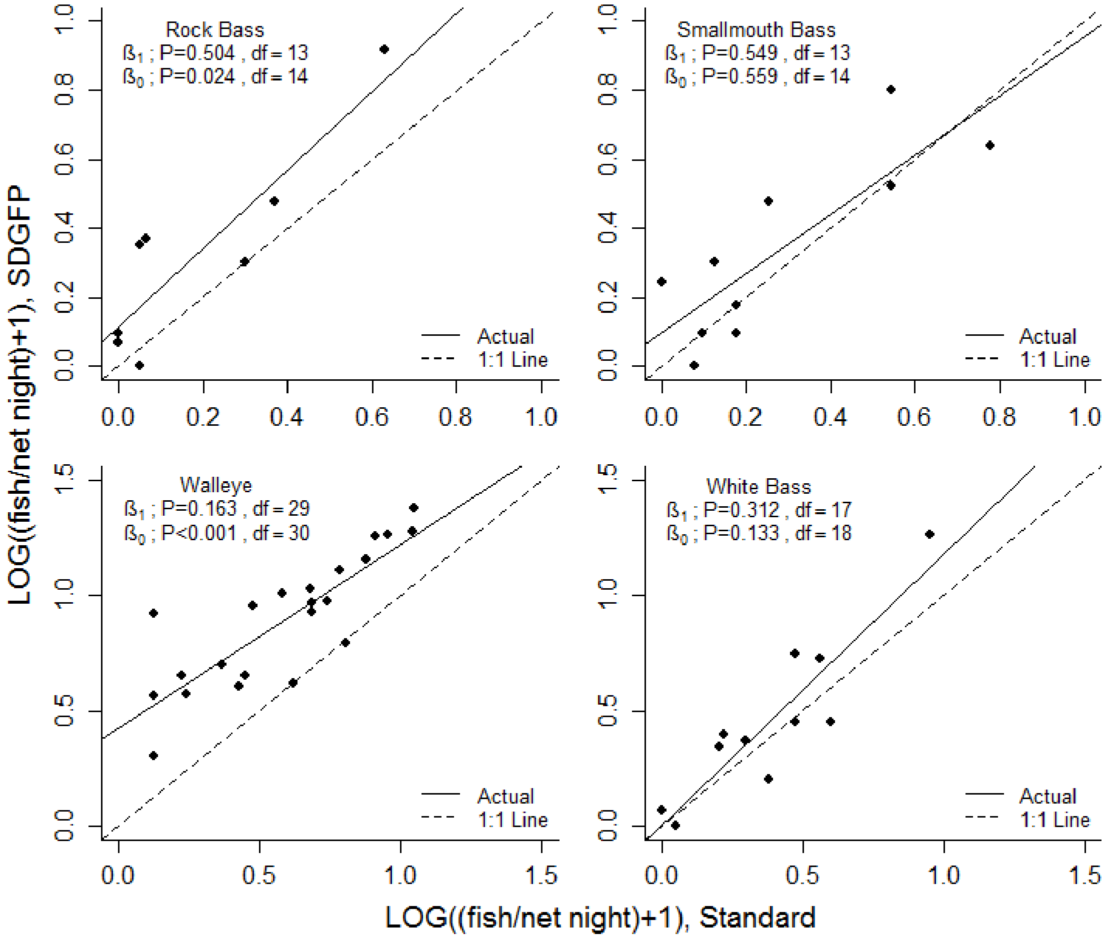

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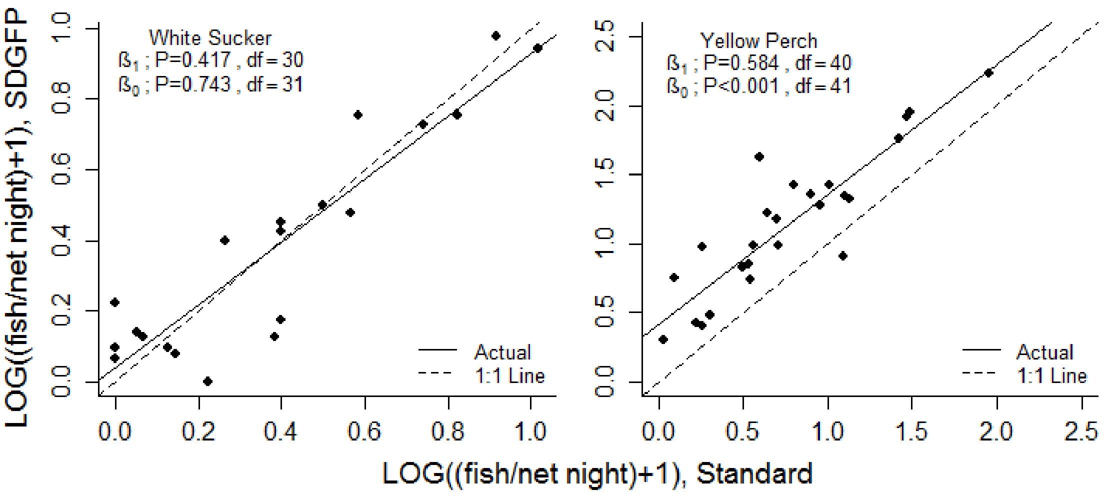

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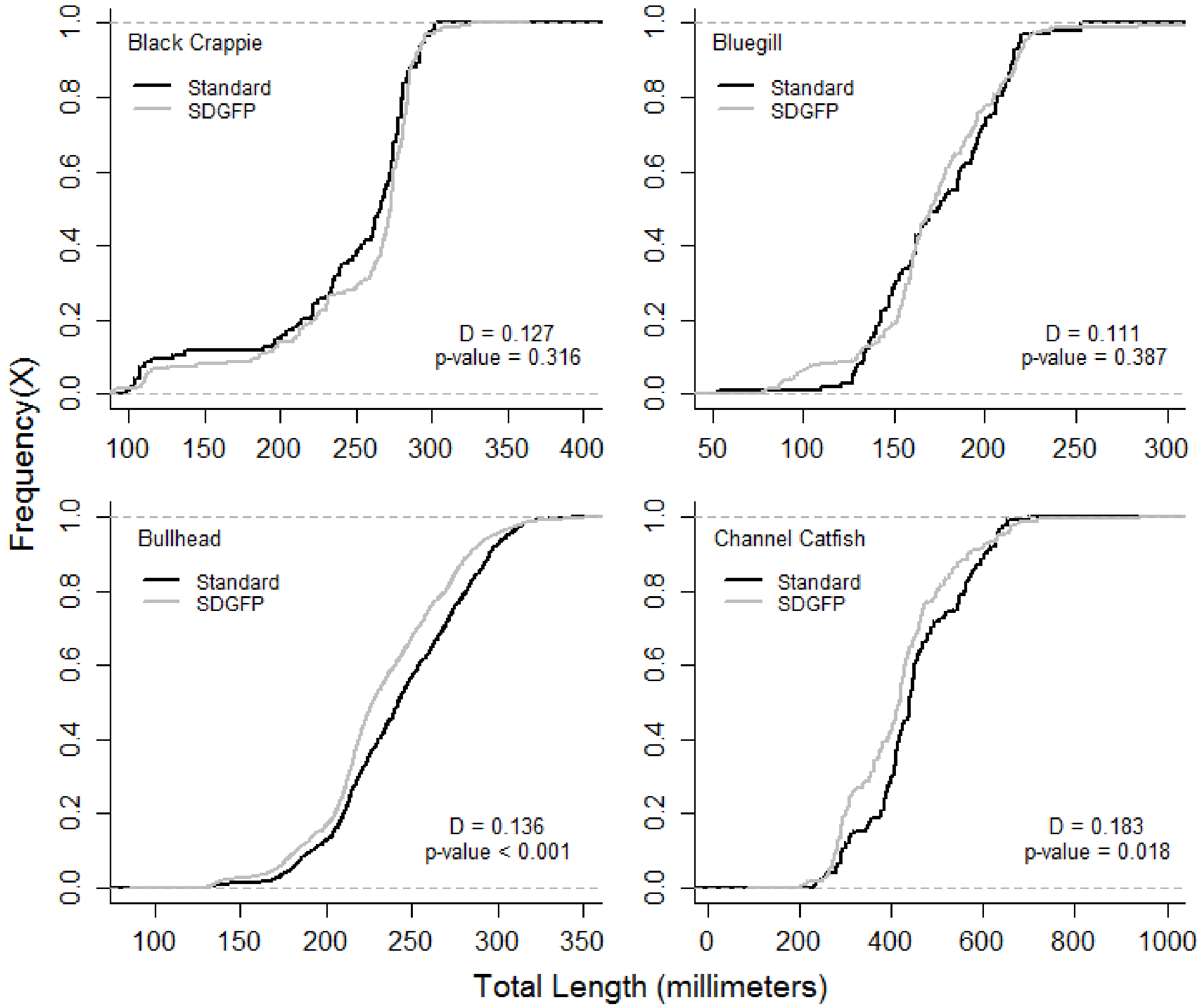

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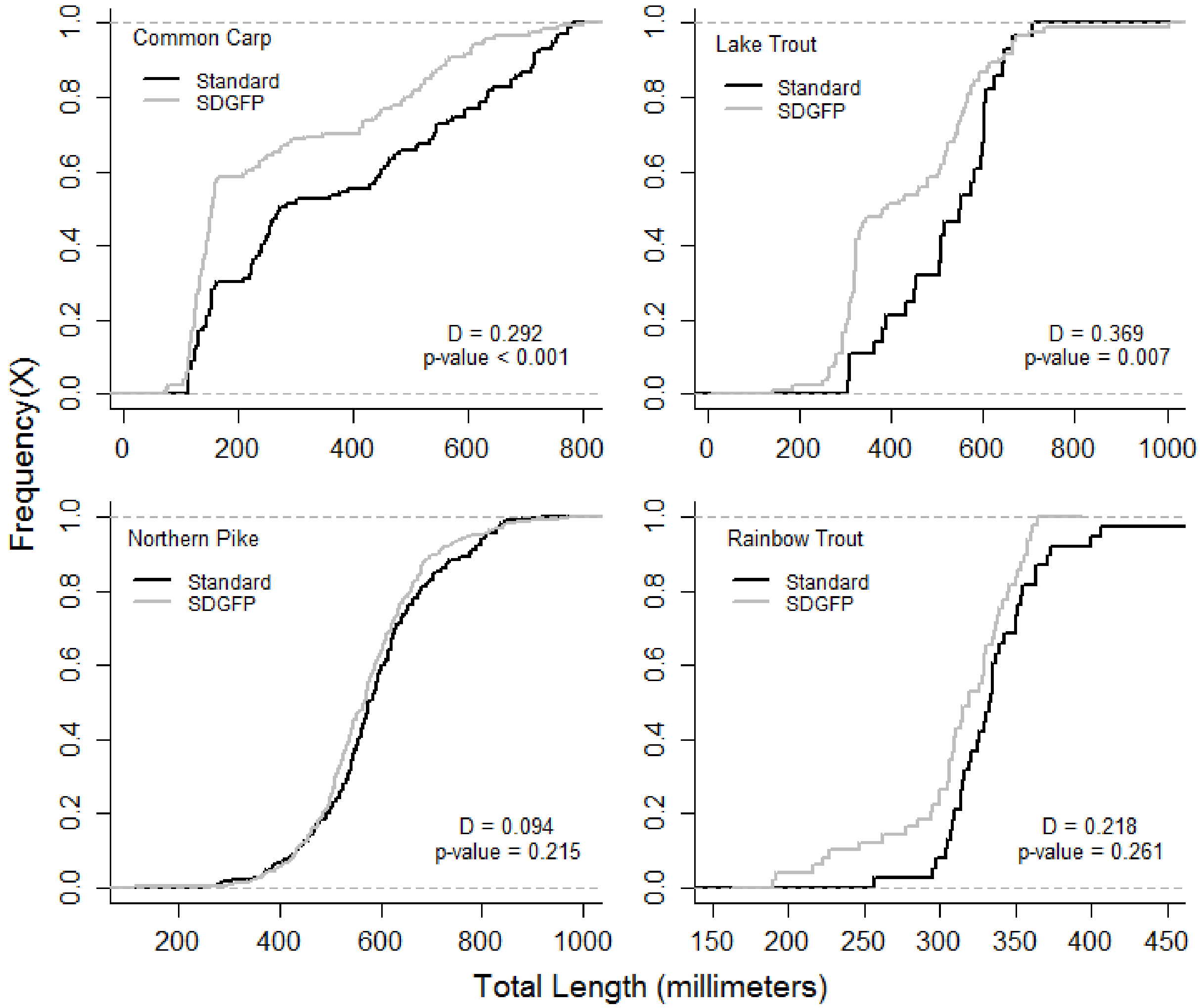

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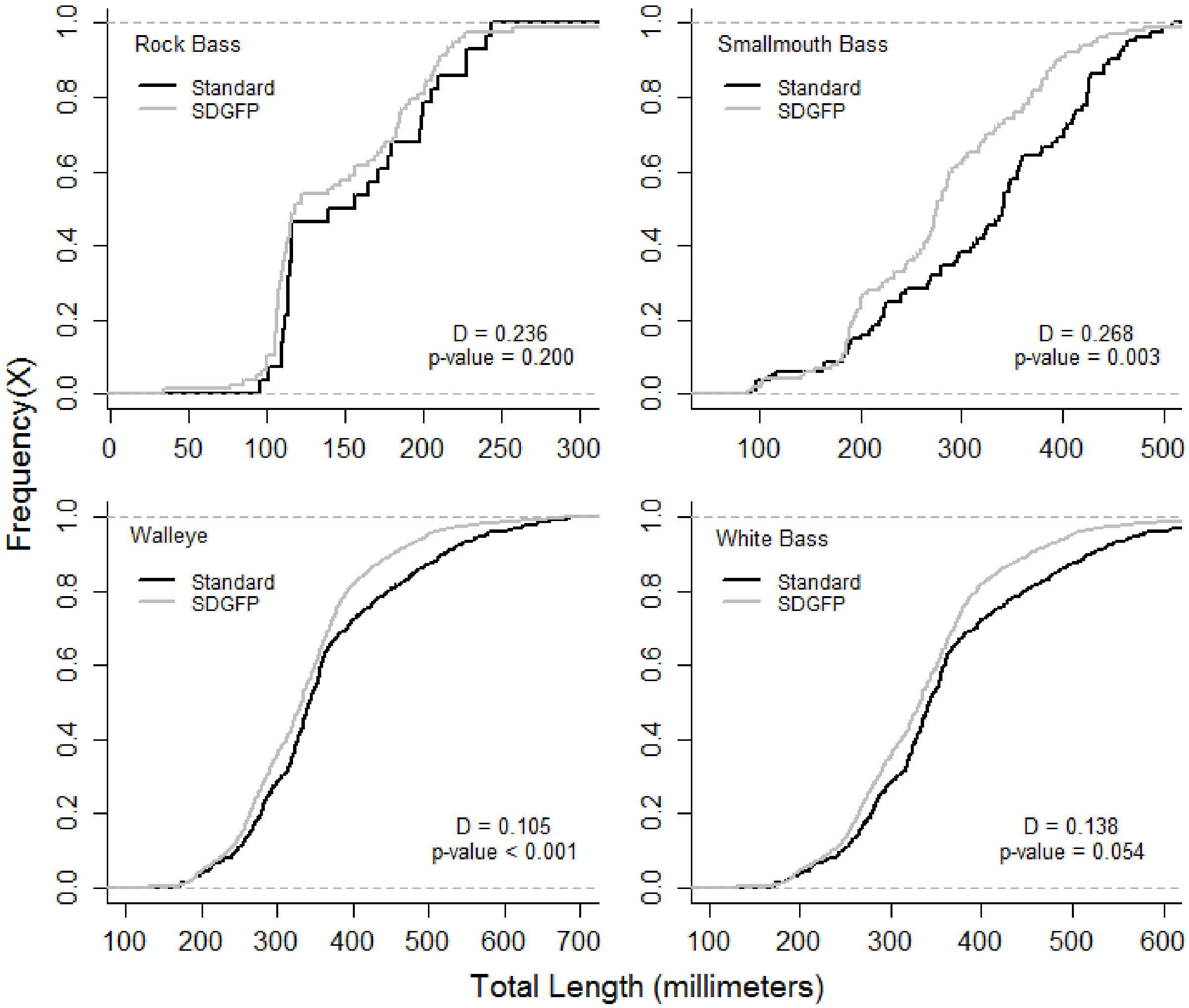

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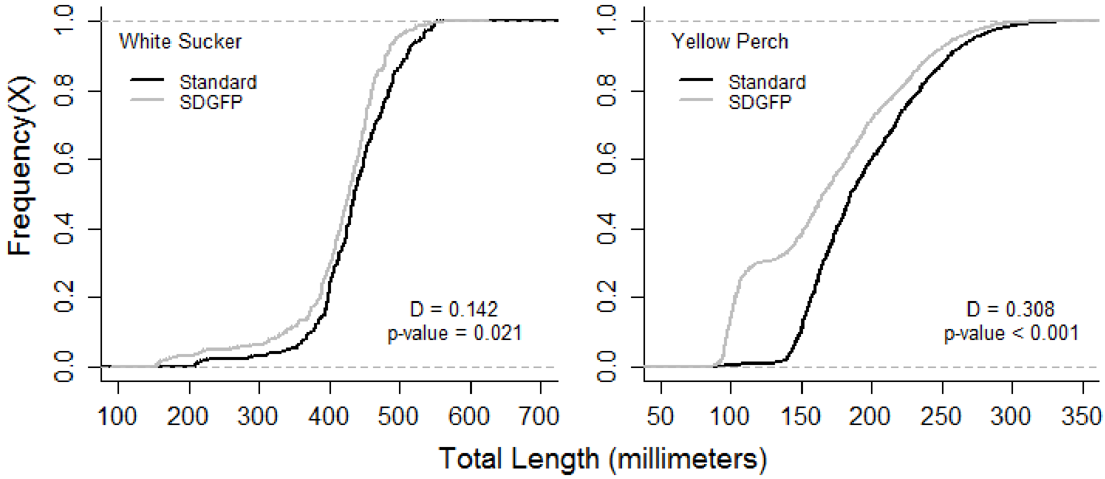

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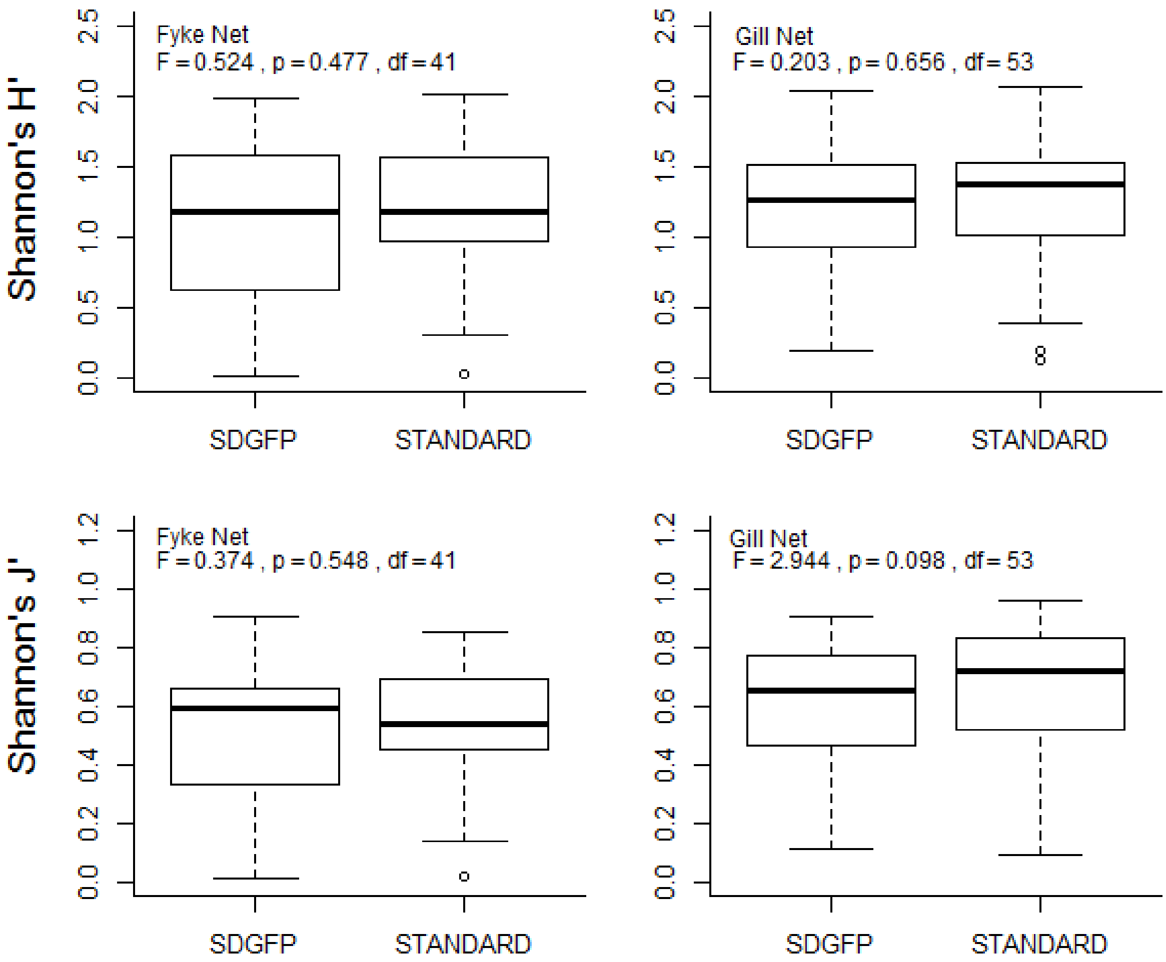

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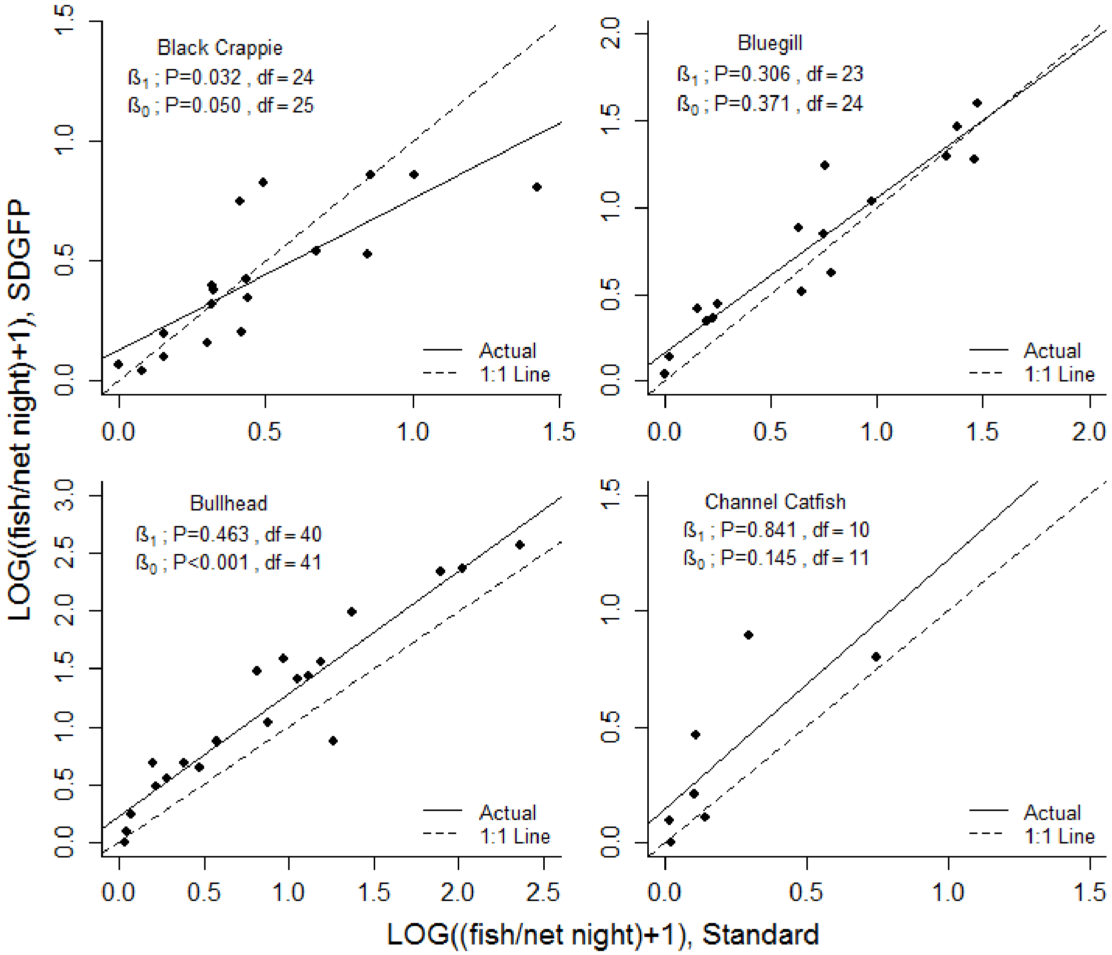

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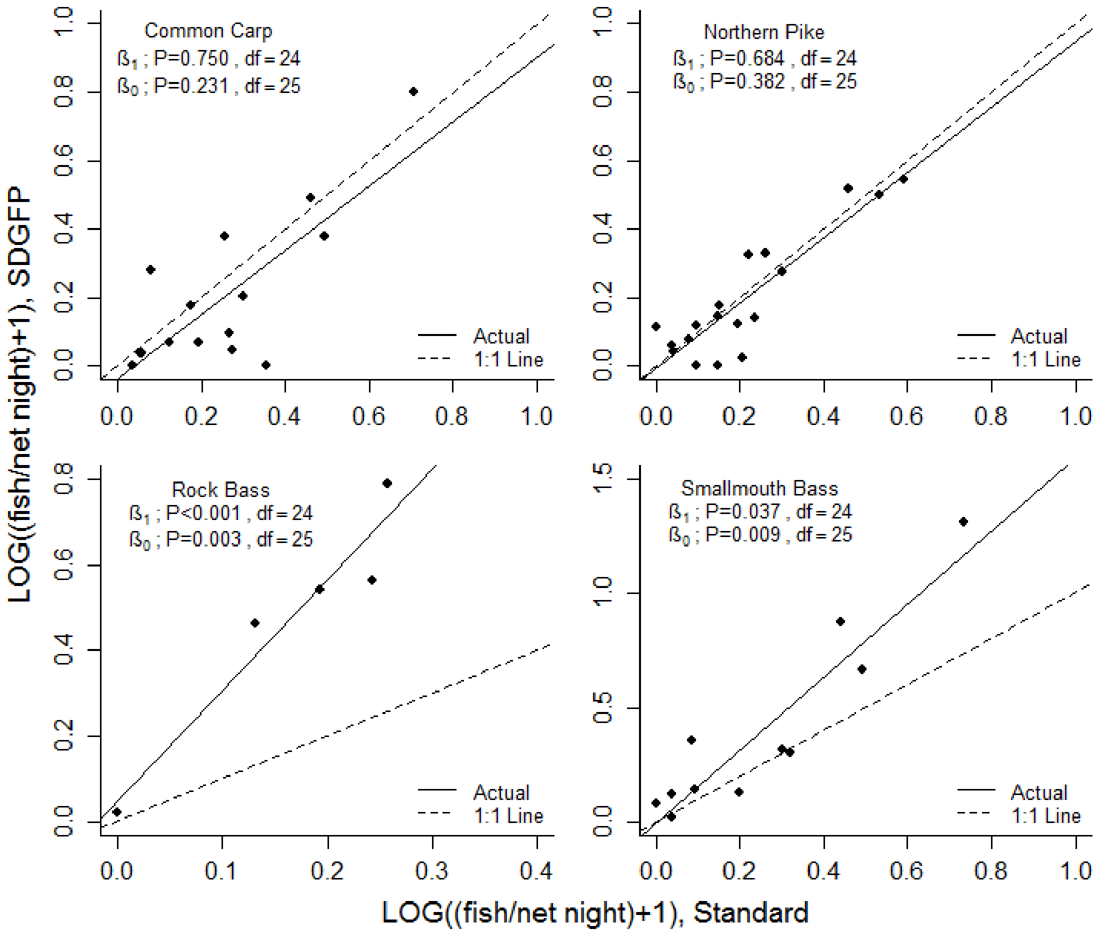

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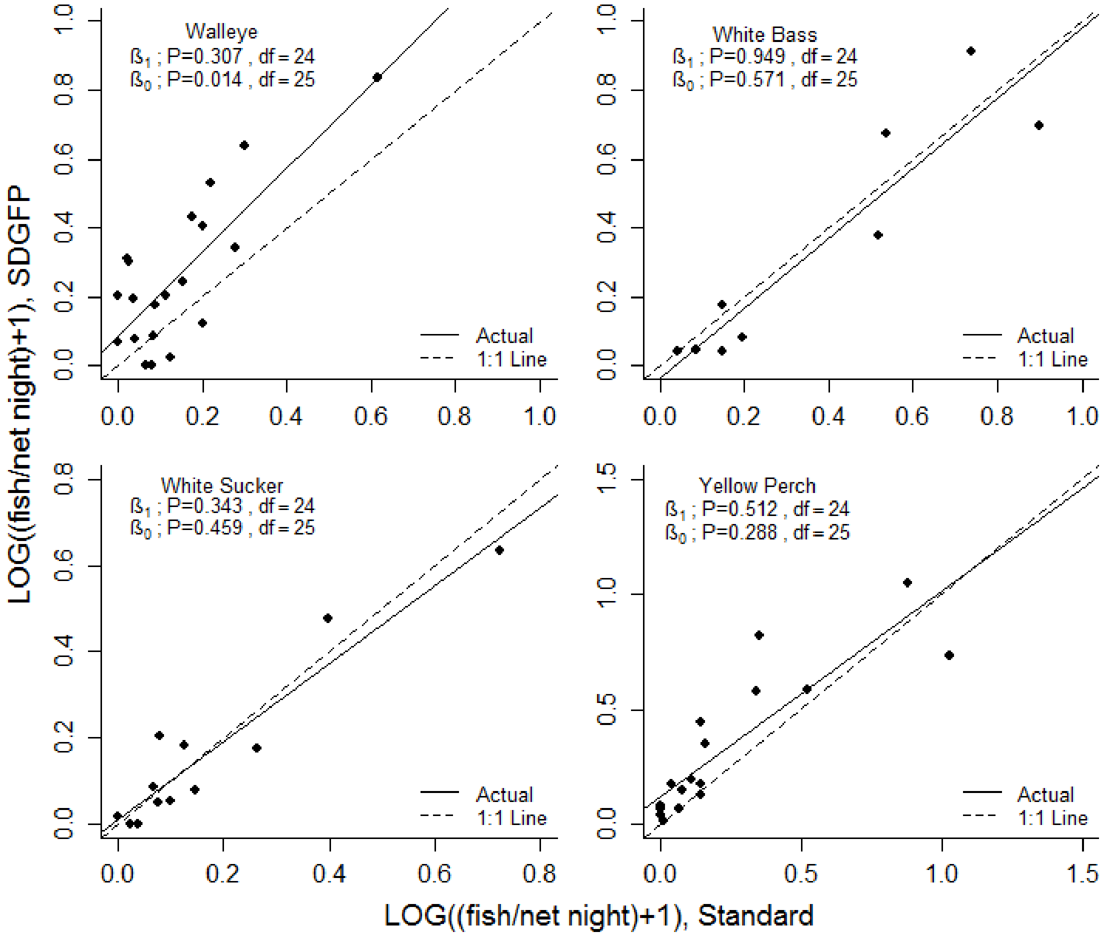

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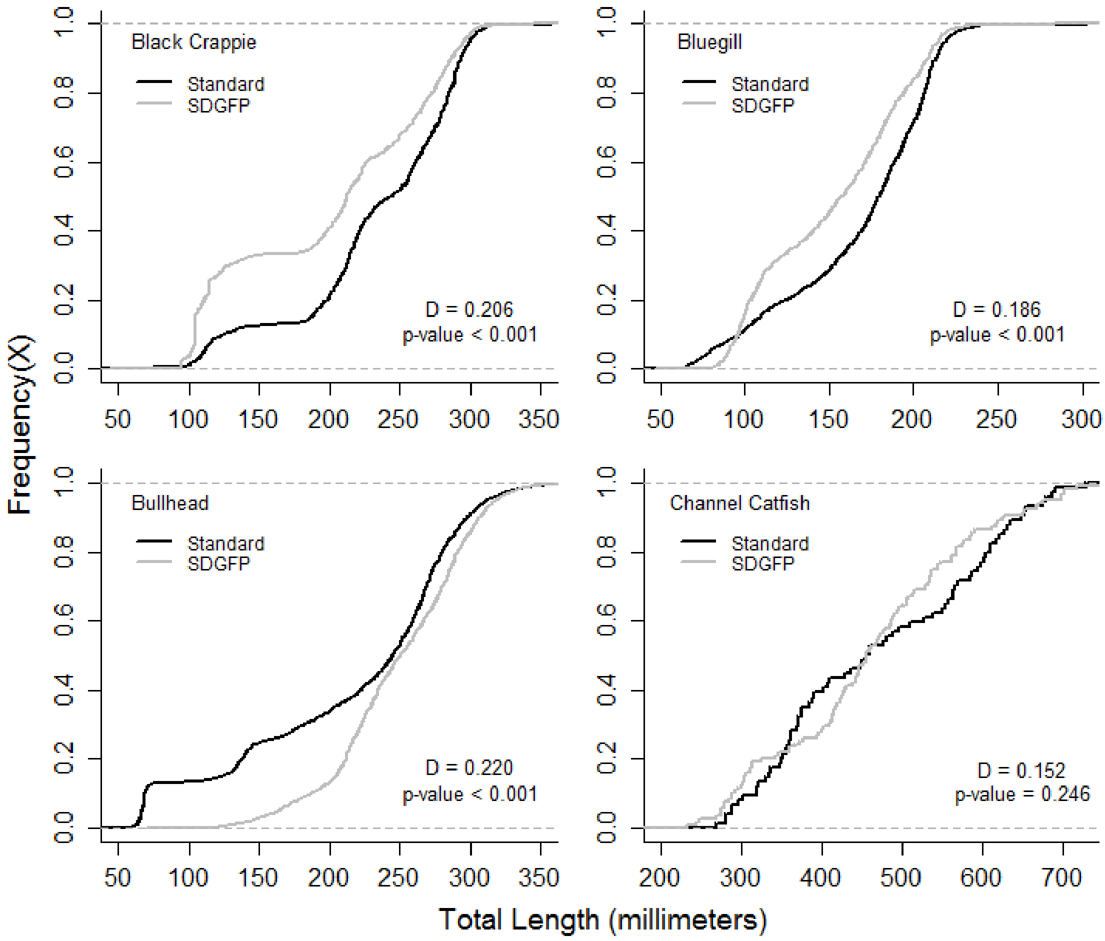

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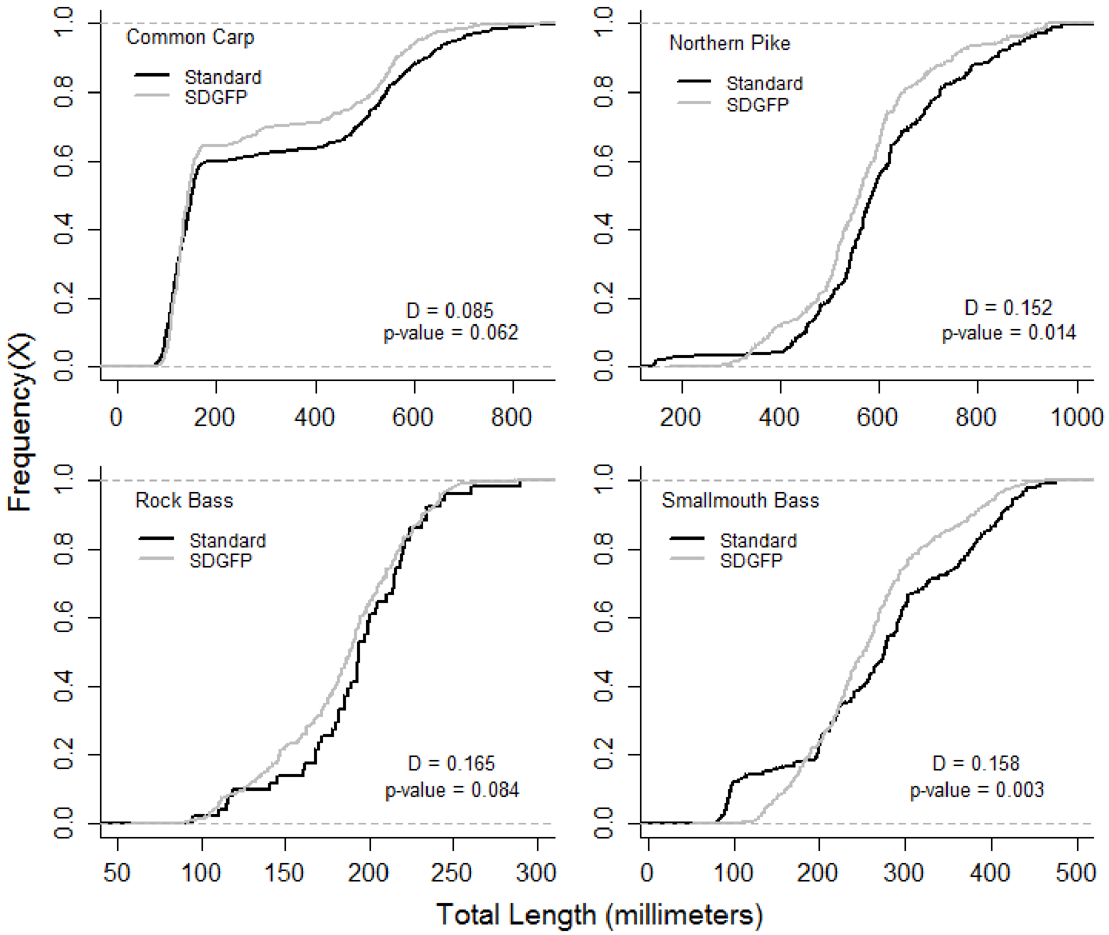

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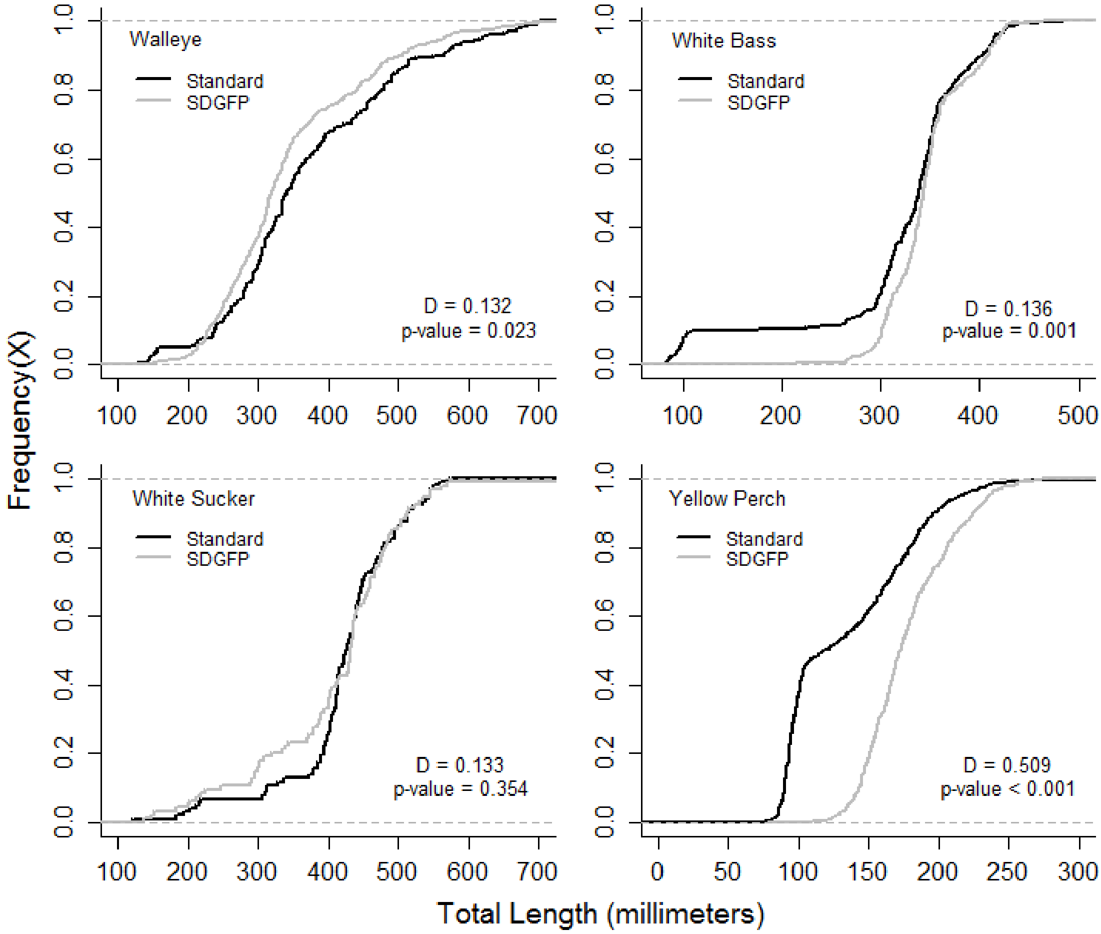

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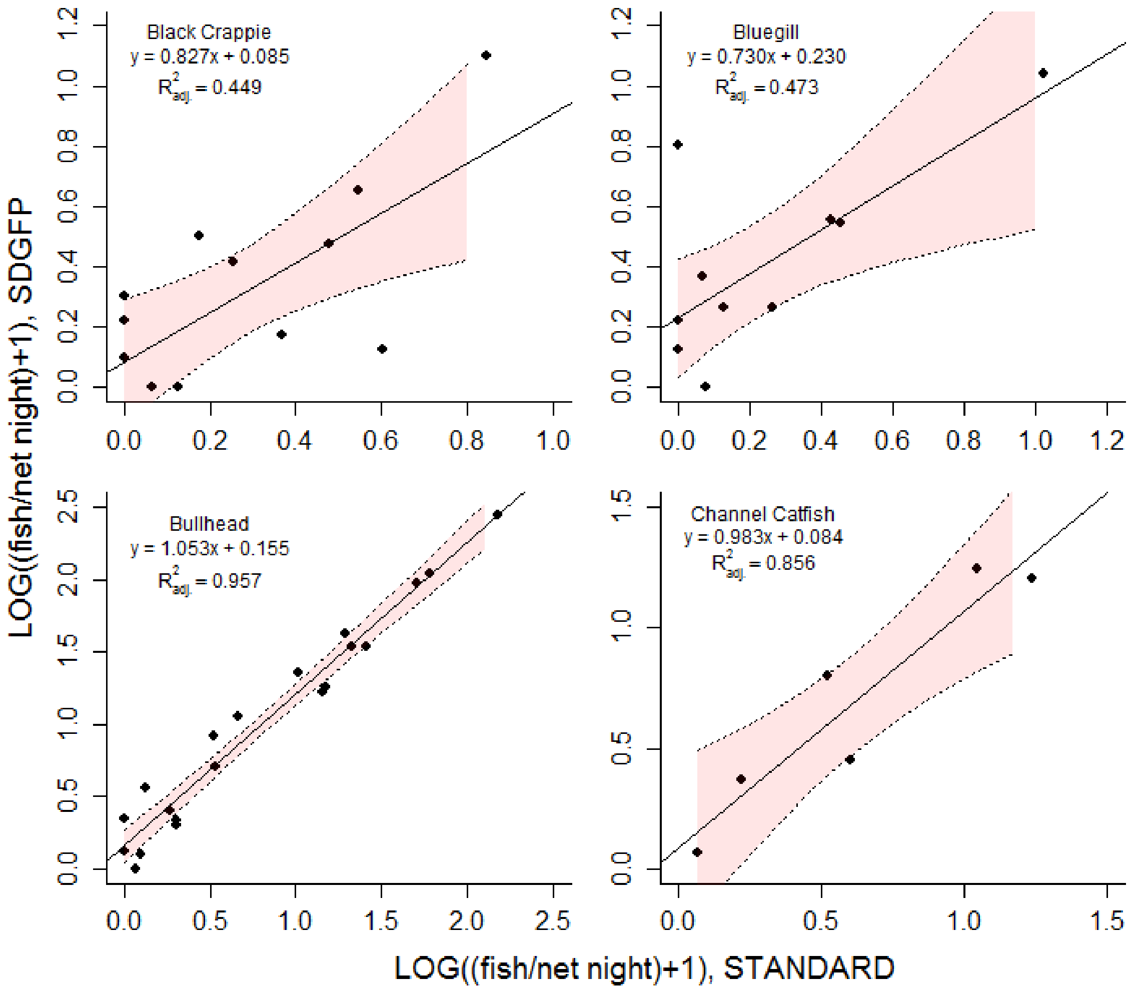

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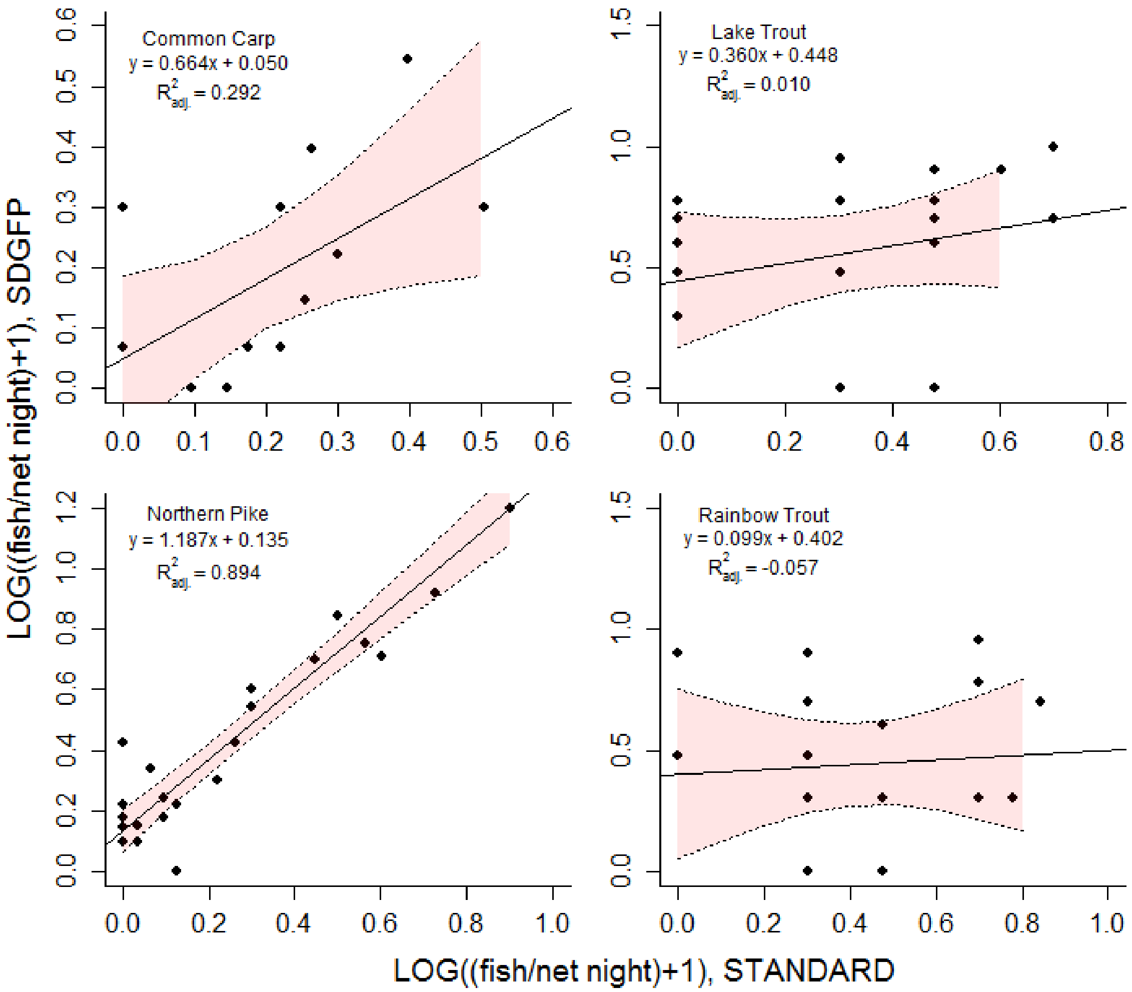

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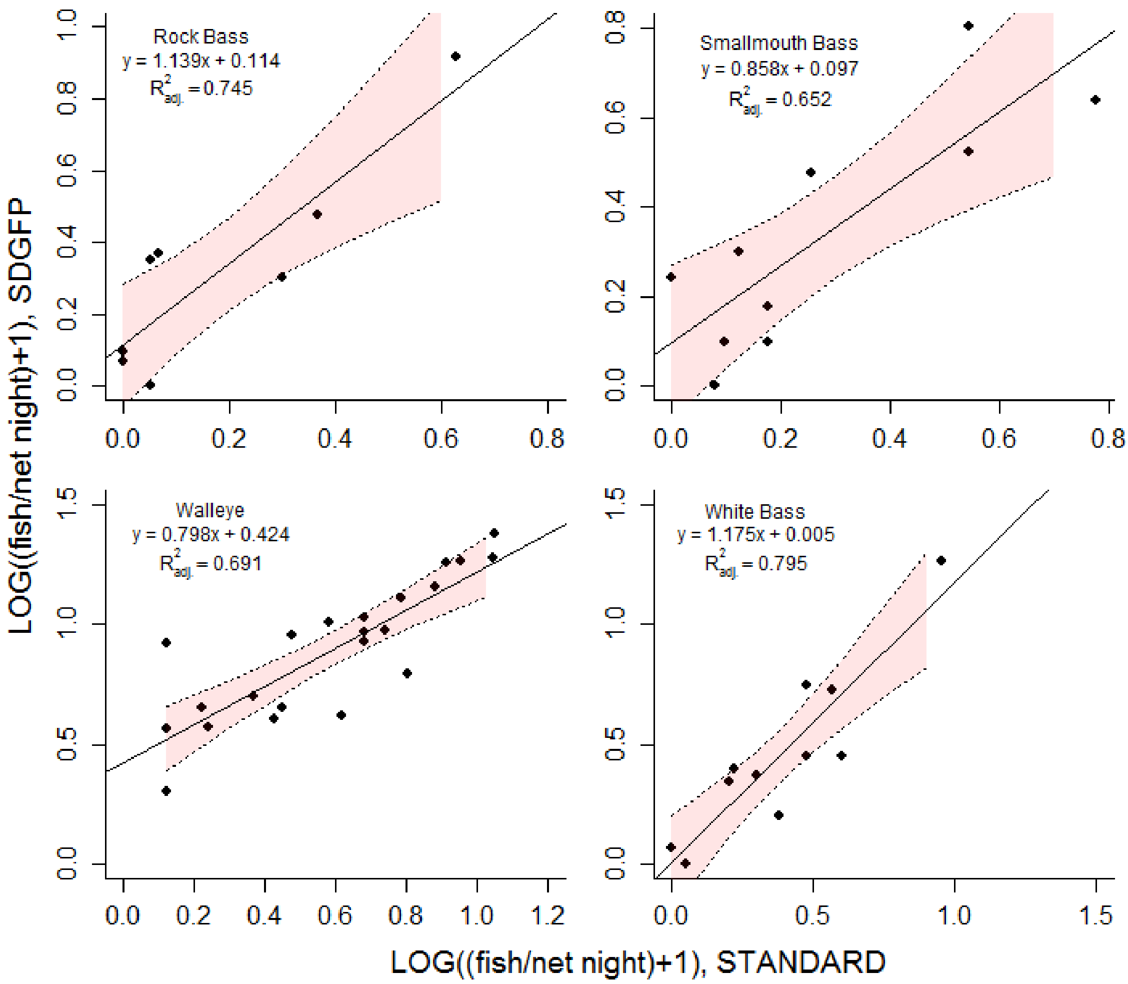

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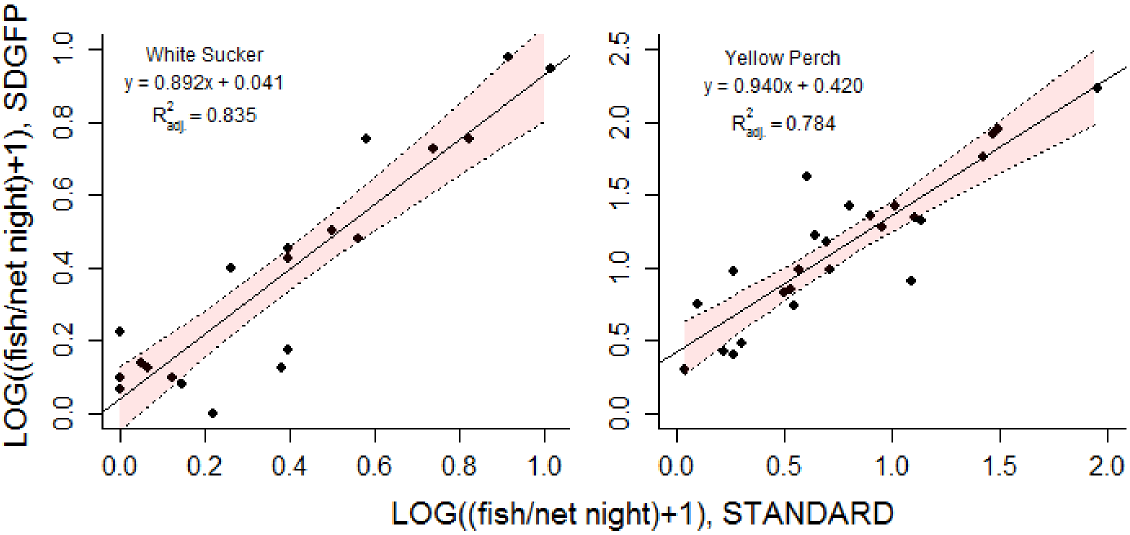

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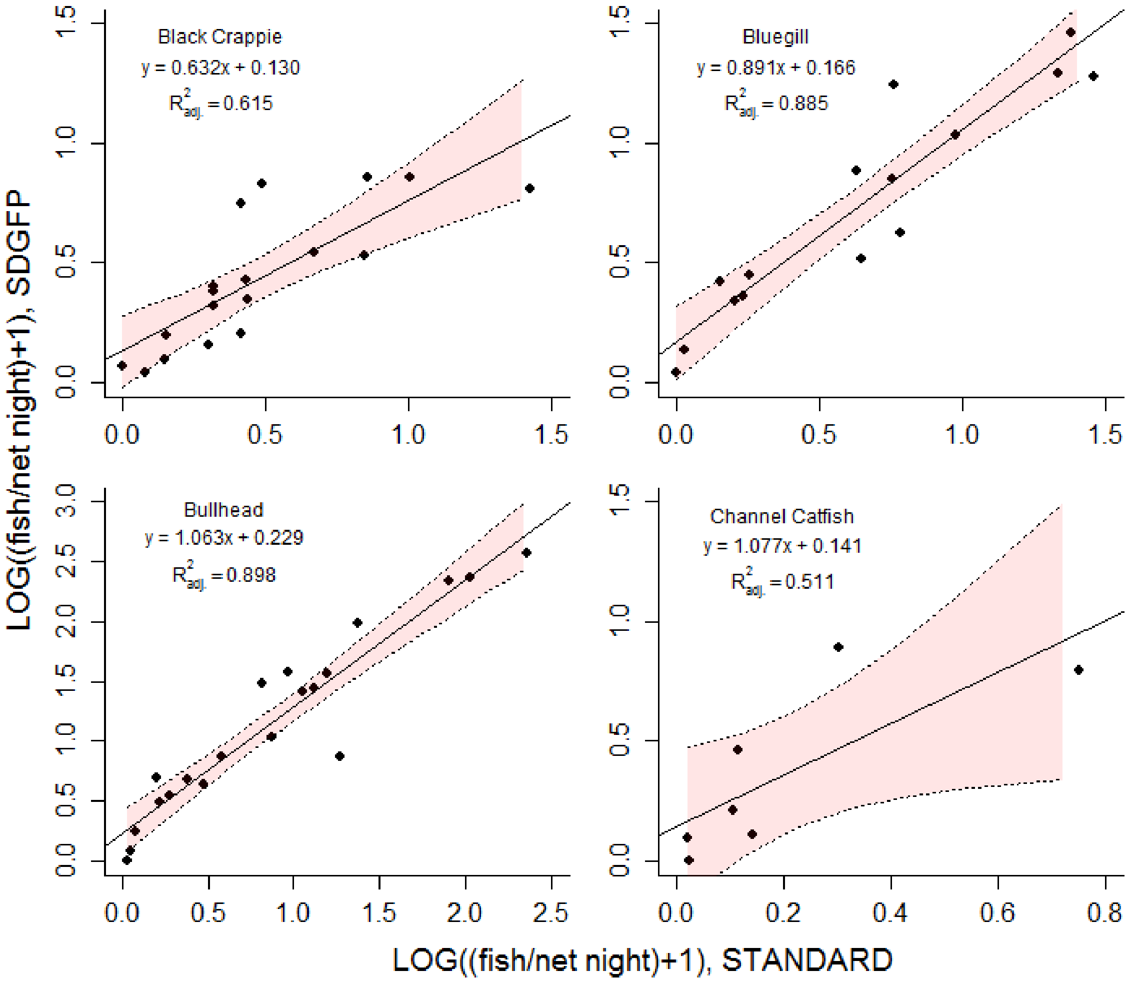

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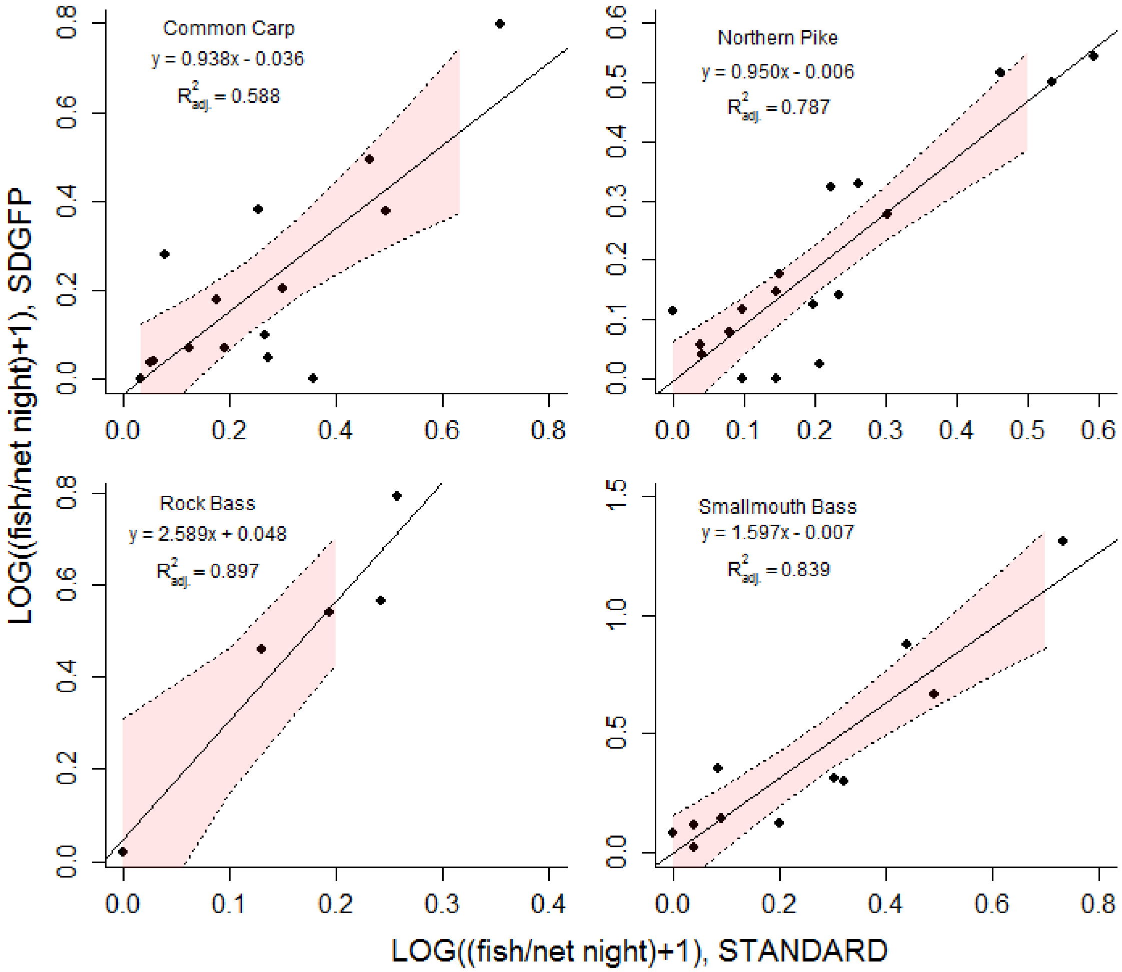

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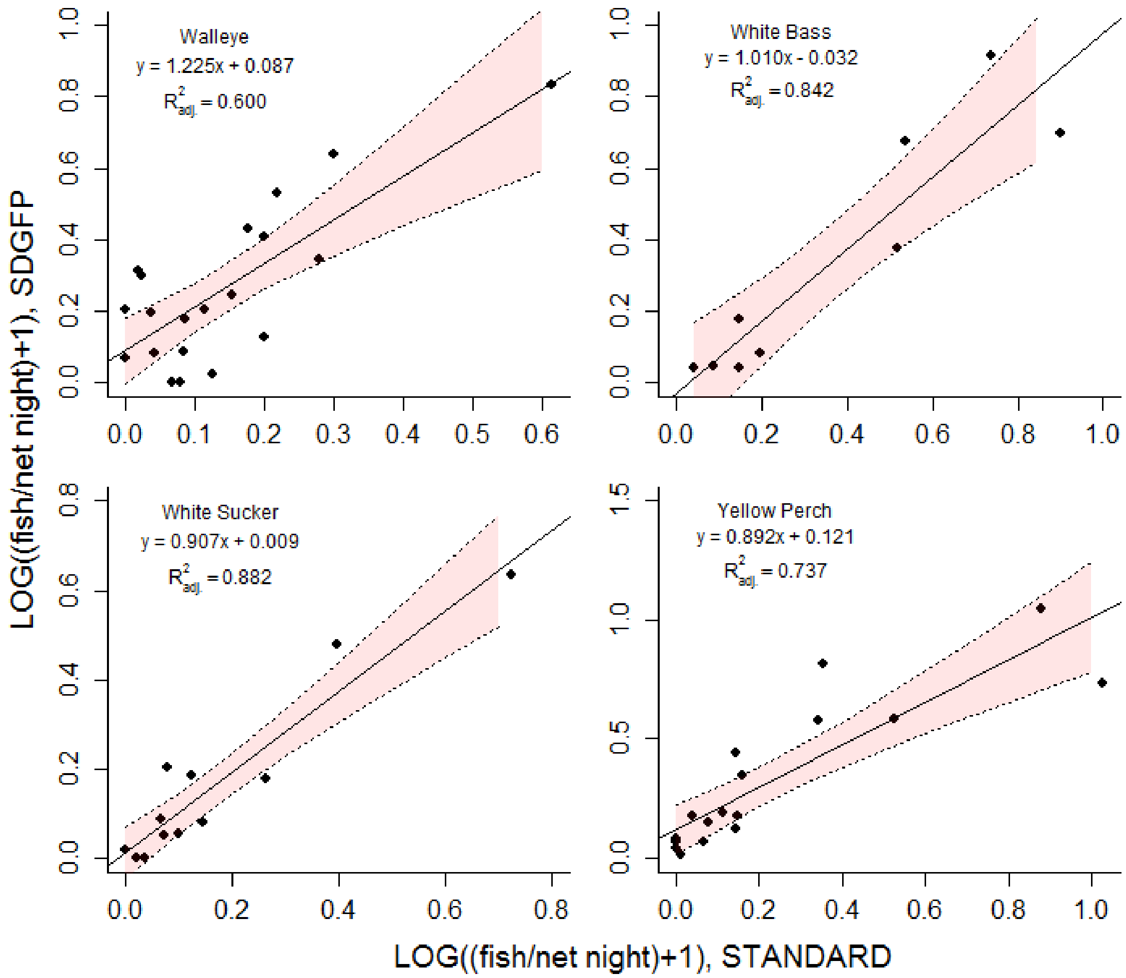

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CHAPTER 3. COMPARISON OF MULTIFILAMENT GILL NETS WITH MONOFILAMENT NORTH AMERICAN STANDARD GILL NETS ON MISSOURI RIVER IMPOUNDMENTS IN SOUTH DAKOTA

Abstract

A paired gear comparison was performed between current multifilament South Dakota Game, Fish and Parks (SDGFP) Missouri River reservoir sampling gill nets and newly proposed monofilament North American Standard (Standard) gill nets on four impoundments of the Missouri River in South Dakota. Multifilament SDGFP nets were 92-m long by 1.83-m deep and included 13, 19, 25, 32, 38, and 51- mm bar-mesh while monofilament Standard nets were 25-m long by 1.83-m deep and included eight randomly ordered panels of 19, 25, 32, 38, 44, 51, 57, and 64-mm bar-mesh. This study was part of a larger effort to standardize sampling gears statewide and required development of conversion factors to ensure utility of historic data after switching to Standard gears. Catch per unit effort (CPUE) was higher for most species collected in the longer SDGFP nets while Standard gill nets generally selected for larger individuals due to additional large bar-mesh panels not included in SDGFP nets. Monofilament twine was found to be more efficient than multifilament twine and the Standard net with eight panels had broader selectivity than SDGFP nets with six panels. Both net types sampled similar fish assemblages. Conversion factors developed using regression analyses had adjusted R^2 values ranging from 0.118 to 0.955 and will allow for CPUE data to be converted from one gear to the equivalent CPUE of the other gear for commonly collected Missouri River reservoir species in South Dakota. The increased efficiency

and broader selectivity of the Standard gill net make conversion to North American Standard gill nets advisable and timely given the push within the fisheries science to standardize gears and methods across North America.

Introduction

Recently, the American Fisheries Society (AFS) proposed standard gears and methods for sampling freshwater fishes (Bonar et al. 2009) and currently efforts are underway in several states to implement these standards. At the state level, South Dakota Game, Fish and Parks (SDGFP) has prioritized standardization of annual sampling gears statewide and is considering whether to adopt North American Standard gears, hereafter referred to as Standard (State Components Work Group 2014). However, potential loss of long-term data sets resulting from adoption of North American standards has caused concern among management biologists. Thus, a gear comparison between current and potential new standards is necessary to understand and correct for biases between gears and allow for continued use of long-term data sets (Bonar et al. 2009a).

Of paramount importance to SDGFP is continued use of data collected with current SDGFP multifilament gill nets on mainstem Missouri River impoundments (i.e., Lakes Oahe, Sharpe, Francis Case, and Lewis and Clark) that support robust Walleye *Sander Vitreus* fisheries (Graeb et al. 2008). Standard monofilament “core-mesh” gill nets recommended for sampling in large lakes and reservoirs (Miranda and Boxrucker 2009) vary drastically from current SDGFP multifilament gill nets creating concern due to the highly selective nature of gill nets (Hamley 1975).

Comparisons of varying gill net configurations have led researchers to conclude that variability in virtually every feature of gill nets generates bias (Hamley 1975, Jester 1977, Yokota 2001). Bar-mesh size is the most selective feature of gill nets though mesh material (e.g., cotton, multifilament, and monofilament) also plays an important role in gill net selectivity (Hamley 1975). Attempts to increase efficiency have driven innovation in gill net construction. For example, gill nets used to be constructed with cotton and later multifilament (Pycha 1962) until monofilament was found to be the most efficient material available (Washington 1973, Collins 1979, Henderson and Nepszy 1992). Aside from reducing visibility to fishes monofilament may also yield larger size structure for some species due to increased elasticity that allows larger fish to become wedged (Hansen 1974).

With the continued confusion surrounding gill net biases and a desire to standardize sampling gears, we performed a paired-gear comparison to quantify differences in CPUE, size structure, efficiency, selectivity and diversity between multifilament SDGFP gillnets and monofilament "core-mesh" Standard gill nets in four mainstem impoundments of the Missouri River in South Dakota. Conversion factors for CPUE data were developed to allow for continued use of long-term data sets. The utility of mini-mesh add-ons to the "core-mesh" Standard gill nets was also assessed.

Methods

Study area – The Missouri River was impounded at four locations in South Dakota for the primary purpose of flood control during the 1950's and 1960's as part of the Pick-Sloan Plan creating four reservoirs that vary in size from 10,500 ha (Lewis and Clark Lake) to 145,000 ha (Lake Oahe). Reservoir conditions vary greatly between upstream and downstream portions within each reservoir. Upstream lotic sections tend to be turbid and eutrophic followed by a more mesotrophic transition zone and at the lowest portion conditions are oligotrophic (Fincel 2011). Fish communities are similarly complex and reflect the diversity of conditions available in these reservoirs. Native riverine species intermingle with intensively managed Walleyes and Salmonids (i.e., Chinook Salmon *Oncorhynchus tshawytscha* in Lake Oahe) along thermal and productivity gradients within each reservoir (Fincel 2011). Standard summer gill net catches are typically dominated by Channel Catfish *Ictalurus punctatus* and Walleyes.

Gear Description- Multifilament SDGFP gill nets used during annual surveys were 92-m long by 1.83-m deep and comprised of six bar-mesh panels (i.e., 13, 19, 25, 32, 38, and 51 mm) but on Lake Oahe an extra 64-mm panel is included to target large Walleyes bringing the total length to 107 meters. For the purpose of this study, only the six bar-mesh panels common to all SDGFP nets across all reservoirs are included and compared with Standard nets. Data from 64 mm bar-meshes of SDGFP nets were only used for a comparison of CPUE between SDGFP gill nets with and without their 64-mm panel to assess whether removal of 64-mm bar-mesh data significantly influenced overall estimates of CPUE in lake Oahe. North American Standard monofilament gill nets are 25-m long by 1.83-m deep and include eight randomly ordered panels (i.e., 19, 25, 32, 38, 44, 51, 57, and 64 mm bar-mesh) but for experimental purposes three additional mini-mesh add-on panels (i.e. 10, 13, and 16 mm bar-mesh) were connected to the end of each Standard net (Bonar et al. 2009b). Catches from mini-meshes were not combined with catches from the other meshes for analyses (Miranda and Boxrucker 2009).

Sampling protocol - Annual summer gill net sampling by SDGFP on Missouri River impoundments involves setting between 12 and 54 multifilament gill nets at one to nine standard sampling stations on each reservoir. Half the nets set in shallow water ≤ 7-m and half are set in water > 7-m. Lewis and Clark Lake received the least sampling effort and Lake Oahe the most. Multifilament SDGFP gill nets were set for 24 hrs at the first sampling station then checked and moved to the next sampling station. Paired gear comparisons were performed concurrently with this standard gill net survey during 2013 and 2014 by randomly assigning Standard nets to be set 100 m to the right or left and parallel to each SDGFP gill net at all sampling stations on each reservoir during both study years. All fish captured in both gear configurations were measured for total length (TL; mm), weighed (g), and the mesh they were captured in was recorded.

Data analysis – For species-specific comparisons of CPUE reservoir-years were treated as replicate units except for Shovelnose Sturgeon *Scaphirhynchus platorynchus* and White Crappie *Pomoxis annularis* where station-year was used instead due to the fact that they were not found in all four reservoirs. Mean CPUE was calculated across all nets used of each net type during each reservoir-year. Data were $\mathrm{LOG}_{10}(X + 1)$ transformed and CPUE of Standard nets were regressed against SDGFP data then compared using Analysis of Covariance (ANCOVA) to a 1:1 line that represented a hypothetical equivalent CPUE between net types. Using ANCOVA significant differences in slope or intercept between empirical data and the 1:1 line indicated that catch rates between gears were not analogous.

Size structure between net types was compared by two methods using pooled data from all four reservoirs and during both sampling years. First, species-specific length-frequency distributions were compared between net types using a Kolmogorov-Smirnov test (KS; Conover 1999; Neumann and Allen 2007). Next, proportional size distribution (PSD) and proportional size distribution of preferred-size fish (PSD-P; Guy et al. 2007) were calculated using length categories provided by Gabelhouse (1984) and Bister et al.

(2000) for each species and gear type. These index values were compared between net types using a Chi-Square test (Conover 1999; Neumann and Allen 2007).

Differences in efficiency between monofilament Standard nets and multifilament SDGFP nets were investigated using only mesh sizes common to both gill net configurations by calculating species and net-specific density (fish/m^2). Net pairings were used as replicates and only non-zero data were included. Comparisons of fish density were analyzed using a Wilcoxon rank-sum test (Conover 1999) due to non-normality of data.

Species-specific selectivities were investigated for each gear type using pooled data from all reservoir-years for the highly abundant and recreationally important Channel Catfish and Walleye using the Share Each LEngth's Catch Total (SELECT) method developed by Millar (1992) and associated Next Generation R code available at (https://www.stat.auckland.ac.nz/~millar/selectware/RNext/). The SELECT method is based on maximum likelihood and fits five potential models (i.e. normal, skew-normal, log-normal, bi-normal, and bi-lognormal) to empirical catch data and calculates model deviances and residuals. Models with the lowest model deviances are assumed to provide the best fit to empirical data (Millar 1992). Measures of selectivity can take either of two forms; relative efficiency or relative efficiency proportional to mesh size, the latter of which accounts for differences in catch between mesh sizes (Millar and Holst 1997). Only relative efficiency was investigated for the purpose of this gear comparison because I was most interested in the shape of selectivity curves and identifying where gaps in selectivity may exist for each net type. Unfortunately, these analyses do not allow for quantitative comparison between gears but instead provide a qualitative way to assess and visualize differences in overall selectivity between net types.

To address concerns that switching gill net types may bias the fish assemblages sampled during annual sampling, I compared fish community metrics produced by each gear type. Metrics chosen for investigation were Shannon's H for diversity and Shannon's J for evenness (Kwak and Peterson 2007). Measures of diversity and evenness were calculated for each gear and reservoir-year then values were compared across reservoir-years using an Analysis of Variance (ANOVA) with lake as a blocking factor (Eggleton et al. 2010).

Conversion factors that would allow for continued use of historic data were developed by regressing $\mathrm{LOG}_{10}(X+1)$ transformed CPUE data of Standard nets against that of SDGFP nets for each species. Regression equations with the highest adjusted R^2 values were judged to be most useful for converting data while regression equations with low goodness of fit should be used with caution. Additional analyses were performed to ensure that exclusion of the 64-mm bar-mesh panel from SDGFP data on Oahe did not significantly influence estimates of lake-wide CPUE. These analyses focused on species where > 5% of total catch in Lake Oahe came from the 64 mm panel. Comparisons of CPUE were made between lake-wide CPUE with and without the 64 mm panel using a lower-tailed t-test. Utility of mini-mesh add-ons was performed qualitatively and applied only to Standard gill nets. An α of 0.05 was assumed for all tests and calculations were performed in R version 3.0.2 "frisbee sailing" (R Core Development Team, 2013).

Results and Discussion

Differences in net length coupled with divergent bar-mesh panel configurations and twine materials between gill net types produced many predictable results. Net length effects are often species-specific with CPUE generally increasing with net length, though counter-examples do exist (Minns and Hurley 1988, Acosta 1994). As expected, longer SDGFP nets typically produced higher CPUE (Figure 1). However, the presence of larger bar-mesh on Standard nets sometimes resulted in equal (i.e., Goldeye *Hiodon alosoides*, White Bass *Morone chrysops*, and White Crappie *Pomoxis annularis*) or higher (i.e. Freshwater Drum *Aplodinotus grunniens*) total catch rates than SDGFP nets (Figure 1). Typically, larger individuals of these four species were collected due to their vulnerability to the larger bar-mesh panels found on Standard nets.

Gill nets are strongly size selective and fish slightly larger or smaller than the optimum length for capture are often not retained by wedging or gilling (Baranov 1948). Addition of larger bar-mesh sizes explained the tendency for Standard nets to select for larger individuals of many species including Channel Catfish and Walleye (Table 1). Similar size structure was observed between net types for Northern Pike *Esox lucius*, Sauger *Sander canadensis*, Shorthead Redhorse *Moxostoma macrolepidotum*, Shovelnose Sturgeon, and Shortnose Gar *Lepisosteus platostomus* though sample sizes were small reducing the power of Chi-Square and KS tests to detect significant differences. Generally, Chi-Square and KS tests corroborated each other; although there were exceptions where the KS Test (Table 1) found significant differences not detected by comparisons of PSD and PSD-P (Table 2). Use of individual fish of abundant species as replicate units can produce large sample sizes and the more sensitive KS test often detects significant differences even where the differences may be minor (Neumann and Allen

2007). Both gill net types typically selected for stock-length fish so for management purposes the more conservative comparisons of PSD and PSD-P will likely be most relevant.

I found that monofilament was more efficient than multifilament for almost all species where sufficient data was available except for Northern Pike, River Carpsucker *Carpoides carpio*, and Shorthead Redhorse (Table 3). This disparity in efficiency between twine materials influenced both CPUE and size structure for each type of experimental gill net. Monofilament is regarded to be more efficient than multifilament for capturing most fish species (Hamley 1975; Hubert 1996) including Walleyes (Henderson and Nepszy 1992). Monofilament is more elastic than multifilament due to smaller twine diameter (Hansen 1974) and is less visible (Jester 1973) explaining the primary differences in efficiency between these twine materials. Henderson and Nepszy (1992) speculated that reduced tensile strength of monofilament may allow larger bodied fish to break free but I did not observe this in the present study.

Selectivities of each gill net type were related primarily to bar-mesh size. Analyses of gill net selectivities using the SELECT method (Millar 1992; Millar and Fryer 1999; Millar and Holst 1997) provided useful visualizations of bar-mesh specific selectivity curves for Channel Catfish (Figure 2) and Walleye (Figure 3) in both gill net types. Gill nets are commonly used to sample Channel Catfish (Pope et al. 2009) but typically other gears are more efficient (Buckmeier and Schlechte 2009) so studies of gill net selectivity for this species are scarce. Bi-lognormal model fits were most parsimonious for Channel Catfish captured in both gill net types though model deviances were lower for Standard nets (Table 4). Inspection of deviance residuals interpreted following methods of Millar and Holst (1997) shows good fit for small bar-mesh sizes but poorer fits as bar-mesh size increases suggesting that selectivity curves for small meshes are indeed bi-modal with a tight selectivity curve for small individuals captured by traditional gilling and a lower, broader second curve for larger individuals captured by tangling primarily by pectoral and dorsal spines.

I found that Walleye selectivity for both net types was best explained by a bi-lognormal fit indicating an element of both wedging and tangling and deviance residuals indicate this trend is strong for small meshes then weakens for increasingly larger meshes (Table 5). Studies of Walleye selectivity are numerous and typically conclude that bi-modal models have the most support. Indirect estimates by Vandergoot et al. (2011) found that bi-normal fits that incorporated deviations best explained Walleye gill net selectivity in Lake Erie. Direct estimates of selectivity by Hamley and Regier (1973) broke down selectivity into two components, wedging and tangling, and found a bi-modal selectivity curve. Selectivity analyses for both species show more thorough coverage by Standard nets across the broad range of sizes observed for these two species. Overall, deviance residuals were low compared to similar analyses for Walleye (Vandergoot et al. 2011) and Yellow Perch (Doll et al. 2014) indicating good model fit to empirical data.

Throughout all reservoir-years 10,719 individuals representing 28 mostly riverine fish species were sampled (Table 6) though not all species were found in each reservoir. Lake Oahe was the largest and most diverse reservoir with 23 species sampled while Lewis and Clark was the smallest and least diverse with only 15 species collected between both gill net types. Minns and Hurley (1988) found that species richness increased with gill net length when sampling Lake Ontario but my comparisons of

Shannon's diversity (F = 3.807, P = 0.092, df = 15) and evenness (F = 4.831, P = 0.064, df = 15) identified no significant differences between gill net types of differing lengths across reservoir-years reducing concerns that switching net types would bias sampling of reservoir fish communities.

Regression analyses comparing CPUE between gill net types were calculated for 16 species and goodness-of-fit measured by adjusted R^2 was generally greater than 0.50 except for a few species (Figure 4). Conversion factors allowing corrections of CPUE between gill net types will allow historic SDGFP lake-wide CPUE data to be converted to its equivalent lake-wide Standard CPUE (Table 7). Exemption of the 64-mm bar-mesh from SDGFP nets on Lake Oahe made no measurable impact on lake-wide CPUE over the two study years except for Common Carp and River Carpsucker where CPUE was significantly lower without the 64 mm panel (Table 8).

Mini-mesh add-ons to the Standard "core-mesh" gill nets sampled 506 individuals comprised of 19 species two of which (i.e., Emerald Shiner *Notropis atherinoides* and Spottail Shiner *Notropis hudsonius*) were not sampled by either Standard or SDGFP regular gill net complements (Table 9). Catches were dominated by Gizzard Shad *Dorosoma cepedianum* (N = 140), Walleye (N = 80), and White Bass (N = 65) but overall these mini-meshes were less productive than "core-mesh" panels as expected due to the low fishing power of small meshes (Hamley 1975; Hamley and Regier 1973) because smaller fish tend to avoid capture in gill nets relative to larger conspecifics (Hubert 1996). The primary purpose for including mini-mesh panels was to broaden selectivity of the experimental gill net particularly for prey species (e.g., Gizzard Shad and Rainbow Smelt *Osmerus mordax*) and sub-stock game fish (i.e., Walleye) though comparatively few sub-stock game fish were captured in these panels over the two years they were deployed. Heard (1962) sampled an Alaskan lake with small-mesh gill nets and collected the majority of fish species present including juvenile Sockeye Salmon *Oncorhynchus nerka*. However, this researcher concluded that bar-meshes less than 13 mm were inefficient and provided only a qualitative method for collecting small-bodied fishes. Regardless of their utility, catches from these mini-meshes or any non-standard mesh add-ons should not be included when reporting catches of North American Standard gill nets (Miranda and Boxrucker 2007). Based on low catches and the additional cost of purchasing these panels I conclude that mini-meshes are not essential when sampling these reservoirs unless there is a specific need for them.

Synthesis of data collected and analyzed over two years across all four Missouri River impoundments in South Dakota has provided thorough understanding of biases between current SDGFP and North American Standard gill nets. Switching from longer multifilament SDGFP nets to shorter monofilament Standard nets would produce biases between current and future datasets. However, such biases can be corrected. My paired sampling design allowed simultaneous sampling of similar fish populations and assemblages in each reservoir by both gears allowing us to control for extraneous factors. Peterson and Paukert (2009) recommended at least ten samples when performing paired gear comparisons but this study far surpassed that mark with 219 paired samples. A similar study in the Colorado River, Arizona used 88 paired samples of differing electrofishing units to investigate gear bias when sampling Rainbow Trout *Oncorhynchus mykiss* (Speas et al. 2004). Use of converted data increases variance and reduces power to detect significant changes (Cohen 1988) so models with the highest adjusted R^2 should be most reliable and those with low R^2 should be used with caution. Historic CPUE data will still be useful if converted to equivalent Standard CPUE but should always be labeled as converted data (Peterson and Paukert 2009).

Converting to sampling with North American Standard gill nets would be challenging initially as observed in gear standardization efforts in other states but pay off in the long-term (Hayes et al. 2003). Using Standard nets would be more efficient due the use of monofilament as twine material and the broader selectivity of the Standard net would yield more thorough coverage when monitoring game fish populations. Switching gears would likely require increasing the number of nets used in each reservoir to achieve similar sample sizes collected using SDGFP nets because Standard nets are much smaller than current SDGFP nets. When the Kansas Department of Wildlife, Parks, and Tourism adopted Standard gill nets for sampling reservoirs, they discovered that precision of CPUE estimates for several species was poor given existing levels of effort and prescribed additional effort or alternative sampling methods to achieve sampling objectives (Koch et al. 2014). Increased effort would likely improve precision for lake-wide CPUE estimates (Veijola 1996). Beyond South Dakota, this project fits into a large, long-term, and far-reaching effort within the fisheries science community to standardize sampling gears, methods, and reporting procedures across North America.

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Table 1. Results of Kolmogorov-Smirnov tests comparing length frequency distributions between North American Standard and South Dakota Game, Fish and Parks gill nets for 16 species sampled during 2013 and 2014 in mainstem impoundments of the Missouri River in South Dakota.

	Sample size				
Species	Standard	SDGFP	D-value	*P*-value	
Channel Catfish	1,178	1,974	0.168	< 0.001	*
Common Carp	86	260	0.126	0.257	
Freshwater Drum	198	213	0.360	< 0.001	*
Goldeye	184	336	0.095	0.445	
Gizzard Shad	107	118	0.231	0.005	*
Northern Pike	28	44	0.123	0.957	
River Carpsucker	53	140	0.292	0.003	*
Sauger	90	415	0.080	0.727	
Shorthead Redhorse	45	231	0.100	0.842	
Shovelnose Sturgeon	78	112	0.101	0.734	
Smallmouth Bass	177	192	0.146	0.040	*
Shortnose Gar	17	38	0.184	0.820	
Walleye	947	2,458	0.164	< 0.001	*
White Bass	78	159	0.415	< 0.001	*
White Crappie	13	60	0.433	0.036	*
Yellow Perch	60	293	0.211	0.016	*

Table 2. Proportional Size Distribution (PSD) and PSD of preferred-length fish (PSD-P) for 13 species sampled using North American Standard (Standard) and South Dakota Department of Game, Fish and Parks (SDGFP) gill nets across four mainstem Missouri River impoundments in South Dakota during 2013 and 2014. Results of Chi-Square tests are shown for each comparison with asterisks denoting significant differences.

	PSD					PSD-P				
Species	Standard	SDGFP	χ^2	*P*-value		Standard	SDGFP	χ^2	*P*-value	
Channel Catfish	61	47	59.344	< 0.001	*	7	5	5.927	0.015	*
Common Carp	93	99	7.591	0.006	*	42	45	0.215	0.643	
Freshwater Drum	82	81	0	1.000		39	30	2.328	0.127	
Gizzard Shad	25	27	0	1.000						
Northern Pike	96	98	0	1.000		52	57	0.070	0.791	
River Carpsucker	96	97	0	1.000		91	92	0	1.000	
Sauger	74	77	0.186	0.666		34	30	0.294	0.588	
Shorthead Redhorse	96	93	0.181	0.671		85	76	1.202	0.273	
Shovelnose Sturgeon	99	100	0.015	0.904		99	100	0.015	0.904	
Smallmouth Bass	71	68	0.480	0.488		27	40	6.182	0.013	*
Walleye	42	17	53.154	< 0.001	*	4	1	2.316	0.128	
White Bass	96	97	0.015	0.904		79	77	0.019	0.890	
Yellow Perch	30	42	3.119	0.077		10	16	1.572	0.210	

Table 3. Wilcoxon Rank-Sum Tests comparing efficiency (fish/m^2) between monofilament and multifilament mesh panels common to both North American Standard (i.e., monofilament) and South Dakota Game, Fish and Parks (i.e., multifilament) gill nets. Sample size is the number of net pairings where at least a single fish of the targeted species was captured between both net types. All fish were collected during summer sampling on four mainstem impoundments of the Missouri River during 2013 and 2014.

		Sum of ranks				
Species	Sample size	Monofilament	Multifilament	W	*P*-value	
Channel Catfish	165	32,124	22,491	1,668	< 0.001	*
Common Carp	15	322	143	11	0.006	*
Freshwater Drum	34	1,729	617	10	< 0.001	*
Goldeye	28	1,067	529	31	< 0.001	*
Gizzard Shad	20	556	264	2	< 0.001	*
Northern Pike	5	40	15	0	0.053	
River Carpsucker	9	105	66	11	0.191	
Sauger	43	2,341	1,400	120	< 0.001	*
Shorthead Redhorse	18	376	290	67	0.433	
Shovelnose Sturgeon	8	83	53	1	0.021	*
Smallmouth Bass	29	1,142	569	21	< 0.001	*
Shortnose Gar	6	57	21	0	0.036	*
Walleye	179	39,792	24,469	2,137	< 0.001	*
White Bass	14	291	115	0	< 0.001	*
Yellow Perch	30	1,232	598	25	< 0.001	*

Table 4. Parameter and model deviance values calculated for five potential gill net selectivity models applied to Channel Catfish data using the SELECT method (Millar 1997). Fish were collected using North American Standard and South Dakota Game, Fish and Parks gill nets on four mainstem impoundments of the Missouri River during 2013 and 2014.

	Fitted	Model deviance	
Models	parameters	Standard	SDGFP
Normal (fixed spread)	2	555.89	879.10
Normal (proportional spread)	2	905.90	1379.61
Lognormal	2	581.30	882.75
Bi-normal	5	242.23	399.57
Bi-lognormal	5	210.48	268.02

Table 5. Parameter and model deviance values calculated for five potential gill net selectivity models applied to Walleye data using the SELECT method (Millar 1997). Fish were collected using North American Standard and South Dakota Game, Fish and Parks gill nets on four mainstem impoundments of the Missouri River during 2013 and 2014.

	Fitted	Model deviance	
Models	parameters	Standard	SDGFP
Normal (fixed spread)	2	395.14	327.89
Normal (proportional spread)	2	330.42	845.10
Lognormal	2	283.86	354.61
Bi-normal	5	150.28	214.04
Bi-log-normal	5	140.98	133.89

Table 6. Total catch from North American Standard (Standard) and South Dakota Game, Fish and Parks (SDGFP) gill nets during summer sampling on four mainstem impoundments of the Missouri River during 2013 and 2014.

Common name	Scientific name	Standard	SDGFP	Total
Bigmouth Buffalo	*Ictiobus cyprinellus*	4	6	10
Black Bullhead	*Ameiurus melas*	0	1	1
Black Crappie	*Pomoxis nigromaculatus*	5	9	14
Bluegill	*Lepomis macrochirus*	0	1	1
Burbot	*Lota lota*	0	1	1
Channel Catfish	*Ictalurus punctatus*	1,178	2,210	3,388
Chinook Salmon	*Oncorhynchus tshawytscha*	0	1	1
Common Carp	*Cyprinus carpio*	86	261	347
Flathead Catfish	*Pylodictis olivaris*	3	1	4
Freshwater Drum	*Aplodinotus grunniens*	198	216	414
Goldeye	*Hiodon alosoides*	161	188	349
Gizzard Shad	*Dorosoma cepedianum*	109	135	244
Largemouth Bass	*Micropterus salmoides*	0	1	1
Northern Pike	*Esox lucius*	28	44	72
Rainbow Trout	*Oncorhynchus mykiss*	1	1	2
River Carpsucker	*Carpoides carpio*	53	140	193
Smallmouth Buffalo	*Ictiobus bubalus*	4	23	27
Sauger	*Sander canadensis*	90	418	508
Shorthead Redhorse	*Moxostoma macrolepidotum*	46	235	281
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*	78	112	190
Smallmouth Bass	*Micropterus dolomieu*	177	193	370
Shortnose Gar	*Lepisosteus platostomus*	17	38	55
Walleye	*Sander vitreus*	958	2,535	3,493
White Bass	*Morone chrysops*	78	188	266
White Crappie	*Pomoxis annularis*	13	60	73
White Sucker	*Catostomus commersonii*	4	34	38
Western Silvery Minnow	*Hybognathus argyritis*	0	1	1
Yellow Perch	*Perca flavescens*	67	308	375
Total		3,358	7,361	10,719

Table 7. Species-specific regression equations to convert lake-wide $LOG_{10}(X + 1)$ transformed Catch Per Unit Effort (CPUE) data between North American Standard (Standard) and South Dakota Department of Game, Fish and Parks (SDGFP) gill nets used on Missouri River reservoirs in South Dakota.

Species	Standard to SDGFP	SDGFP to Standard
Channel Catfish	SDGFP = 1.355 * (Standard) - 0.108	Standard = (SDGFP + 0.108)/1.355
Common Carp	SDGFP = 1.033 * (Standard) + 0.159	Standard = (SDGFP - 0.159)/1.033
Freshwater Drum	SDGFP = 0.700 * (Standard) - 0.014	Standard = (SDGFP + 0.014)/0.700
Goldeye	SDGFP = 1.062 * (Standard) - 0.024	Standard = (SDGFP + 0.024)/1.062
Gizzard Shad	SDGFP = 0.993 * (Standard) + 0.043	Standard = (SDGFP - 0.043)/0.993
Northern Pike	SDGFP = 1.073 * (Standard) + 0.032	Standard = (SDGFP - 0.032)/1.073
River Carpsucker	SDGFP = 1.515 * (Standard) + 0.042	Standard = (SDGFP - 0.042)/1.515
Sauger	SDGFP = 2.157 * (Standard) + 0.080	Standard = (SDGFP - 0.080)/2.157
Shorthead Redhorse	SDGFP = 3.337 * (Standard) + 0.006	Standard = (SDGFP - 0.006)/3.337
Shovelnose Sturgeon	SDGFP = 0.906 * (Standard) + 0.132	Standard = (SDGFP - 0.132)/0.906
Smallmouth Bass	SDGFP = 0.094 * (Standard) + 0.206	Standard = (SDGFP - 0.206)/0.094
Shortnose Gar	SDGFP = 1.100 * (Standard) + 0.046	Standard = (SDGFP - 0.046)/1.100
Walleye	SDGFP = 1.007 * (Standard) + 0.239	Standard = (SDGFP - 0.239)/1.007
White Bass	SDGFP = 1.007 * (Standard) + 0.010	Standard = (SDGFP - 0.010)/1.007
White Crappie	SDGFP = 0.551 * (Standard) + 0.162	Standard = (SDGFP - 0.162)/0.551
Yellow Perch	SDGFP = 1.156 * (Standard) + 0.172	Standard = (SDGFP - 0.172)/1.156

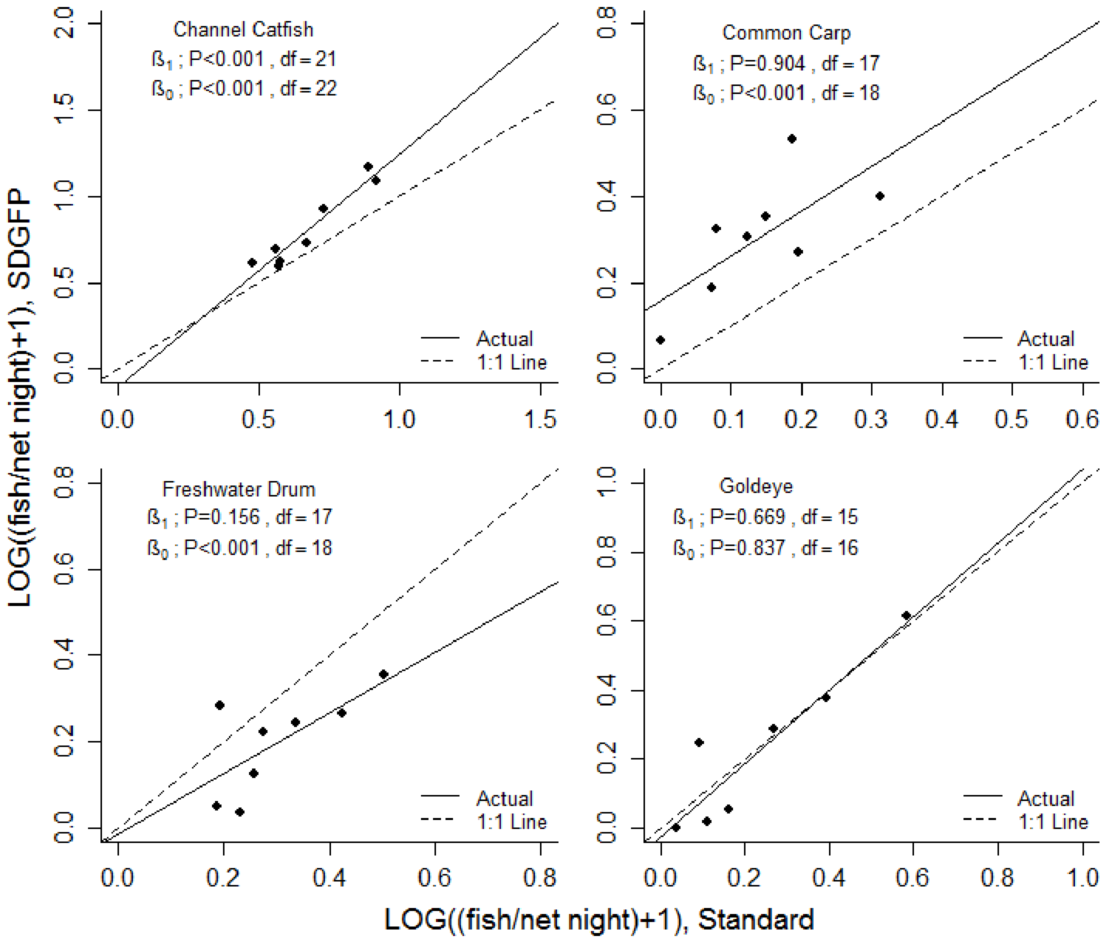
Table 8. Catch per unit effort (CPUE) for eight species sampled using South Dakota Game, Fish and Parks (SDGFP) reservoir sampling gill nets on Lake Oahe with (i.e. Oahe) and without (i.e. SDGFP) the 64 mm bar mesh panel. Results of lower-tailed t-tests comparing lake-wide CPUE where asterisks indicate significant differences.

	CPUE					
Species	Oahe	SDGFP	t-statistic	df	*P*-value	
Channel Catfish	14.67	13.65	-0.686	195.49	0.248	
Common Carp	2.86	2.13	-2.062	120.01	0.021	*
Freshwater Drum	1.83	1.72	-0.451	104.02	0.327	
Northern Pike	1.50	1.41	-0.454	60.95	0.326	
River Carpsucker	2.33	1.54	-1.845	48.72	0.036	*
Smallmouth Bass	2.78	2.62	-0.288	98.94	0.387	
White Bass	1.93	1.81	-0.495	70.16	0.311	
White Crappie	2.36	2.25	-0.154	27.01	0.561	

Table 9. Total catch of mini-meshes tied to North American Standard "core-mesh" gill nets used on four mainstem impoundments of the Missouri River, South Dakota during 2013 and 2014.

		Bar-mesh			
Common name	Scientific name	10 mm	13 mm	16 mm	Total
Black Crappie	*Pomoxis nigromaculatus*	2	1	0	3
Channel Catfish	*Ictalurus punctatus*	1	8	6	15
Common Carp	*Cyprinus carpio*	2	2	6	10
Emerald Shiner	*Notropis atherinoides*	5	0	0	5
Freshwater Drum	*Aplodinotus grunniens*	7	25	8	40
Goldeye	*Hiodon alosoides*	0	20	17	37
Gizzard Shad	*Dorosoma cepedianum*	53	45	42	140
Northern Pike	*Esox lucius*	0	1	0	1
River Carpsucker	*Carpoides carpio*	0	1	0	1
Sauger	*Sander canadensis*	2	5	7	14
Shorthead Redhorse	*Moxostoma macrolepidotum*	0	1	0	1
Shovelnose Sturgeon	*Scaphirhynchus platorynchus*	1	4	5	10
Smallmouth Bass	*Micropterus dolomieu*	3	4	0	7
Shortnose Gar	*Lepisosteus platostomus*	1	0	1	2
Spottail Shiner	*Notropis hudsonius*	6	0	1	7
Walleye	*Sander vitreus*	7	28	45	80
White Bass	*Morone chrysops*	9	43	13	65
White Crappie	*Pomoxis annularis*	21	4	1	26
Yellow Perch	*Perca flavescens*	15	3	24	42
Total		135	195	176	506

List of Figures



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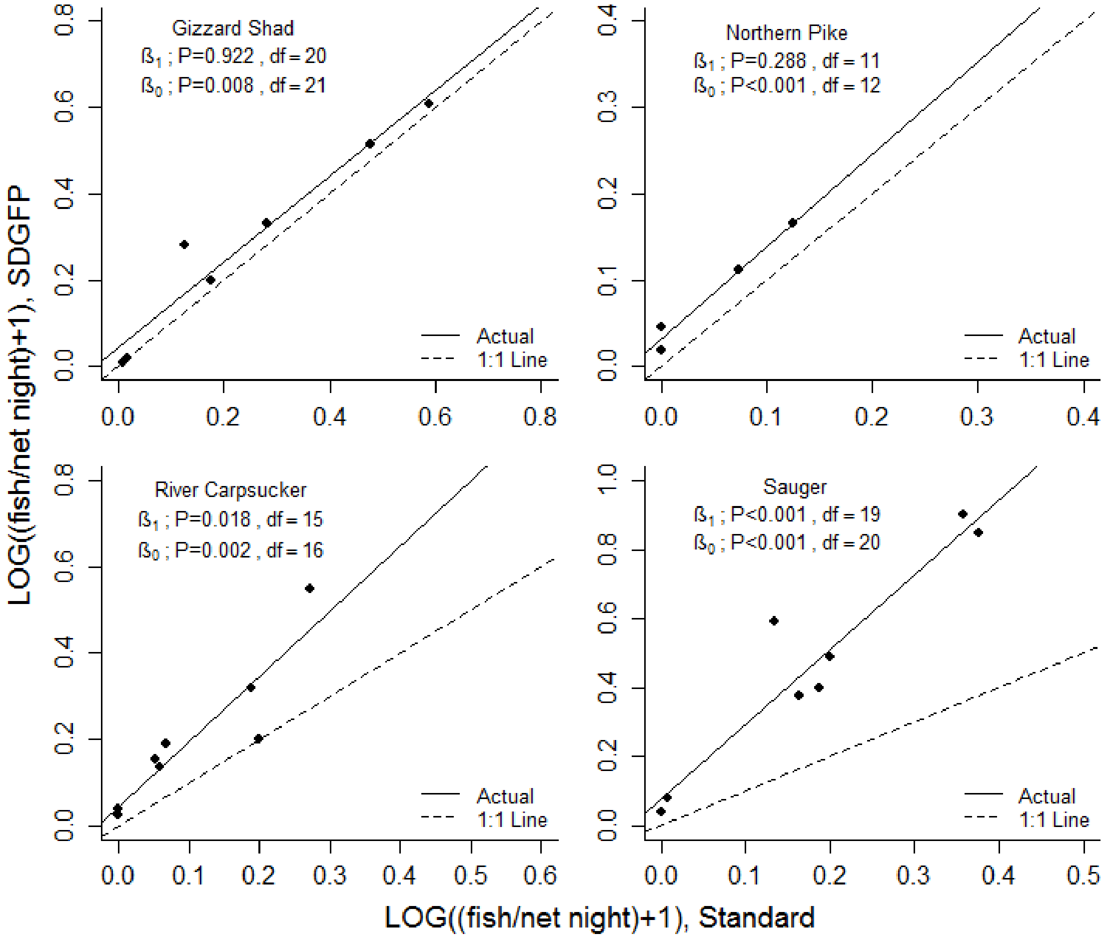

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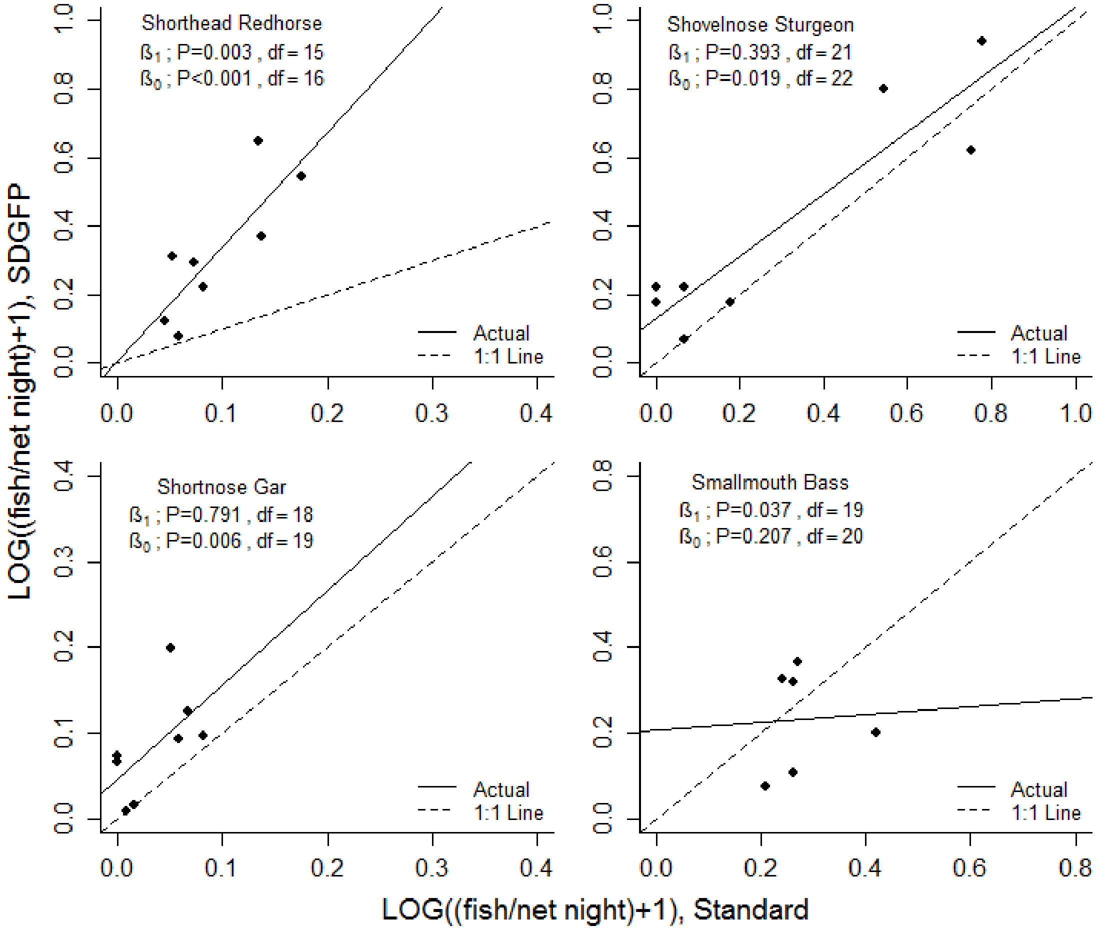

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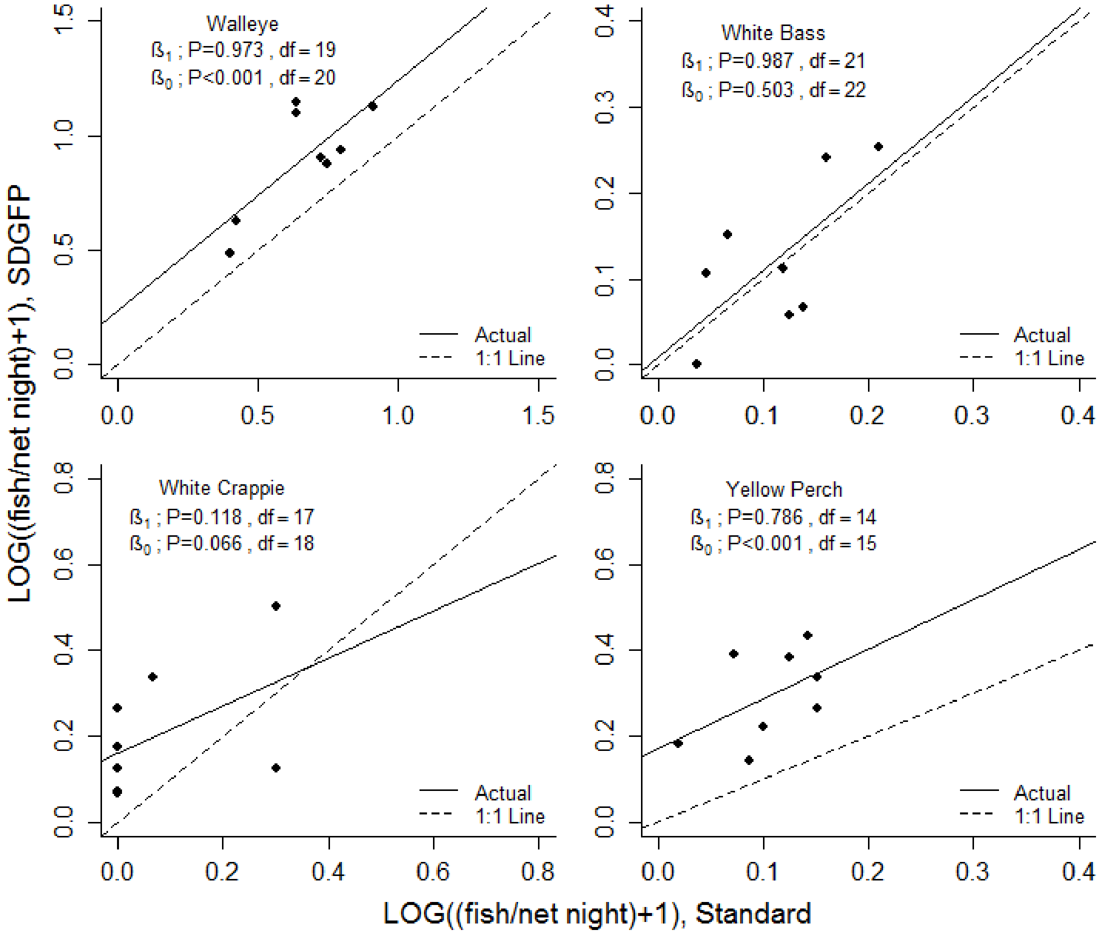

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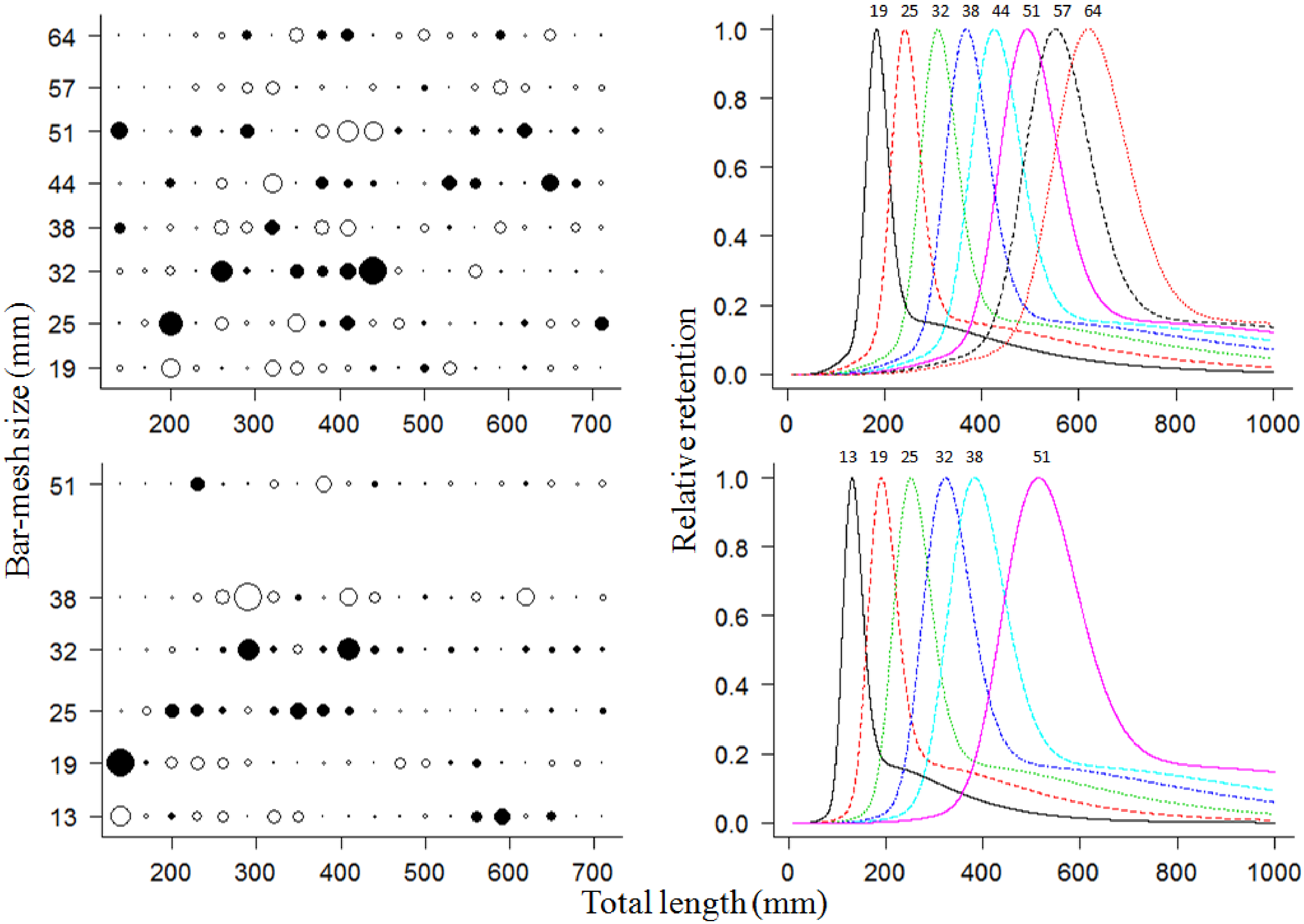

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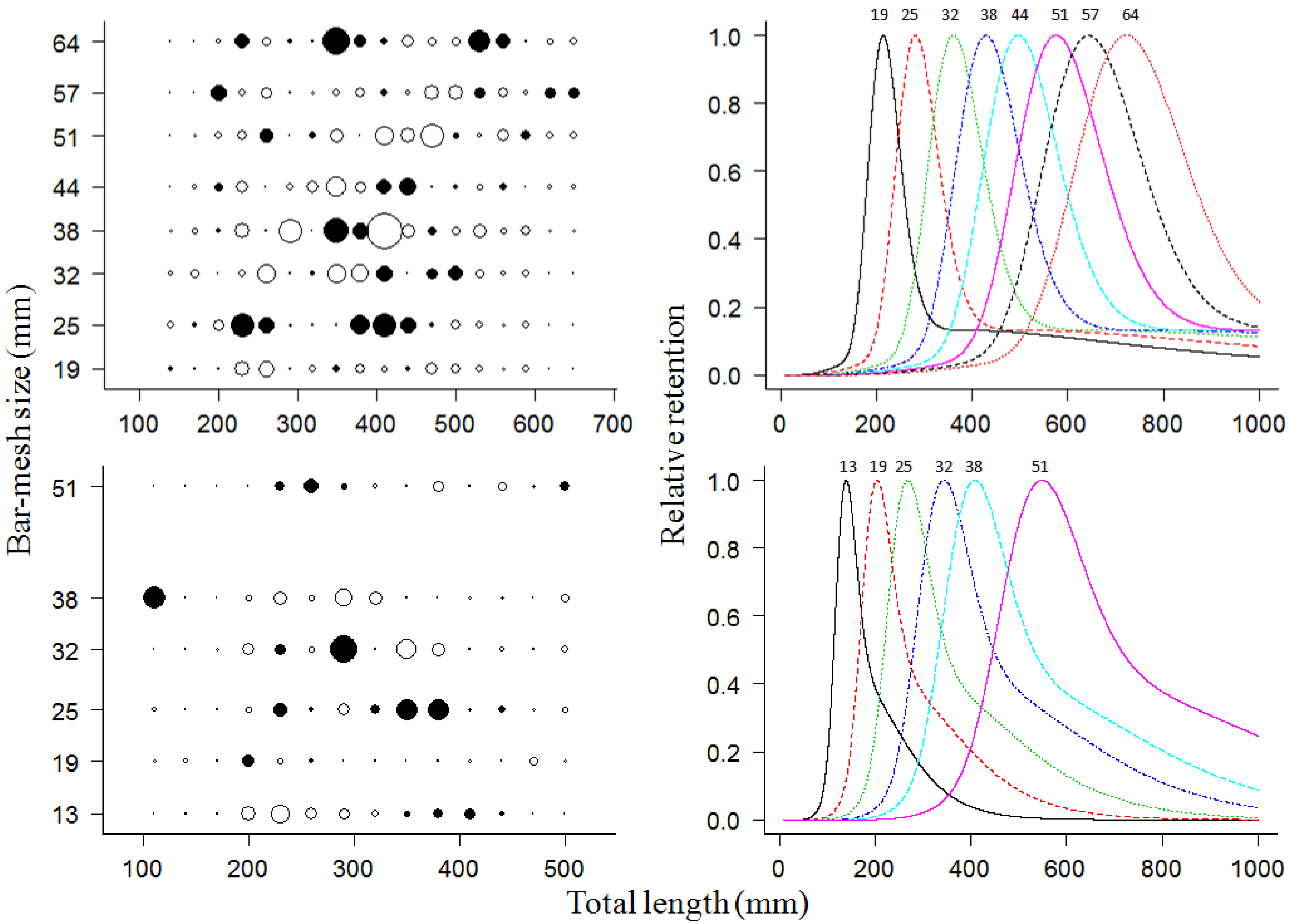

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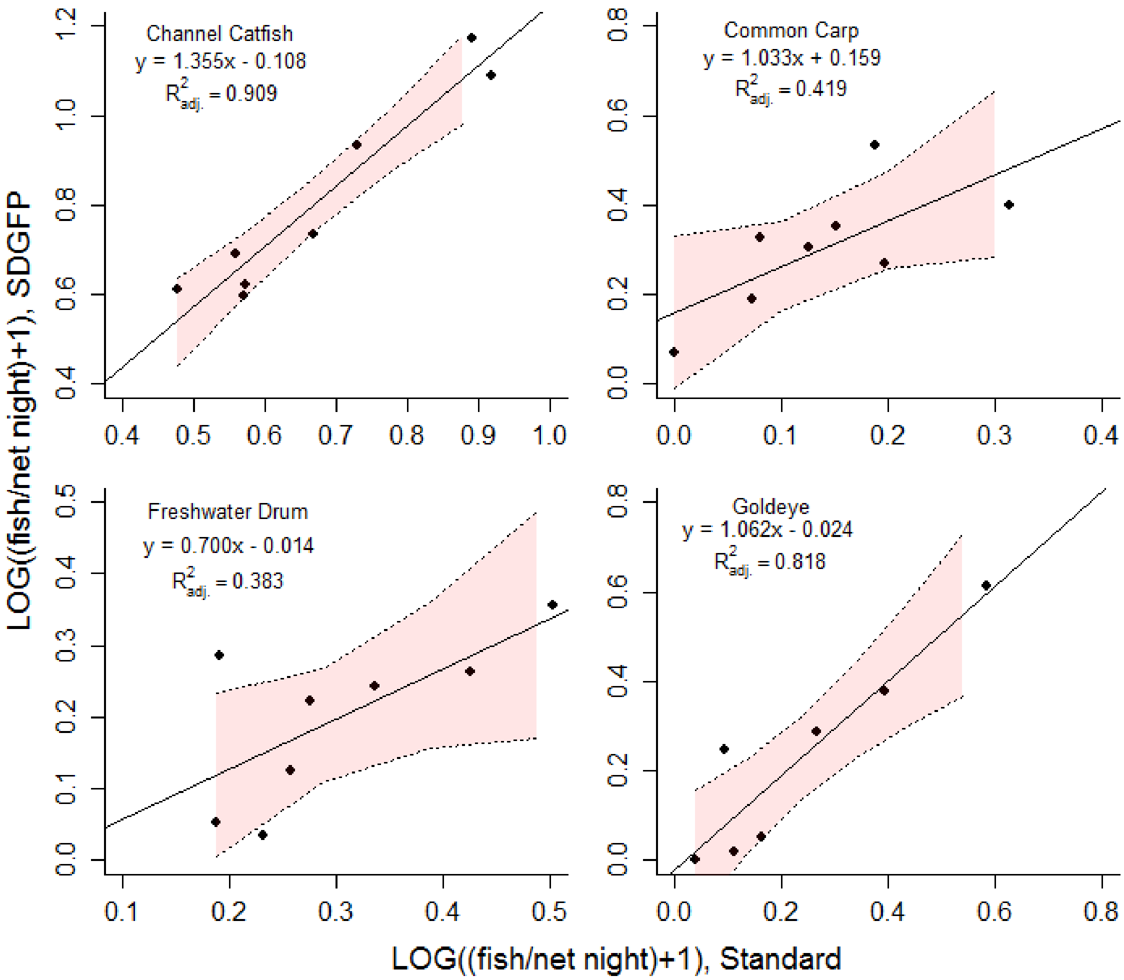

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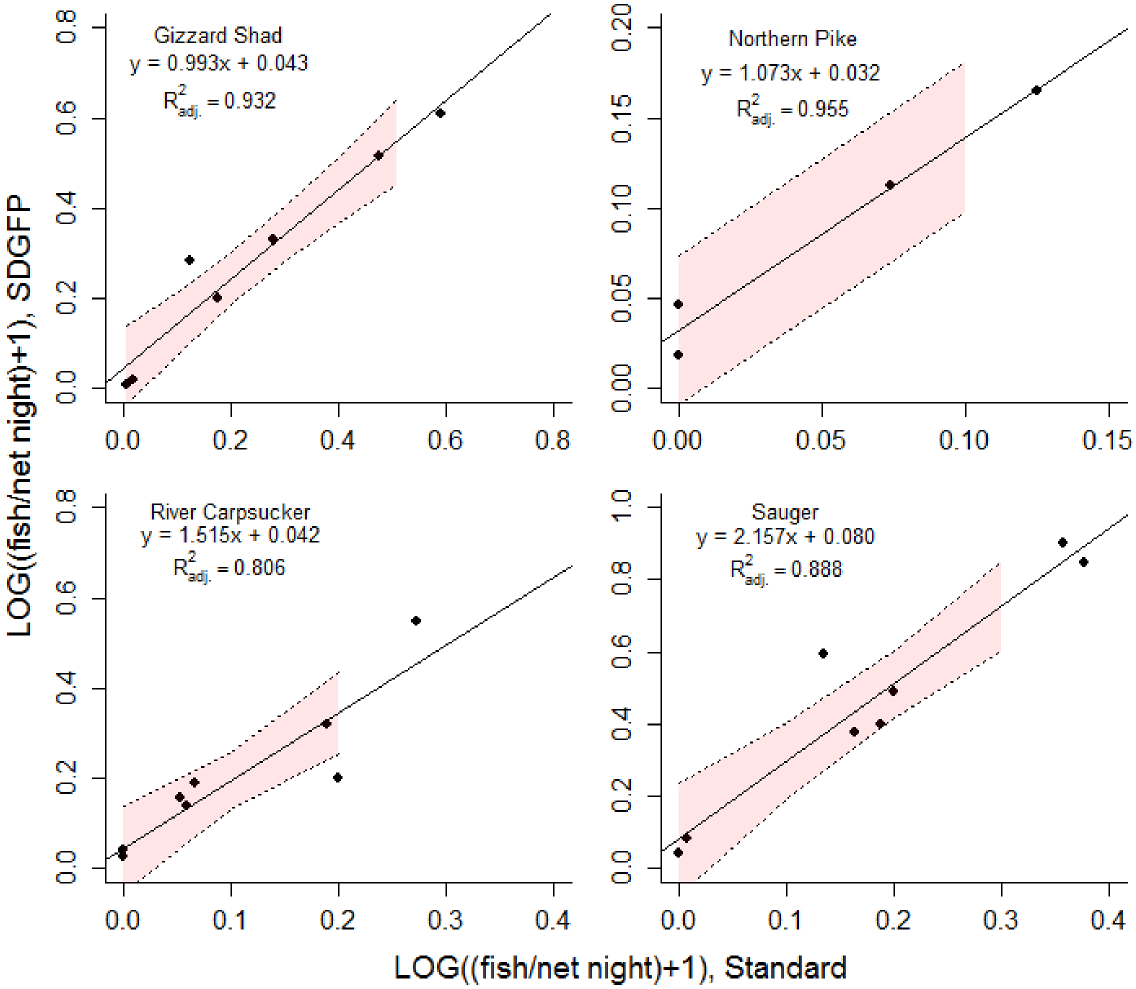

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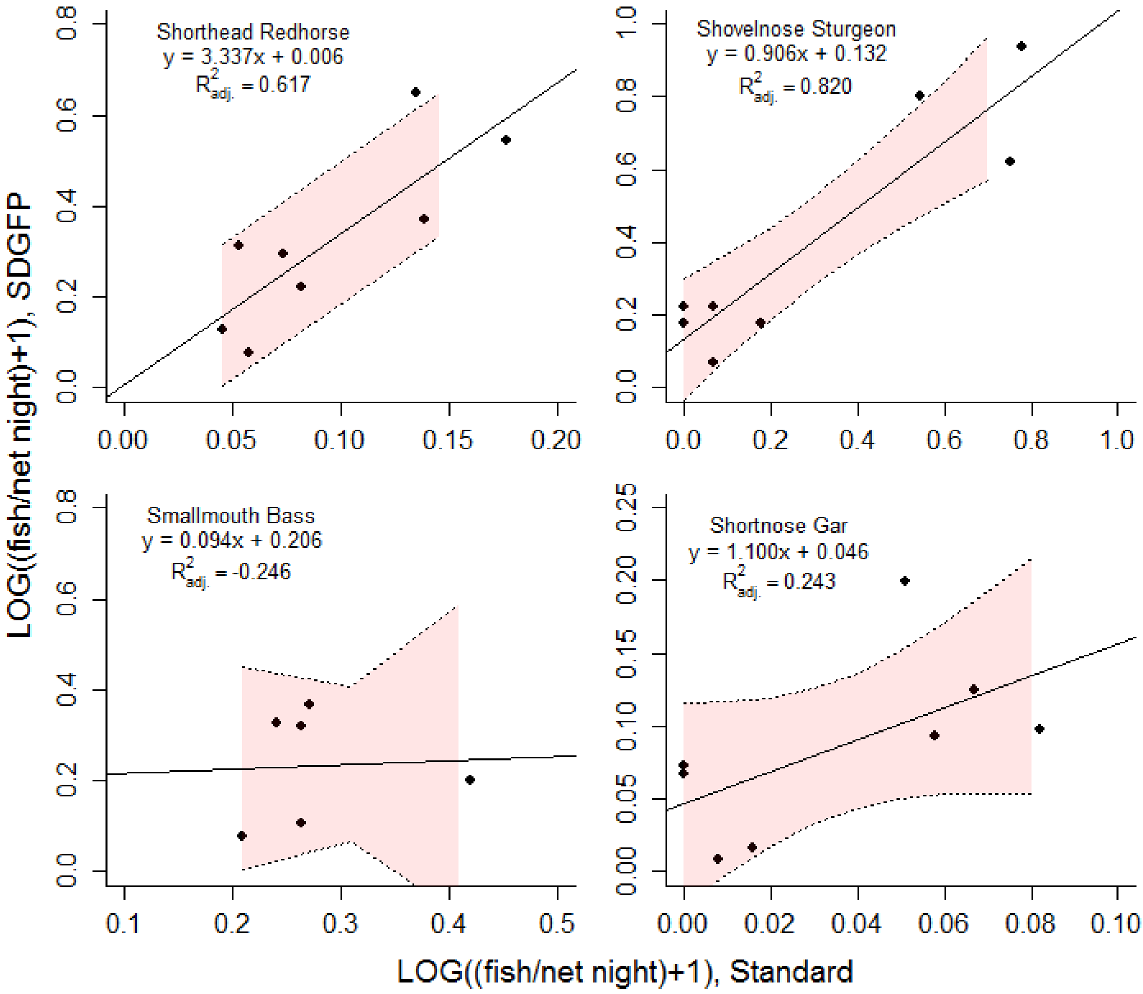

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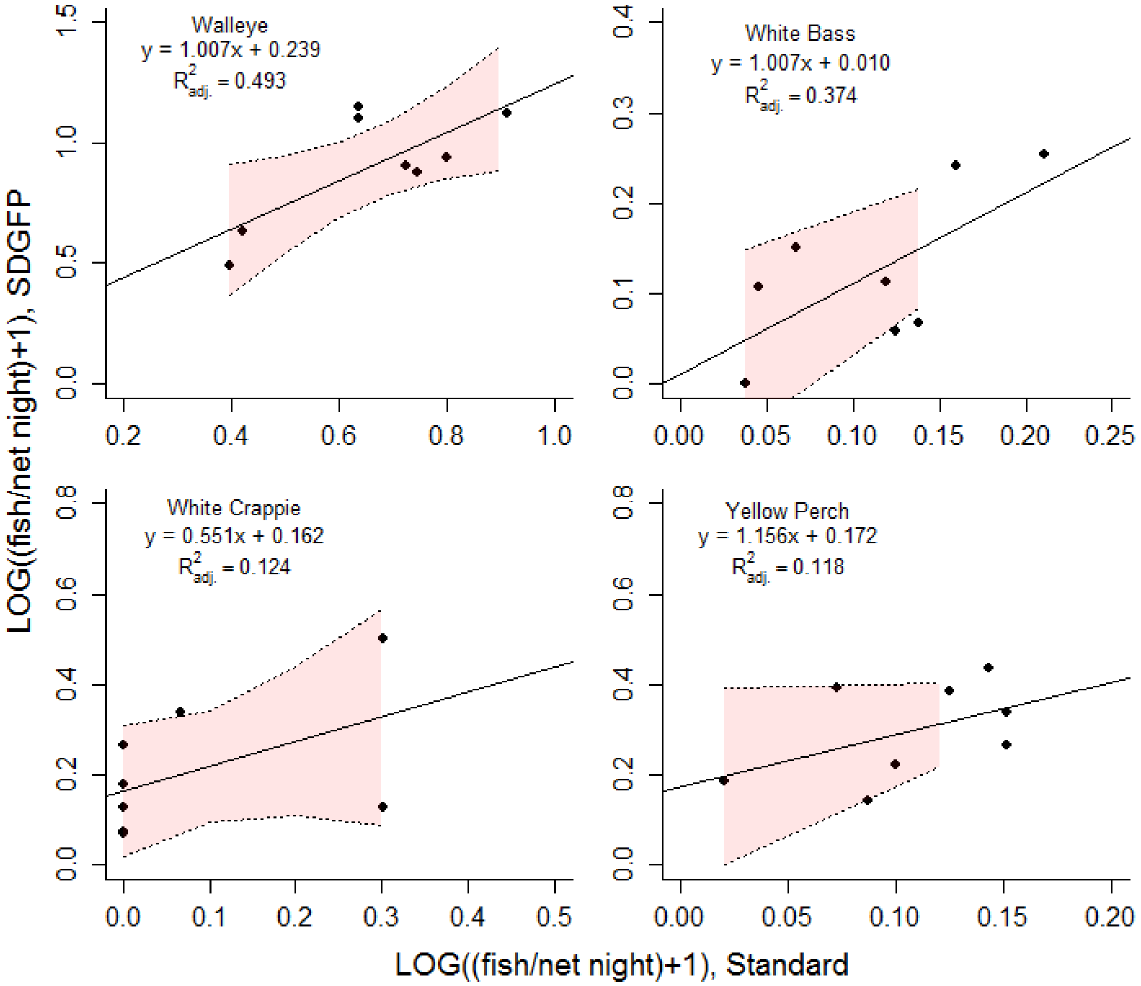

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CHAPTER 4. INDIRECT ESTIMATES OF GILL NET SELECTIVITY FOR 18 NORTH AMERICAN FRESHWATER FISH SPECIES

Abstract

Indirect estimates of gill net selectivity were calculated for eighteen fish species sampled throughout South Dakota with North American standard (Standard) gill nets. Monofilament Standard gill nets were 25-m long by 1.83-m deep and included eight randomly ordered panels of 19, 25, 32, 38, 44, 51, 57, 64 mm bar-mesh. Five potential models (i.e., normal, skew-normal, log-normal, bi-normal, and bi-lognormal) were fit to empirical catch data using the SELECT method. Models that included bi-modality produced the best fit for 14 species including Channel Catfish *Ictalurus punctatus*, Common Carp *Cyprinus carpio*, Northern Pike *Esox lucius*, Walleye *Sander vitreus*, and Yellow Perch *Perca flavescens* indicating that they were caught by wedging and tangling. Uni-modal models best described selectivity for Black Crappie *Pomoxis nigromaculatus*, Gizzard Shad *Dorosoma cepedianum*, Shorthead Redhorse *Moxostoma macrolepidotum*, and Shovelnose Sturgeon *Scaphirhynchus platorynchus* indicating that these species were caught by wedging. Inspection of model deviances and deviance residuals suggest that models of best-fit provide useful estimations of gill net selectivity for these species. Our estimates of selectivity should be broadly applicable for these commonly sampled North American freshwater fishes when sampled with Standard gill nets.

Introduction

Gill nets are commonly used to capture fish in both freshwater and marine systems for research and commercial exploitation (Hamley 1975) but are known to be highly selective based on fish size (Prchalová et al. 2009), behavior (Rudstam et al. 1984), and morphology (Reis and Pawson 1999; Carol and Garcia-Berthou 2007). Nearly every attribute of gill nets including twine material (Washington 1973), twine diameter (Yokota et al. 2001), twine color (Jester 1973), net length (Minns and Hurley 1988), and bar-mesh size (Baranov 1914) produce bias, and this bias complicates attempts by fisheries professionals to interpret gill net catch data. Moreover, studies of gillnet selectivity have generally focused only on abundant or commercially valuable species due to the need for reliable estimation of gear selectivity in commercial Great Lakes (Collins 1979; Hansen et al. 1997) and marine fisheries (Olsen 1959; Hovgård 1996). Selectivity studies have been performed for several freshwater game species (Hamley and Regier 1973; Pierce et al. 1994) but few have been completed for non-game freshwater fishes (Carol and Garcia-Berthou 2007) resulting in poor understanding of gill net selectivity for several frequently encountered species.

Many methods exist to estimate gill net selectivity but the direct and indirect methods described by Hamley (1975) continue to be the most popular (Winters and Wheeler 1990; Pierce et al. 1994). The direct method requires sampling a population of known length frequency and is generally regarded to be the most accurate method of estimating gear selectivity but is rarely performed because it is cost-prohibitive and time-consuming (Hamley 1975). Indirect estimation involves fitting potential selectivity curves to empirical catch data and does not require sampling a population of known length frequency, reducing cost and time expenditures but at the expense of accuracy (Millar and Holst 1997). Utility of indirect methods has been aided by development of open source code for statistical software programs (e.g., S-PLUS, SAS, and R) that make estimation of gill net selectivity easier (Millar and Holst 1997; Next Generation R Functions).

In an effort to standardize sampling gears and methods used to sample freshwater fishes across North America, the American Fisheries Society (AFS) published voluntary gear standards for sampling fishes in freshwater systems (Bonar et al. 2009). These standards specify how the North American standard (Standard) gill net should be constructed including bar-mesh sizes, twine material and diameter, panel length, panel depth, and panel order. Given the recent publication of these standards, there is relatively little known about the selectivity of the recommended gill net configuration for commonly collected species across North America. Previous studies of gill net selectivity have generally been region-specific for one to several commercially or recreationally important species (Bronte and Johnson 1984; Henderson and Wong 1991) and rarely have similar gill net configurations been used between studies.

For a voluntary gill net standard to be adopted, an understanding of selectivity must be known for many species across diverse habitats and indirect estimation provides a simple method for doing this. Our objective was to perform indirect estimates of selectivity for species commonly sampled with North American standard gill nets in South Dakota waters. Although sampling was completed in South Dakota, all species included in this study are widespread across North America and were sampled in diverse habitats that should be representative of conditions encountered by many fisheries researchers and managers. We anticipate that this project will provide a timely contribution to the current effort to standardize sampling gears in North America and provide an understanding of selectivity for this widely used gear type.

Methods

Study area and sampling design - Gill net sampling took place during June-October of 2013 and 2014. Study sites encompassed a representative sample of available waters, trophic states, and fish community diversity encountered statewide including 19 natural glacial lakes, 4 prairie stream impoundments, 3 montane impoundments in the Black Hills, 5 tributaries to the Missouri River, and all 4 mainstem impoundments of the Missouri River in South Dakota (Table 1). Sampling was performed once at each system except Pactola Reservoir in the Black Hills and all four mainstem impoundments of the Missouri River in South Dakota where sampling occurred during both study years. Nets used in lakes and impoundments were set on the bottom at fixed sampling sites used by South Dakota Department of Game, Fish, and Parks (SDGFP). Tributaries of the Missouri River were sampled by setting gill nets in slack-water areas adjacent to bridges or were anchored to sandbars and set downstream. All nets were set during the afternoon then retrieved the following morning.

Gear description - The North American standard, "core-mesh" gill net, is constructed of eight randomly ordered monofilament panels 3.05-m long and 1.83-m deep with 19, 25, 32, 38, 44, 51, 57, and 64-mm bar-meshes of varying twine diameter for an overall length of 24.38-m. See Bonar et al. (2009b) for a more detailed description of the North American Standard gill net. To provide a better estimate of juvenile Gizzard

Shad *Dorosoma cepedianum* and Yellow Perch *Perca flavescens* selectivity we tied mini-mesh add-ons to all "core-mesh" gill nets fished in Missouri River impoundments during 2013 and 2014 and all natural glacial lakes and prairie stream impoundments sampled during 2014, respectively. Mini-mesh add-ons were constructed of three randomly ordered monofilament panels that were 3.05-m long by 1.83-m deep with bar-mesh sizes of 10, 13, and 16-mm. For the purpose of gear standardization and data reporting only the "core-mesh" panels are considered to be the North American standard and mini-mesh add-ons were treated separately (Peterson and Paukert 2009). We include estimates of selectivity for several species sampled with these mini-mesh add-ons because we acknowledge that due to the high selectivity of gill nets these smaller mesh sizes may be needed to index the smallest size classes of several important species. Researchers have used mini-meshes to sample juvenile Sockeye Salmon *Oncorhynchus nerka* in Alaska lakes (Heard 1962) and Yellow Perch and Alewife *Alosa pseudoharengus* in Lake Michigan (Janssen and Luebke 2004).

Indirect estimation of selectivity – Among the numerous methods for estimating indirect measures of selectivity (Millar and Fryer 1999) we chose the Share Each LEngth's Catch Total (SELECT) method developed by Millar (1992) because of its widespread use in both marine (Treble et al. 1998; Dos Santos et al. 2003) and freshwater research (Carol and Garcia-Berthou 2007; Doll et al. 2014) and availability of open-source code for analyses (i.e., Next Generation R Functions available at https://www.stat.auckland.ac.nz/~millar/selectware/RNext/). This method does not require the true length frequency of the sample population to be known *a priori*. Using Next Generation R Functions the SELECT method involved fitting five potential models (i.e., normal, skew-normal, log-normal, bi-normal, and bi-lognormal) to empirical catch data and calculating model deviances and residuals to identify the model of best-fit (Millar and Fryer 1999). Identifying the best model required inspection of deviance residuals and overall model deviance (Millar and Holst 1997). Models of best-fit have model deviances approximately equal to their degrees of freedom (df) or smaller (Vandergoot et al. 2011). Model deviances larger than their df indicate some lack-of-fit or over-dispersion (Millar and Holst 1997).

Fishing power is the product of gear efficiency and fishing effort. Fishing power generally increases with larger bar-mesh sizes (Hamley 1975; Miller and Holst 1997) because fish vulnerable to those meshes are larger and faster swimming leading to higher encounter probability (Rudstam et al. 1984). We modeled selectivity under the assumption of equal fishing power between meshes because we were most interested in identifying the shape (i.e., uni-modal or bi-modal) of selectivity curves and approximate peak modal lengths of capture for each mesh. Modeling with fishing power proportional to mesh size would not likely change our findings.

Beyond indirect estimation of selectivity for individual meshes we were interested in the species-specific selectivity of the entire net. Gill nets often select for larger individuals (Hubert et al. 2012) relative to other passive gears (Willis et al. 1985). Histograms of “core-mesh” gill net data were plotted for each species across all mesh sizes, including mini-mesh catches of Yellow Perch and Gizzard Shad.

Species chosen for analysis were relatively abundant and widespread across South Dakota and are also found throughout North America (Froese and Pauly 2014). Fish captured with Standard gill nets were measured for fork length (i.e., Shovelnose

Sturgeon) or TL (i.e., all other species) and mesh panel of capture was recorded. Selectivity analyses were performed on pooled statewide data for species where ≈ 50 individuals or more were captured. Minimum sample size for individual bar-meshes was generally 10 individuals. For each species, a data matrix of catch per bar-mesh panel by length bin was constructed. Bin lengths were 10, 20, 30, or 40-mm and chosen based on fish length, quantity of available data, and desired level of resolution. Species and mesh-specific peak modal lengths of capture were identified from these matrices and mean TL of capture was calculated. Inspection of model deviances and residuals were used to identify the best model fit to empirical catch data. All calculations were performed in R version 3.0.2 “frisbee sailing” (R Core Development Team, 2014).

Results

Bi-lognormal models provided the best fits for 8 of the 18 species investigated. Bi-normal fits best explained selectivity for six species, skew-normal fits were best for two species, and both normal and log-normal models each explained selectivity for a single species (Figure 1). Inspection of deviance residuals revealed an element of bi-modality for most species (Figure 2). Not all meshes could be included for each species analysis due to limited data resulting from low likelihood of capture for some species in certain mesh sizes (e.g., Yellow Perch in 64-mm bar-mesh).

Models of best fit were easiest to identify for species with the largest data sets (i.e., Black Bullhead *Ameiurus melas*, Channel Catfish *Ictalurus punctatus*, Walleye *Sander vitreus*, and Yellow Perch) due to low model deviance relative to other potential models and comparatively small deviance residuals (Table 2). Small data sets for several species (i.e., River Carpsucker *Carpiodes carpio*, Shorthead Redhorse *Moxostoma macrolepidotum*, and Shovelnose Sturgeon *Scaphirhynchus platorynchus*) hampered efforts to identify a best model fit due to comparatively large deviance residuals for all models but similar overall model deviances. Interpreting these results relied more on close inspection of deviance residuals than of model deviances. For example, the bi-normal model had the lowest model deviance for Shorthead Redhorse but deviance residuals indicated this fit was best for only one mesh and was not likely representative of overall selectivity for this species.

For several species (i.e., Black Crappie *Pomoxis nigromaculatus*, Gizzard Shad, and Shovelnose Sturgeon) there were two-way ties between models for lowest model deviance indicating both models equally explained selectivity (Millar 1995). These ties occurred between bi-modal models with five fitted parameters and uni-modal models with two fitted parameters. In these situations deviance residuals were scrutinized for evidence of bi-modality and if none was consistently observed we invoked the principle of parsimony and chose the model with the fewest fitted parameters (McCullagh and Nelder 1989).

Model deviances for top models were approximately equal to or slightly larger than their df indicating little evidence of lack-of-fit or over-dispersion. Inspection of deviance residuals showed consistent bias for some meshes within species models indicating lack of model fit to those meshes as demonstrated by Millar and Holst (1997) with Sockeye Salmon *Oncorhynchus nerka* data collected by Holt (1963). For example, there were moderately strong and consistent negative deviance residuals for Goldeye *Hiodon alosoides* captured in the 51-mm bar-mesh indicating poor fit of the bi-lognormal model for large individuals in that mesh (Figure 2). Walleye and Yellow Perch model deviances were high relative to their df but no consistent bias was observed from deviance residuals and may indicate over-dispersion.

Inspection of length-frequency histograms for catch data provides a useful visualization of selectivity for Standard gill nets (Figure 3). Overall, selectivity follows a normal distribution for most species despite prevalence of bi-modality for individual mesh selectivity curves. Notable exceptions are Gizzard Shad and Yellow Perch that include mini-mesh catch data resulting in strong overall bi-modality for Yellow Perch that reflects several high catches of sub-stock fish, and weak bi-modality for Gizzard Shad where Standard nets typically target fish smaller than 250 mm TL but still collect much larger individuals. Overall selectivity for Common Carp was also bi-modal and resulted from several high catches of sub-stock fish in 19 and 25-mm bar-mesh panels. Standard gill nets did not sample the smallest individuals in the population even with mini-mesh add-ons but generally collected larger individuals particularly for Black Crappie, River Carpsucker, and Shovelnose Sturgeon.

Peak modal lengths from species and mesh-specific catch data matrices (Table 3) corroborated approximate peak modal lengths observed from model fits using the SELECT method (Figure 1) and match well for species that were primarily captured by gilling or wedging and had large data sets. Data for larger individuals of most species was scarce resulting in divergent estimates of mesh-specific peak modal efficiency between empirical data and modeled fits. Shovelnose Sturgeon serve as a useful example because they were sampled infrequently and were often captured by tangling so peak modal lengths of capture varied considerably between empirical data and modeled selectivity curves. Arithmetic mean TL was generally larger than empirical peak modal lengths across species and bar-mesh sizes due to bi-modality of gill net selectivity (Table 3).

Discussion

Our findings build on previous studies by corroborating selectivity studies for important recreational species and by applying the SELECT method to many species with unknown gill net selectivities. We found Baranov's assumption of geometric similarity (Baranov 1914) not applicable for many species because selectivity curves broadened as fish length and bar-mesh size increased, indicating that larger bar-meshes were more efficient and less selective than small ones. Small meshes are perceived to be more visible to small fish and less elastic than larger meshes increasing selectivity of these meshes and reducing catch of the smallest fish in the population (Hubert et al. 2012).

Shape and location of selectivity curves was strongly related to fish morphology. Girth is the most important factor influencing fish capture by wedging because girth needs to be approximately equal to or slightly larger than the perimeter of the mesh to be captured (Baranov 1948; Reis and Pawson 1999; Carol and Garcia-Berthou 2007). Most fish grow allometrically with age (e.g., grow plumper) and get captured by means other than wedging around the gills (i.e., gilling) or further back on the body (i.e., wedging) as they grow larger. Vandergoot et al. (2011) found gilling and wedging to be the primary means of capture followed by tangling for Lake Erie Walleyes. Our findings suggest that tangling influenced selectivity for many species, especially those with large maxillaries, teeth, and spines (e.g., Walleye, Northern Pike, and Channel Catfish).

We found that smooth-bodied fish were caught by wedging themselves in the net and usually had uni-modal selectivity curves, similar to the streamlined estuarine and marine fishes studied by Trent and Pristas (1977); however, the interaction of wedging and tangling for most species produced the numerous bi-modal model fits observed in the present study, as predicted by Hamley (1975) for species with more than one mode of capture (e.g., gilling *and* tangling by spines). Pierce et al. (1994) identified tangling as an important factor for capturing Northern Pike *Esox lucius* and our finding of bi-lognormal model fit corroborates empirical catch data presented by Neumann and Willis (1994) though these researchers did not fit selectivity curves to their data for us to compare against. Northern Pike in the our study were commonly tangled by teeth and maxillaries, often after attacking Yellow Perch captured in small meshes producing the broad selectivity curve for all meshes. Bi-lognormal fits for Walleye, a species commonly tangled by teeth, maxillaries and spines were similar to the bi-modal model fits described by Hamley and Regier (1973) in their direct estimate of selectivity, and closely resembled bi-normal model fits of Vandergoot et al. (2011) that incorporated deviations. Our bi-lognormal fit for Yellow Perch contradicts Doll et al. (2014) that found log-normal fits to be best. This discrepancy likely exists because bi-modal fits were not included by Doll et al. (2014) and inspection of their deviance residuals indicates evidence of bi-modality for smaller meshes. Carol and Garcia-Berthou (2007) did not include bi-modal models in their analyses for Common Carp *Cyprinus carpio* and found no significant model fit. When incorporating bi-modality we found the bi-normal model best explained our data. Bi-modality occurred because Common Carp were often captured by their serrated dorsal and anal spines, not by wedging alone. Log-normal fits for Black Crappies were similar to selectivity curves found by Guy et al. (1996) for White Crappies in Kansas reservoirs.

Several species with large model deviances not explained by lack-of-fit were probably examples of over-dispersion. Over-dispersion occurs because not all fish behave independently (Berst and McCombie 1963); the result is high model deviance without consistent directionality (McCullagh and Nelder 1989). This phenomenon was likely true of Yellow Perch that are known to school with conspecifics of similar size and age (Becker 1983). Small Yellow Perch (≤ 140-mm TL) were sampled infrequently with 10, 13, and 16-mm bar-meshes but, were locally abundant when found. Doll et al. (2014) sampled Yellow Perch in Lake Michigan with micro-mesh gill nets and found similar model deviances to ours with approximately equal sample sizes indicating that some degree of over-dispersion may be common for Yellow Perch data. This finding would not likely influence our conclusions because, as McCullagh and Nelder (1989) noted, these random processes, regardless of their origin, should have minimal impact on model fit.

Comparing empirical catch data with modeled selectivity curve fits demonstrated the utility of modeled mesh-specific selectivity curves fitted using the SELECT method. Model fits were most accurate for frequently sampled species primarily captured by gilling or wedging. For infrequently sampled species (e.g., River Carpsucker and Shovelnose Sturgeon) and larger individuals there was greater disparity between empirical and modeled peak modal efficiency though model fits still reflected the range of sizes observed from empirical catch data, allowing models developed using the SELECT method to be useful. Previous studies of gill net selectivity have fit SELECT models to data sets with as few as 19 individuals (Garcia-Berthou 2007) to more than 6,000 (Millar and Holst 1997). Individual mesh selectivities have been fit with as few as 6 fish (Doll et al. 2014), approximately equal to the smallest sample size used in this study.

Selectivity models developed during this study should aid in management and conservation of game and non-game species throughout North America. Our conclusions corroborated earlier findings for Walleye selectivity (Hamley and Regier 1973; Vandergoot et al. 2011) and built on previous modeling efforts for Yellow Perch (Doll et al. 2014) and Northern Pike (Pierce et al. 1994) by including bi-modal models. Our study expanded knowledge of gill net selectivity by including numerous non-game species that are often collected in standard gill net sampling. Inclusion of individual mesh selectivity curves fitted using the SELECT method and histograms of overall gill net selectivity provide thorough understanding of biases when using Standard gill nets and demonstrate the utility of non-standard meshes for targeting Gizzard Shad and Yellow Perch. Future studies may use this information for several purposes including: optimizing gill nets to avoid non-target species (see Price and Rulifson 2004), avoiding capture of under-sized commercial species (see Kraft and Johnson 1992), monitoring native riverine species, or contributing to our understanding of this relatively new standardized sampling gear. This study should aid managers in understanding gill net sampling biases for non-game species that have received increased emphasis in recent decades (Cooke et al. 2005). Future efforts could expand on this research by including additional species of regional interest. Our understanding of selectivity may also be improved by using more robust data sets for species that were sampled in low numbers during the present study. We used all five models currently available in the Next Generation R Code but incorporating additional models to analyses may improve model fit for some species.

Hamley (1975) warned that no set of selectivity curves could be accurate across water bodies unless gears and methods were standardized. Fortunately, by using a standardized gill net with standard sampling methods, our results should be broadly applicable for the eighteen species we investigated. Current efforts to adopt (Bonar and Hubert 2002; Bonar et al. 2009) and transition (Koch et al. 2014; Statewide Components Work Group 2014) to standard sampling gears makes knowledge of North American standard gill net selectivity a valuable addition to our understanding of this widely used sampling gear. This study should provide a broadly applicable source of gill net selectivity for managers and researchers and help facilitate further adoption of North American standard gears and methods.

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Table 1. Description of South Dakota waters sampled and gill net effort (i.e. Net nights) used to obtain data for gill net selectivity analyses. Water body size is river length (km) for tributaries to the Missouri River and surface area (ha) for all lakes and impoundments. Pactola reservoir and all Missouri river impoundments were sampled during both 2013 and 2014 while all other water bodies were sampled during only one study year.

Water body	Water body type	Water body size	Max depth (m)	Trophic state	Net nights	Year(s) sampled
Alvin	prairie stream impoundment	43	7.9	eutrophic	3	2014
Bad River	tributary to Missouri River	259	na	na	2	2014
Belle Fourche	tributary to Missouri River	470	na	na	3	2014
Bitter	glacial lake	6,070	8.5	eutrophic	8	2013
Blue Dog	glacial lake	251	2.7	eutrophic	6	2014
Bullhead	glacial lake	66	4.6	eutrophic-hypereutrophic	6	2014
Cheyenne	tributary to Missouri River	475	na	na	2	2014
Clear	glacial lake	192	6.7	mesotrophic-eutrophic	6	2014
Cochrane	glacial lake	58	7.3	eutrophic	6	2014
Deerfield	Black Hills impoundment	176	29.0	mesotrophic	4	2014
East Krause	glacial lake	70	6.1	eutrophic	3	2013
Enemy Swim	glacial lake	868	7.9	mesotrophic-eutrophic	6	2014
Francis Case	Missouri River impoundment	≈ 41,000	43.0	eutrophic-oligotrophic	39	2013,2014
Kampeska	glacial lake	2,125	4.9	eutrophic	6	2014
Lewis and Clark	Missouri River impoundment	≈ 13,000	14.0	eutrophic-oligotrophic	23	2013,2014
Madison	glacial lake	1069	4.9	eutrophic	5	2013
Mina	prairie stream impoundment	326	8.2	eutrophic	6	2013
Mitchell	prairie stream impoundment	271	8.8	eutrophic	4	2014
Moreau	tributary to Missouri River	320	na	na	2	2014
North Rush	glacial lake	1,133	3.7	eutrophic-hypereutrophic	6	2013
Oahe	Missouri River impoundment	≈ 150,000	62.0	eutrophic-oligotrophic	108	2013,2014
Pactola	Black Hills impoundment	318	50.6	oligotrophic	21	2013,2014
Pickerel	glacial lake	397	12.5	eutrophic	6	2013
Richmond	prairie stream impoundment	335	8.8	eutrophic	6	2013
Roy	glacial lake	831	6.4	eutrophic	6	2013
Scott	glacial lake	43	3.4	eutrophic	3	2013
Sharpe	Missouri River impoundment	≈ 23,020	24.0	eutrophic-oligotrophic	47	2013,2014
Sheridan	Black Hills impoundment	155	29.3	mesotrophic	2	2014
Sinai	glacial lake	735	10.1	eutrophic	4	2013
South Buffalo	glacial lake	724	4.3	eutrophic	6	2013
Thompson	glacial lake	5,041	7.9	eutrophic	5	2014
Wall	glacial lake	84	7.3	eutrophic	6	2014
Waubay	glacial lake	6,288	9.4	hypereutrophic	8	2013
West 81	glacial lake	554	6.7	hypereutrophic	5	2014
White	tributary to Missouri River	930	na	na	1	2014

Table 2. Sample size, model deviances, and degrees of freedom for each of five models calculated for 18 species using the SELECT method of Millar and Holst (1997). Normal, skew-normal, and log-normal models each have three fitted parameters while bi-normal and bi-lognormal have five fitted parameters. Models of best fit, denoted with asterisks, were identified using model deviances *and* deviance residuals. All fish were sampled using North American standard gill nets comprised of 19, 25, 32, 38, 44, 51, 57, and 64 mm bar-mesh panels throughout South Dakota during June-October of 2013-2014.

Species	n	Model	Model deviance	df	
Black Bullhead	1453	normal	622.35	89	
		skew-normal	524.07	89	
		log-normal	456.25	89	
		bi-normal	126.87	86	*
		bi-lognormal	149.76	86	
Black Crappie	96	normal	93.54	43	
		skew-normal	90.20	43	
		log-normal	83.30	43	*
		bi-normal	90.20	40	
		bi-lognormal	83.30	40	
Bluegill	96	normal	92.56	38	
		skew-normal	109.12	38	
		log-normal	85.29	38	
		bi-normal	49.53	35	*
		bi-lognormal	85.29	35	
Channel Catfish	1380	normal	653.56	145	
		skew-normal	1061.79	145	
		log-normal	651.32	145	
		bi-normal	272.44	142	
		bi-lognormal	232.90	142	*
Common Carp	182	normal	271.97	117	
		skew-normal	324.73	117	
		log-normal	254.82	117	
		bi-normal	163.87	114	*
		bi-lognormal	254.35	114	
Freshwater Drum	242	normal	165.98	76	
		skew-normal	237.71	76	
		log-normal	215.25	76	
		bi-normal	96.41	73	
		bi-lognormal	95.51	73	*

Gizzard Shad	231	normal	65.43	54	
		skew-normal	62.78	54	*
		log-normal	68.95	54	
		bi-normal	62.78	51	
		bi-lognormal	67.89	51	
Goldeye	166	normal	77.86	34	
		skew-normal	105.72	34	
		log-normal	84.39	34	
		bi-normal	57.15	31	
		bi-lognormal	53.08	31	*
Northern Pike	227	normal	148.70	112	
		skew-normal	188.38	112	
		log-normal	163.36	112	
		bi-normal	114.88	109	
		bi-lognormal	113.60	109	*
River Carpsucker	46	normal	39.15	18	
		skew-normal	40.87	18	
		log-normal	38.97	18	
		bi-normal	29.08	15	*
		bi-lognormal	29.74	15	
Sauger	91	normal	71.66	31	
		skew-normal	86.78	31	
		log-normal	70.65	31	
		bi-normal	50.07	28	
		bi-lognormal	51.04	28	*
Shorthead Redhorse	54	normal	24.43	28	*
		skew-normal	31.69	28	
		log-normal	26.44	28	
		bi-normal	20.78	25	
		bi-lognormal	26.44	25	
Shovelnose Sturgeon	73	normal	59.41	54	
		skew-normal	56.87	54	*
		log-normal	57.93	54	
		bi-normal	56.87	51	
		bi-lognormal	57.96	51	

Smallmouth Bass	253	normal	194.51	82	
		skew-normal	172.69	82	
		log-normal	152.92	82	
		bi-normal	107.56	79	*
		bi-lognormal	152.92	79	
Walleye	1505	normal	685.49	131	
		skew-normal	658.64	131	
		log-normal	502.98	131	
		bi-normal	254.53	128	
		bi-lognormal	224.60	128	*
White Bass	218	normal	83.12	43	
		skew-normal	116.36	43	
		log-normal	94.51	43	
		bi-normal	46.18	40	*
		bi-lognormal	47.14	40	
White Sucker	228	normal	66.52	38	
		skew-normal	81.16	38	
		log-normal	64.08	38	
		bi-normal	27.99	35	
		bi-lognormal	26.98	35	*
Yellow Perch	2094	normal	2813.70	142	
		skew-normal	2383.70	142	
		log-normal	2107.05	142	
		bi-normal	1254.70	139	
		bi-lognormal	1211.78	139	*

Table 3. Species-specific sample size parameters relevant to indirect estimates of selectivity for eighteen freshwater fish species collected in South Dakota during 2013 and 2014 using gill nets constructed to specifications outlined in *Standard Methods for Sampling North American Freshwater Fishes*. Bin widths were necessary for construction of data matrices used in selectivity analyses and were chosen based on maximum fish length and sample size. Only bar-meshes with sufficient data to warrant analyses were included. Mini-meshes (i.e., 10, 13, and 16-mm bar-meshes) are included for Gizzard Shad and Yellow Perch due to their utility in collecting smaller individuals of those species.

Species	Bin width (mm)	Bar-mesh (mm)	N	Modal length bin (mm)	Mean TL (mm)	Minimum TL (mm)	Maximum TL (mm)
Black Bullhead	20	19	47	120	178	121	279
		25	245	180	204	160	314
		32	490	220	235	177	344
		38	358	260	262	175	321
		44	234	100	283	161	336
		51	46	300	272	186	342
		57	21	na	296	212	391
		64	13	280	281	239	325
Black Crappie	20	19	8	100	127	101	240
		25	8	na	235	129	295
		32	26	260	273	201	310
		38	10	180	228	189	278
		44	29	260	254	209	295
		51	15	280	271	239	292
Bluegill	20	19	5	na	164	106	207
		25	24	120	143	110	215
		32	29	140	173	143	253
		38	11	180	181	160	210
		44	18	200	195	142	220
		51	9	200	204	162	235
Channel Catfish	30	19	72	170	314	165	632
		25	164	230	336	145	746
		32	259	350	369	234	705
		38	195	350	396	161	672
		44	245	410	454	214	696
		51	195	500	500	161	700
		57	143	500	532	358	694
		64	107	590	566	298	713

Common Carp	40	19	27	100	266	108	747
		25	20	140	271	132	614
		32	11	460	450	210	693
		38	19	220	326	222	713
		44	13	na	422	242	636
		51	15	380	522	390	773
		57	29	420	516	281	779
		64	48	500	536	376	757
Freshwater Drum	30	25	10	320	336	193	439
		32	17	230	256	81	378
		38	19	230	289	117	416
		44	63	290	337	91	630
		51	65	350	364	275	435
		57	39	350	383	303	445
		64	30	410	427	379	491
Gizzard Shad	10	10	51	60	68	56	142
		13	44	90	92	68	109
		16	40	110	117	95	139
		19	66	130	142	117	167
		25	31	na	179	161	189
Goldeye	30	25	20	300	344	225	461
		32	37	300	341	251	426
		38	48	330	355	227	466
		44	54	360	379	281	475
		51	8	360	430	378	580
Northern Pike	40	19	22	na	584	305	808
		25	33	420	529	284	835
		32	43	500	563	276	916
		38	51	500	584	262	832
		44	41	na	632	373	874
		51	14	820	717	370	930
		57	23	780	755	364	1020
River Carpsucker	30	51	12	390	441	371	565
		57	18	420	417	327	580
		64	16	450	469	431	548

Sauger	30	19	16	na	294	185	454
		25	35	300	337	235	496
		32	33	360	388	337	474
		38	7	390	408	356	472
Shorthead Redhorse	30	25	18	na	317	214	395
		32	21	330	330	232	395
		38	10	360	395	327	470
		44	6	na	424	376	495
Shovelnose Sturgeon	30	19	4	580	636	590	747
		25	17	610	640	550	936
		32	12	640	631	523	709
		38	7	na	642	369	735
		44	11	640	621	546	690
		51	13	580	653	573	786
		57	8	580	681	586	788
		64	6	na	635	585	696
Smallmouth Bass	30	19	5	150	165	151	184
		25	27	180	215	179	279
		32	41	240	281	189	429
		38	47	270	304	221	488
		44	59	300	331	223	421
		51	29	330	375	331	509
		57	27	390	389	247	467
		64	18	na	395	257	473
Walleye	30	19	202	190	271	167	612
		25	418	280	318	173	721
		32	375	340	366	226	527
		38	252	370	392	210	686
		44	119	430	435	215	617
		51	58	460	459	246	625
		57	43	520	508	211	680
		64	40	370	496	233	684
White Bass	30	32	33	320	303	214	379
		38	23	290	330	241	577
		44	41	320	345	246	595
		51	70	320	361	315	447
		57	28	350	384	345	431
		64	17	410	402	328	441

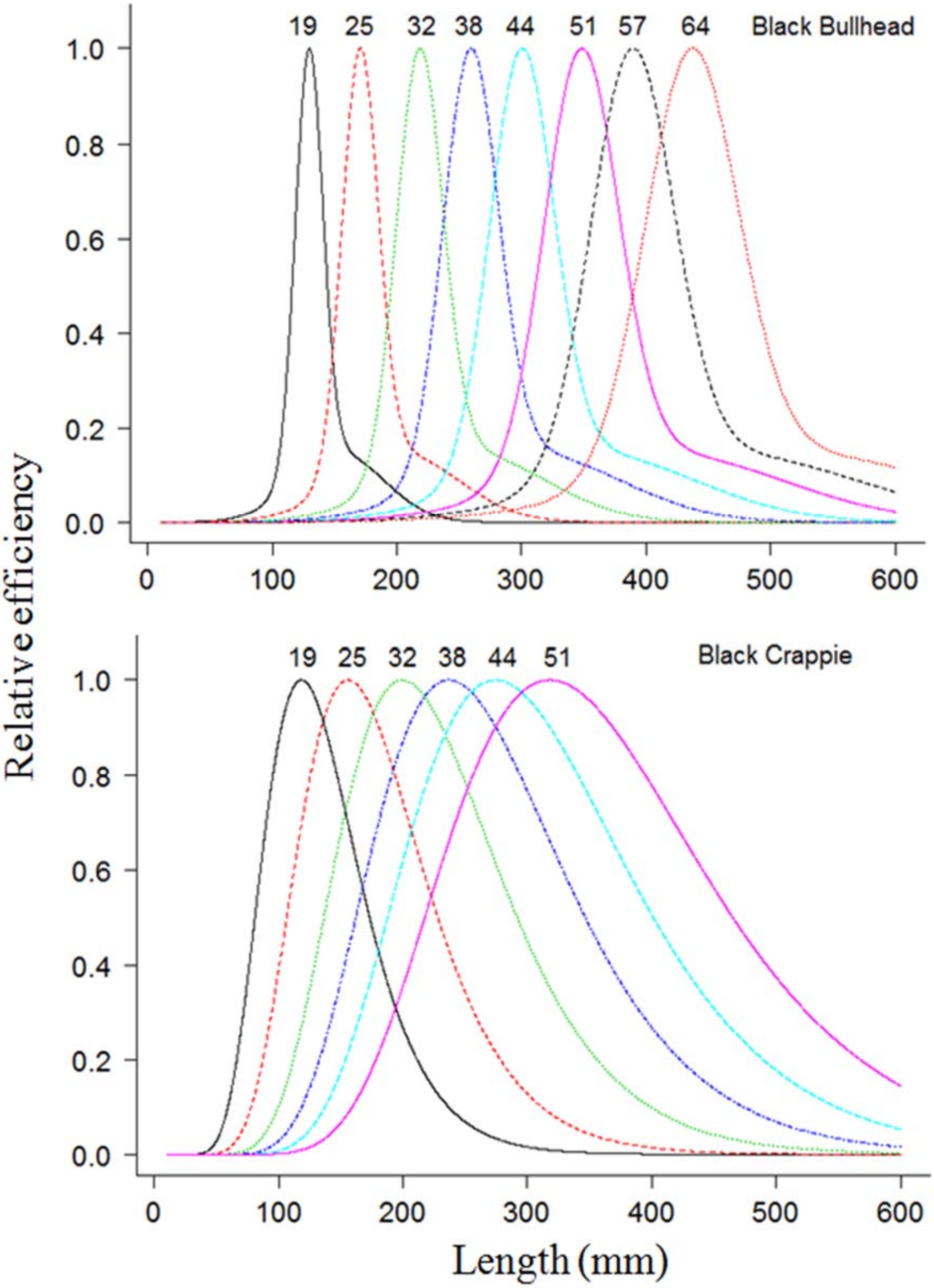
White Sucker	30	38	25	na	417	285	554
		44	51	380	417	354	549
		51	61	410	443	343	550
		57	56	440	463	370	536
		64	24	500	473	382	537
Yellow Perch	20	10	85	60	84	69	161
		13	418	100	108	75	359
		16	172	100	122	74	255
		19	703	140	163	68	284
		25	363	180	206	140	363
		32	223	220	236	142	356
		38	78	240	258	115	329
		44	25	280	284	152	331
		51	18	200	223	190	286
		57	4	100	265	206	303

List of Figures

Figure 1. Gill net selectivity curves for models of best fit identified using the SELECT method of Millar and Holst (1997) for 18 freshwater fish species sampled using North American standard gill nets constructed to specifications outlined in *Standard Methods for Sampling North American Freshwater Fishes* in South Dakota during June-October of 2013-2014. Bar-meshes (mm) are identified for each selectivity curve.

Figure 2. Deviance residuals for models of best fit calculated for 18 freshwater fish species by bar-mesh (mm) and length (mm) using the SELECT method of Millar and Holst (1997). Solid circles represent positive residuals and open circles represent negative residuals where the square of the residual is proportional to circle size. All fish were sampled using North American standard gill nets constructed to specifications outlined in *Standard Methods for Sampling North American Freshwater Fishes* throughout South Dakota during June-October of 2013-2014.

Figure 3. Histograms of total catch across all mesh sizes for 18 freshwater fish species sampled using North American standard gill nets constructed to specifications outlined in *Standard Methods for Sampling North American Freshwater Fishes* throughout South Dakota during June-October of 2013-2014. Gizzard Shad and Yellow Perch plots include catches from mini-meshes (i.e., 10, 13, and 16-mm bar-mesh) because these meshes were highly effective in collecting small individuals. Normal curves were fitted to catch data to visualize overall selectivity.



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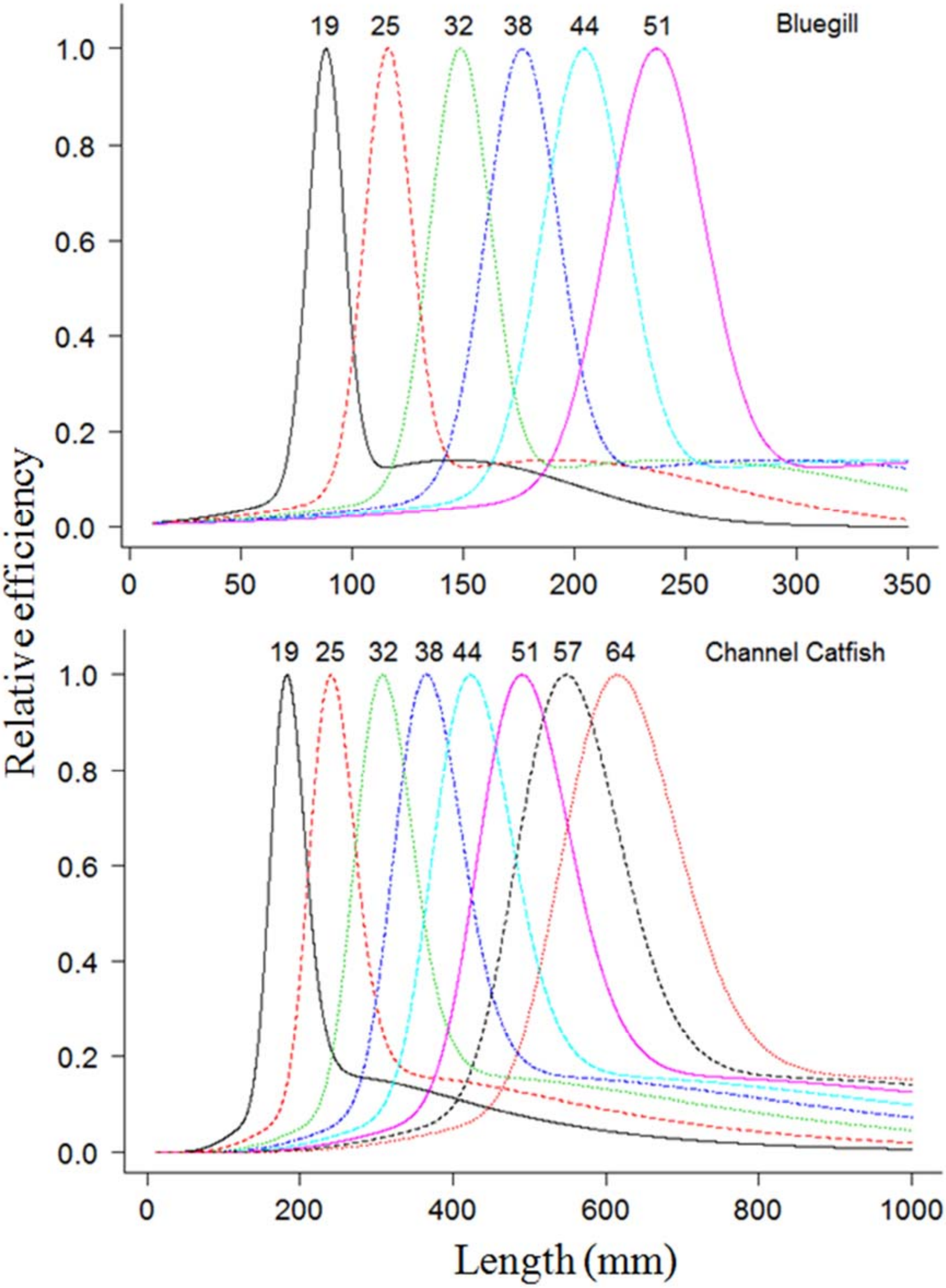

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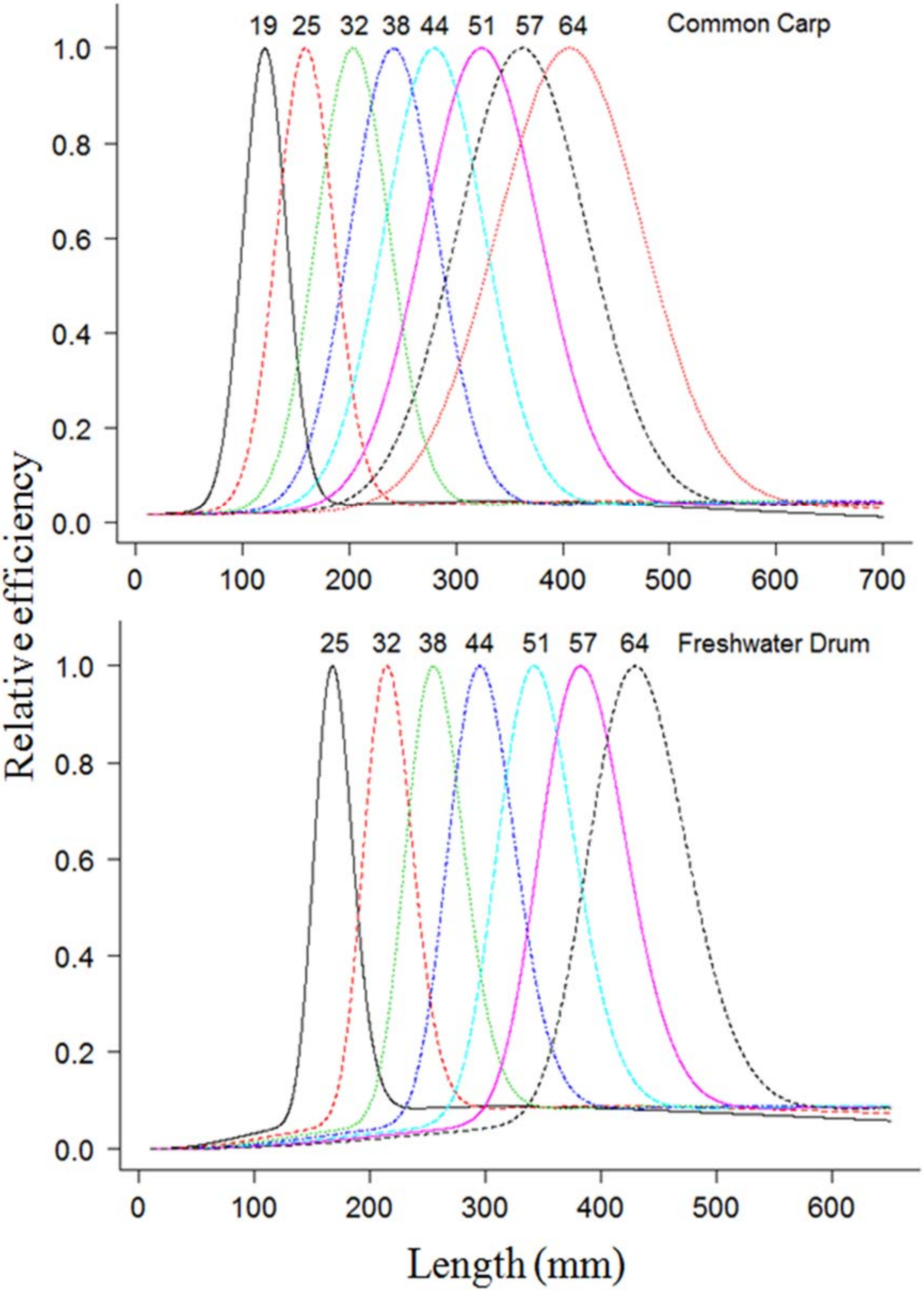

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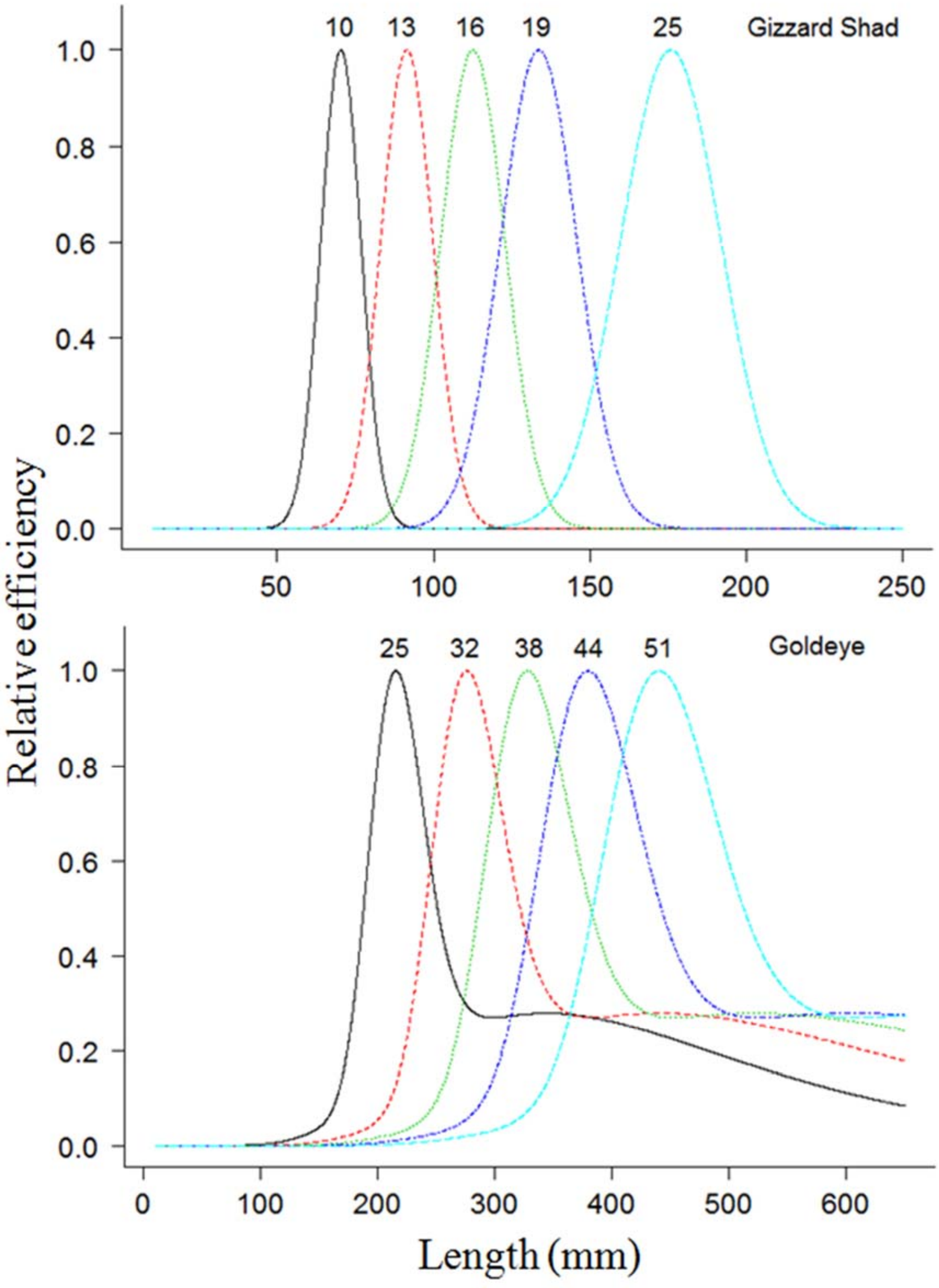

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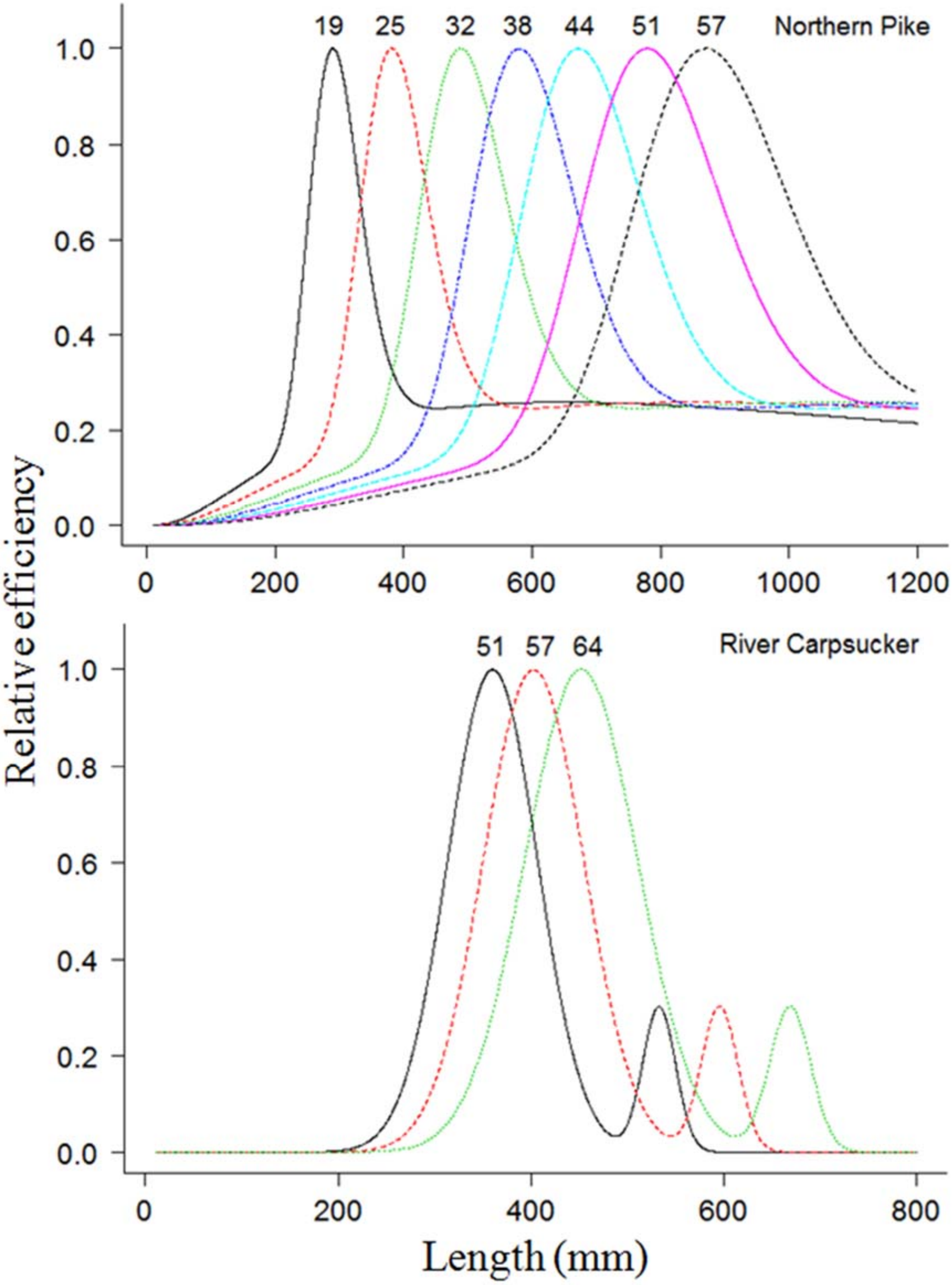

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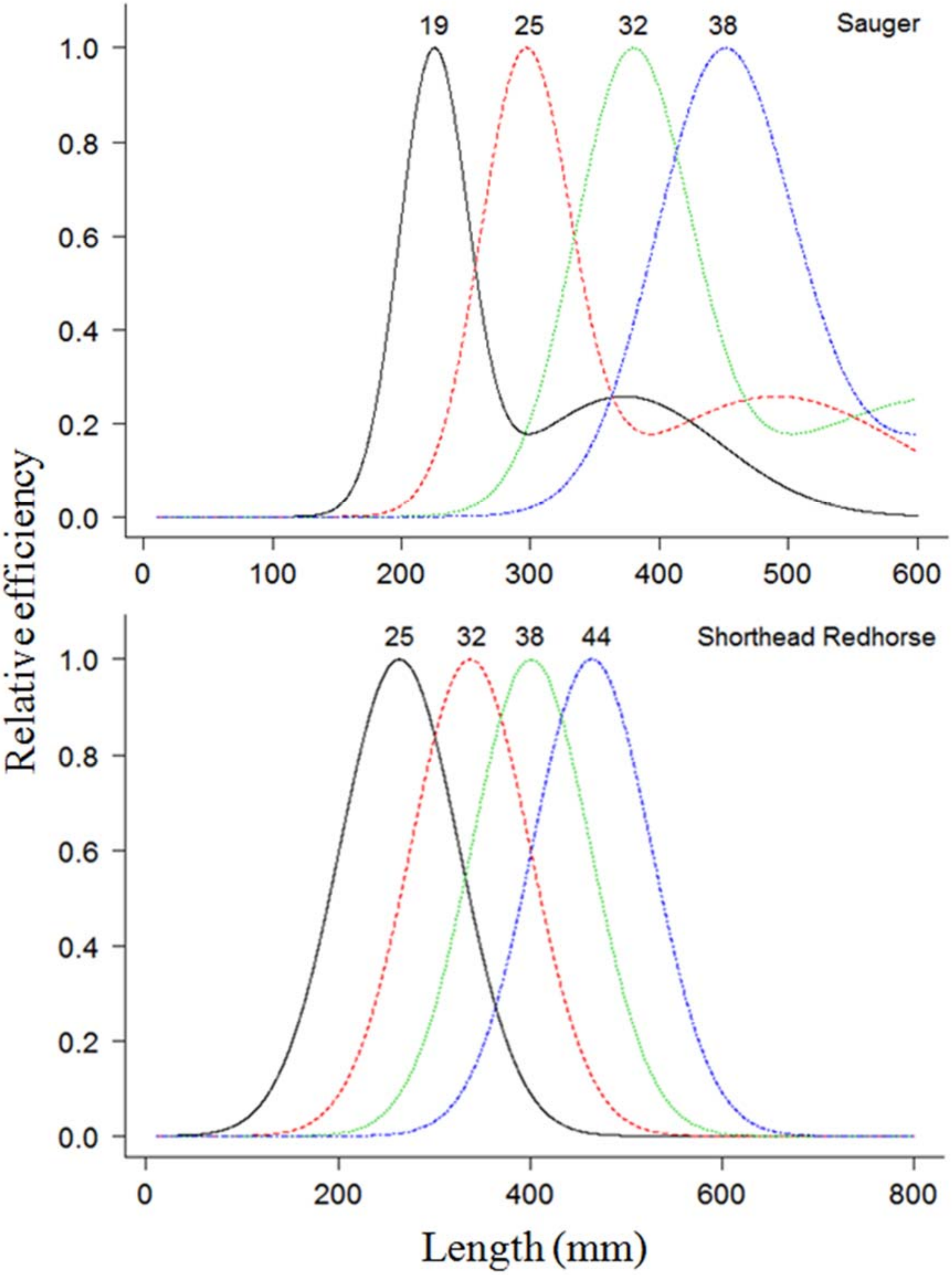

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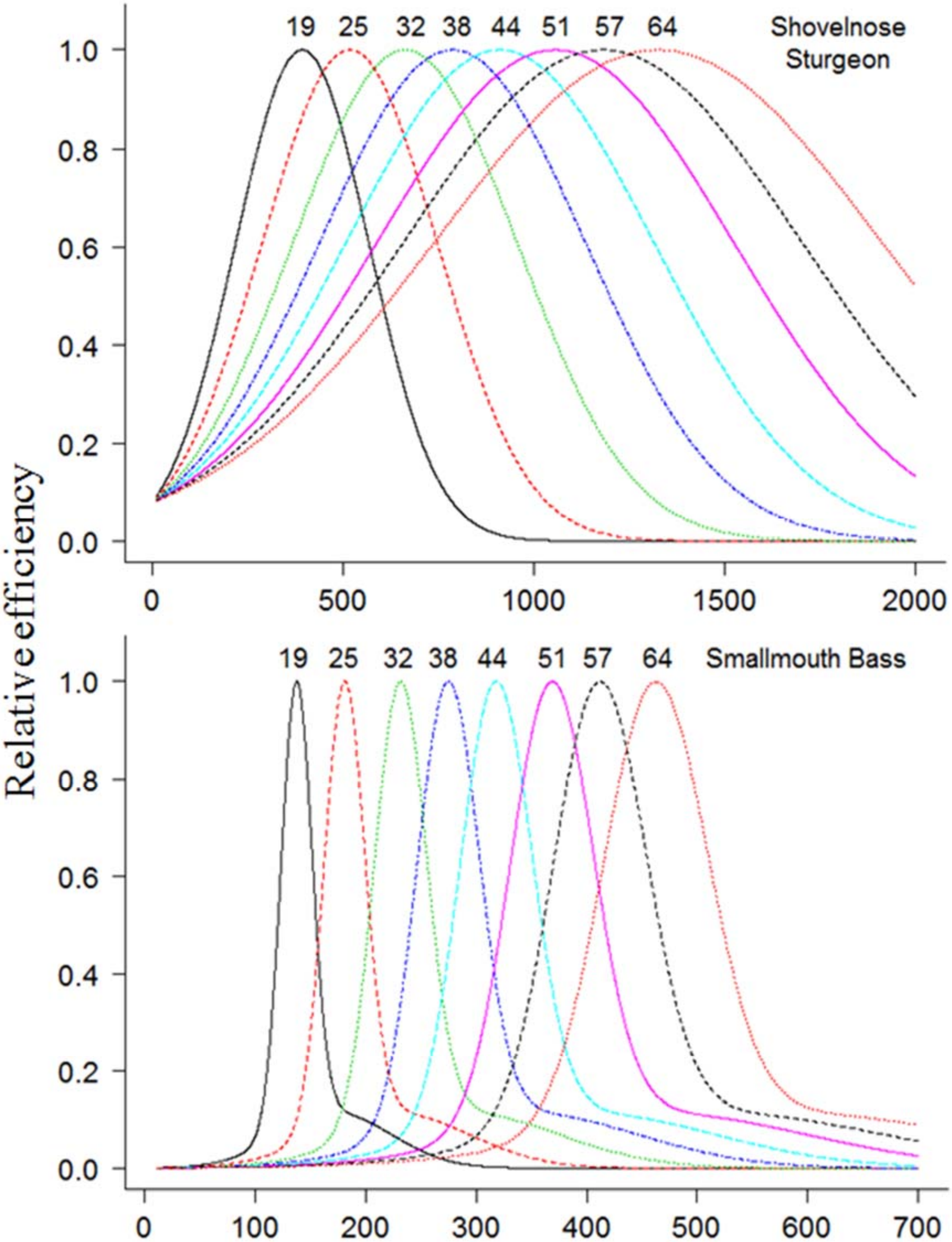

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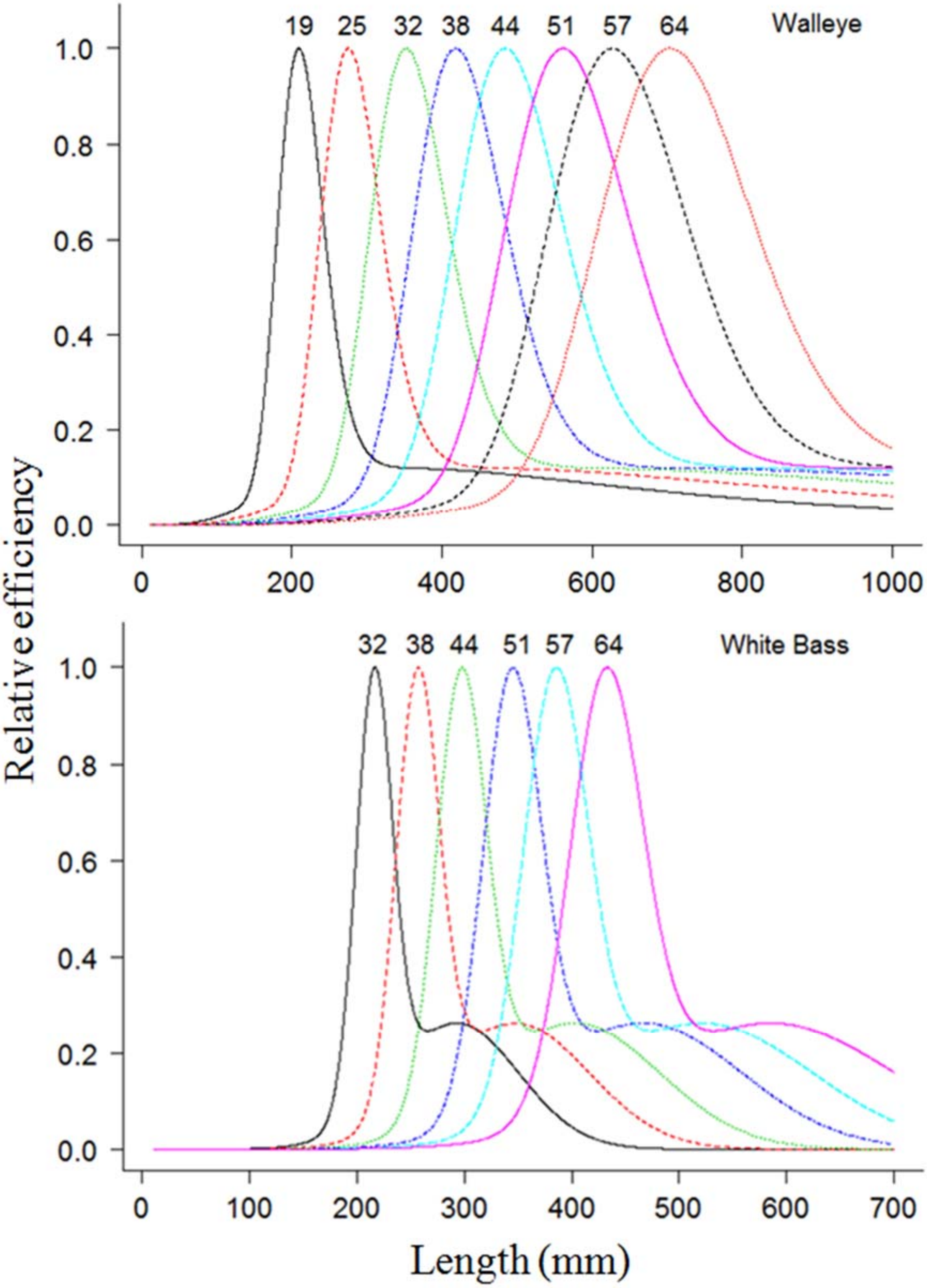

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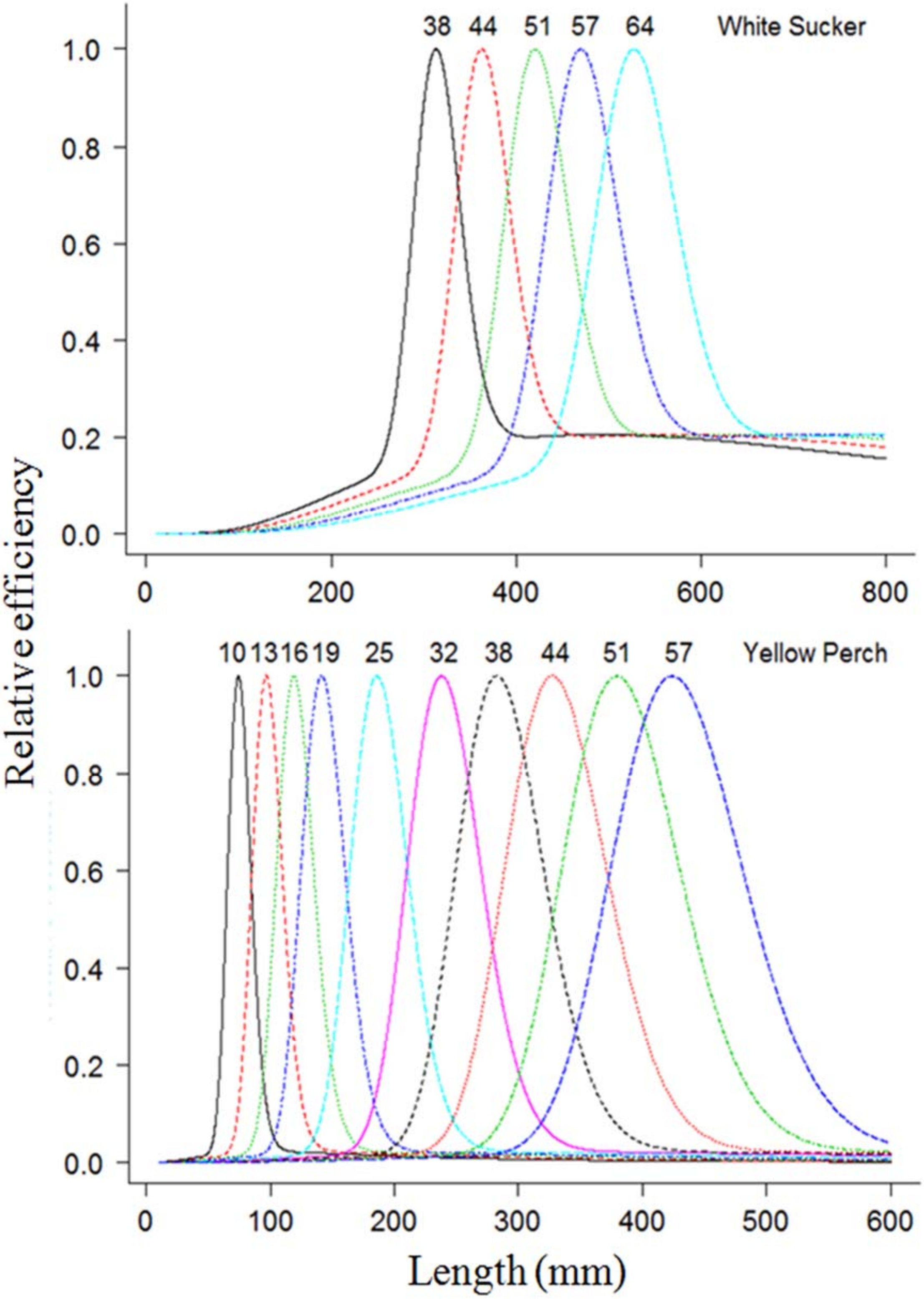

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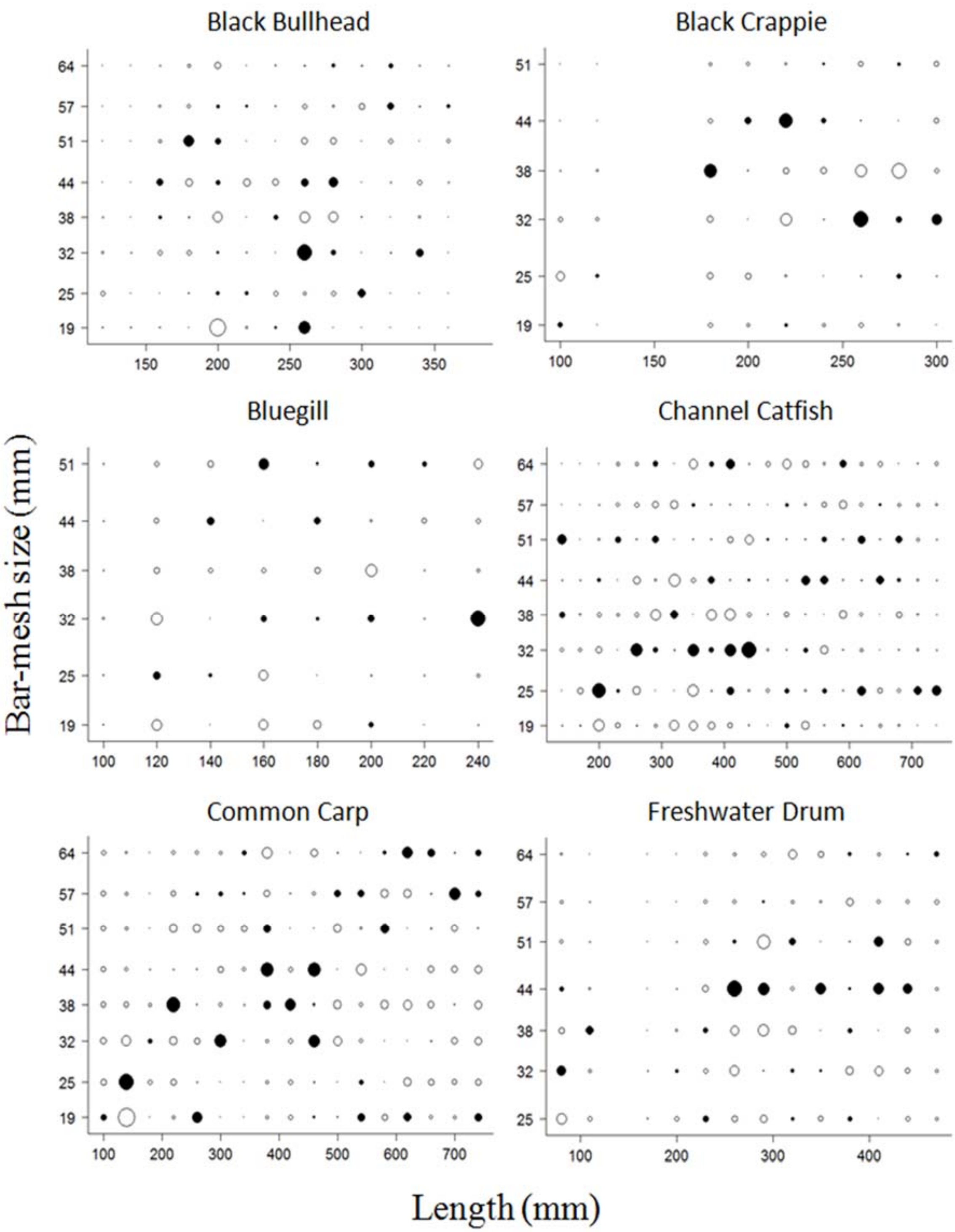

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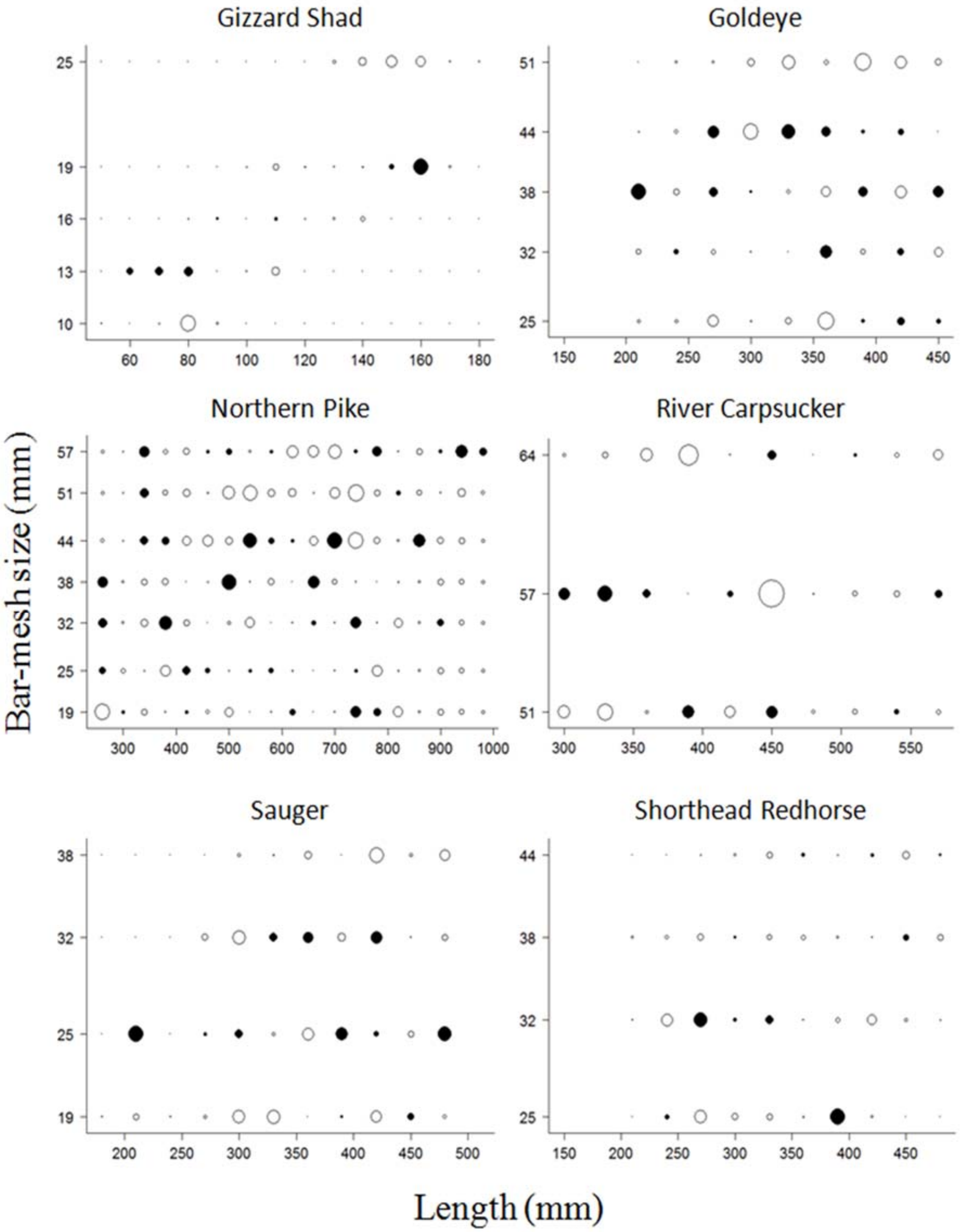

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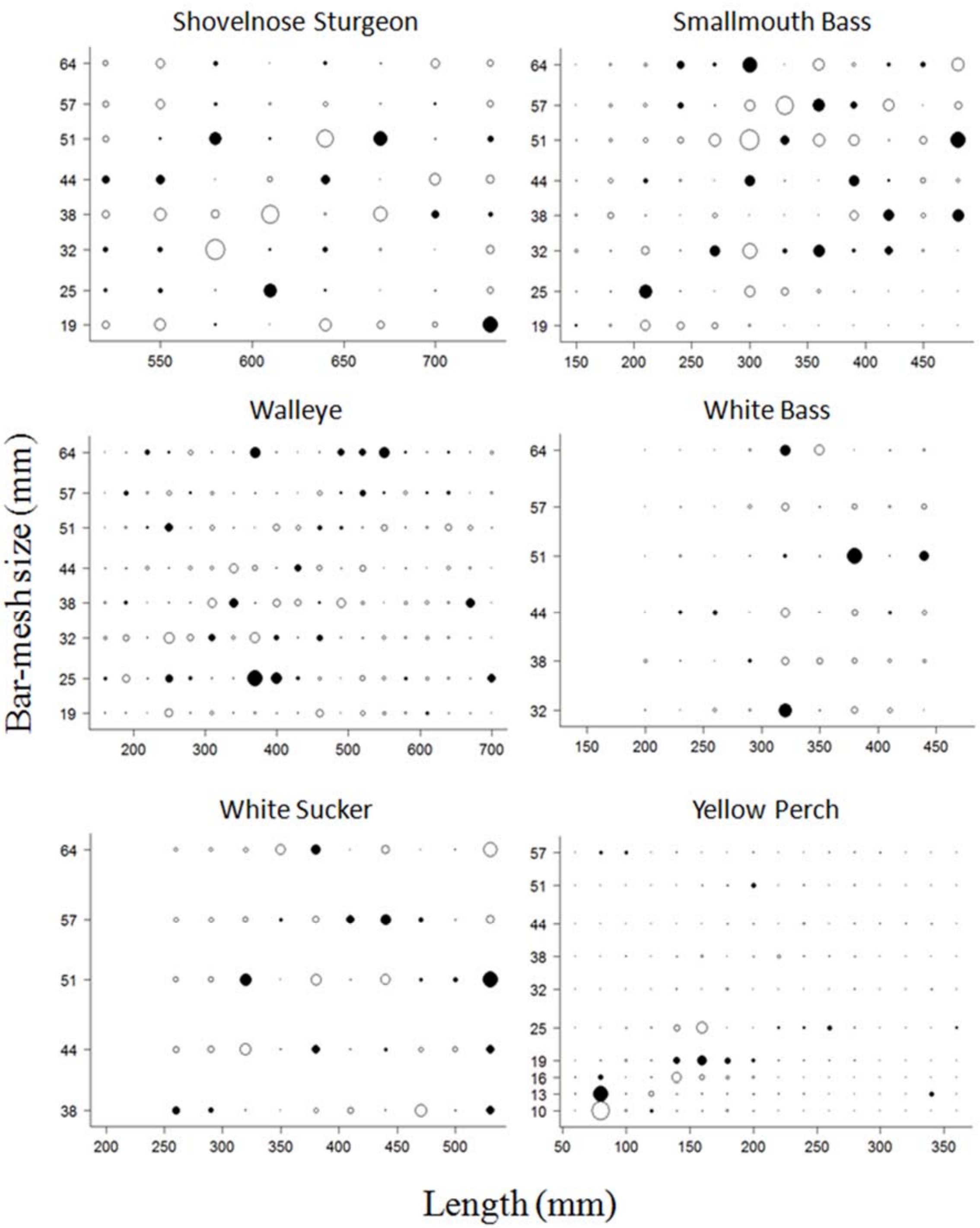

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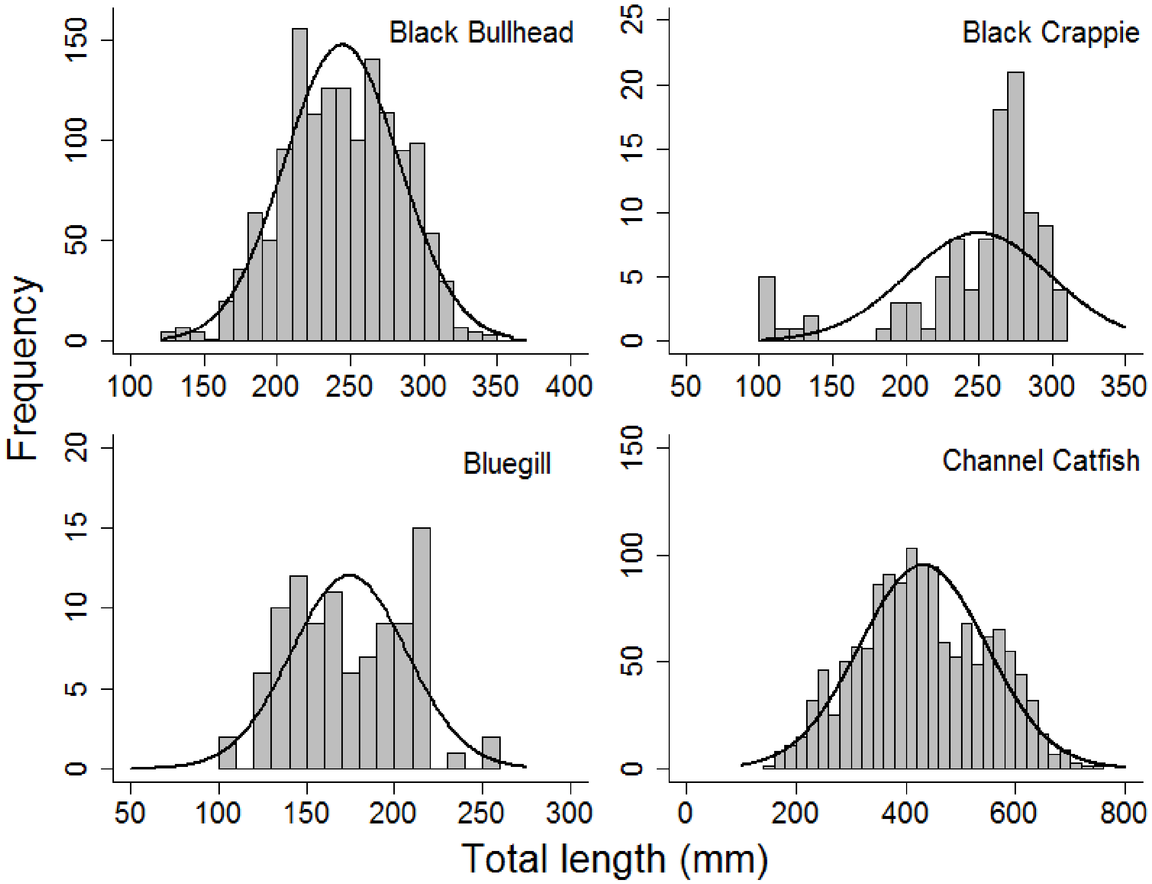

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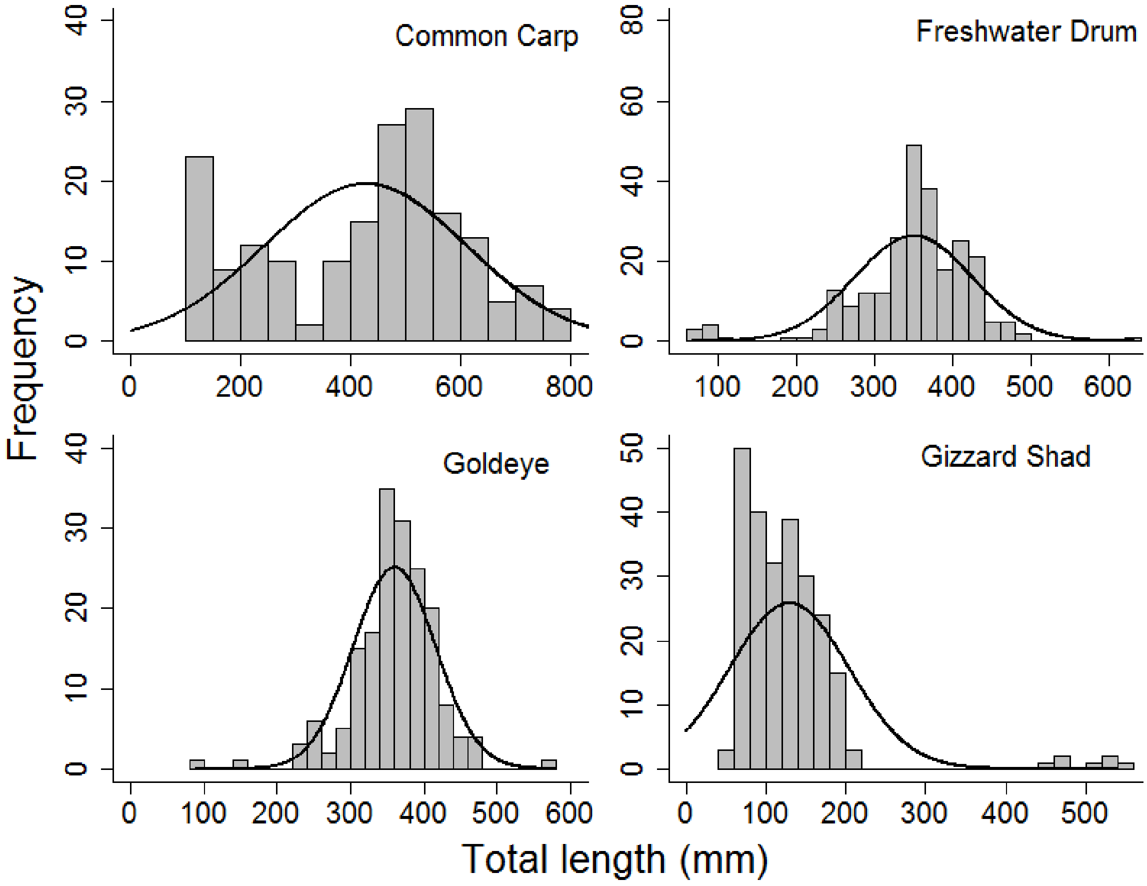

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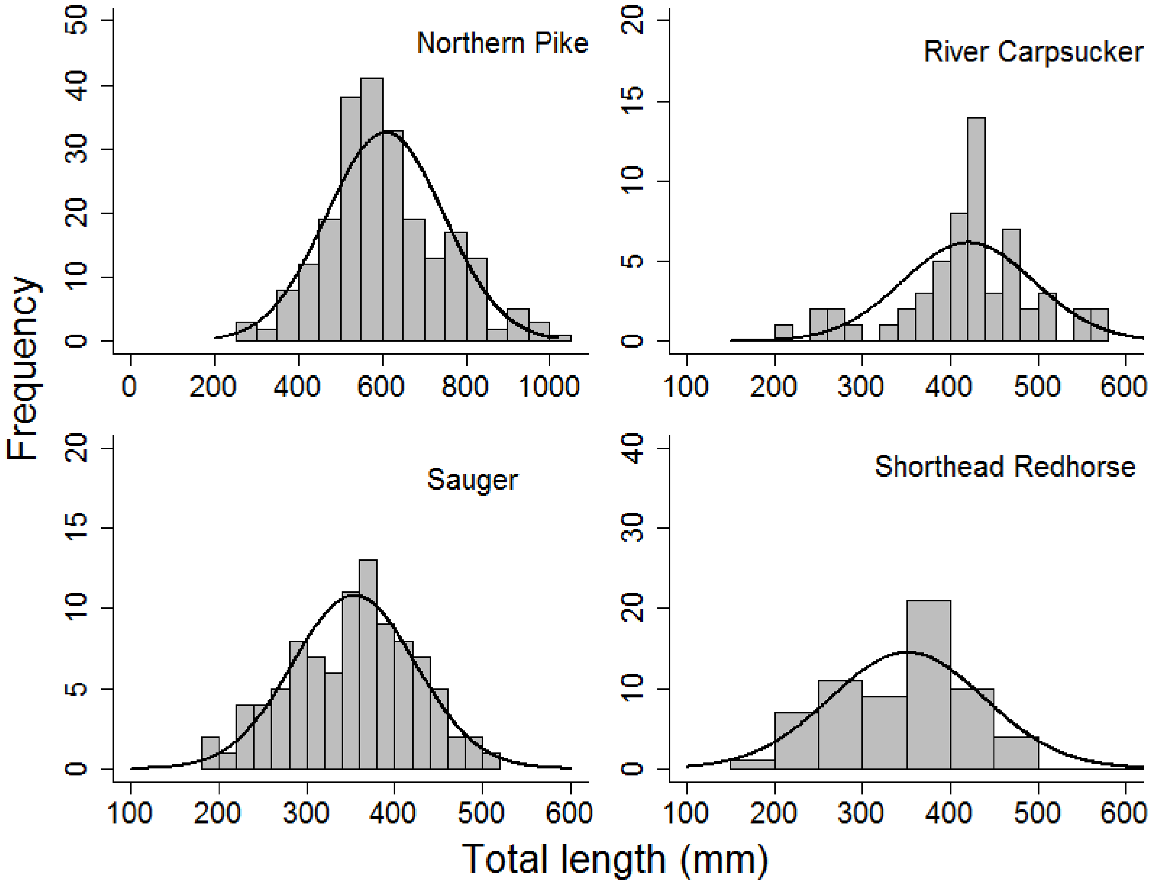

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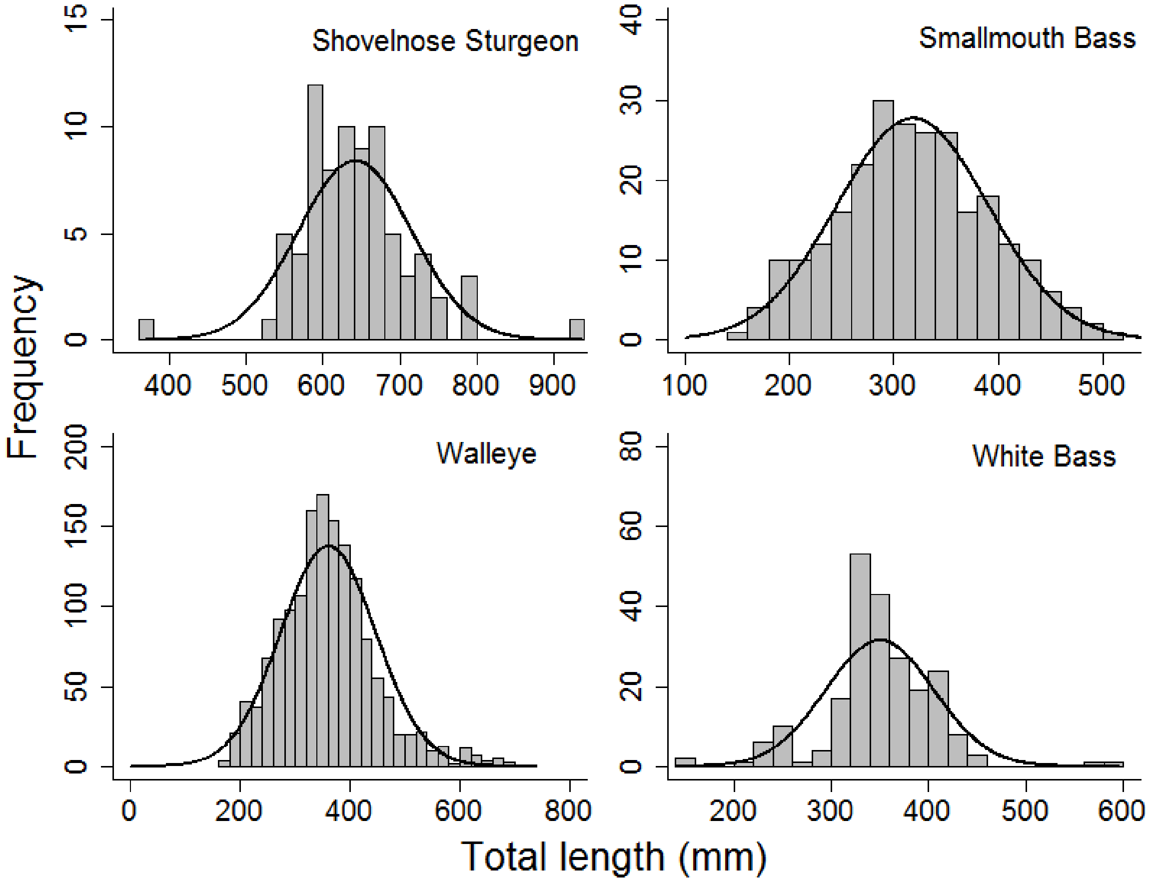

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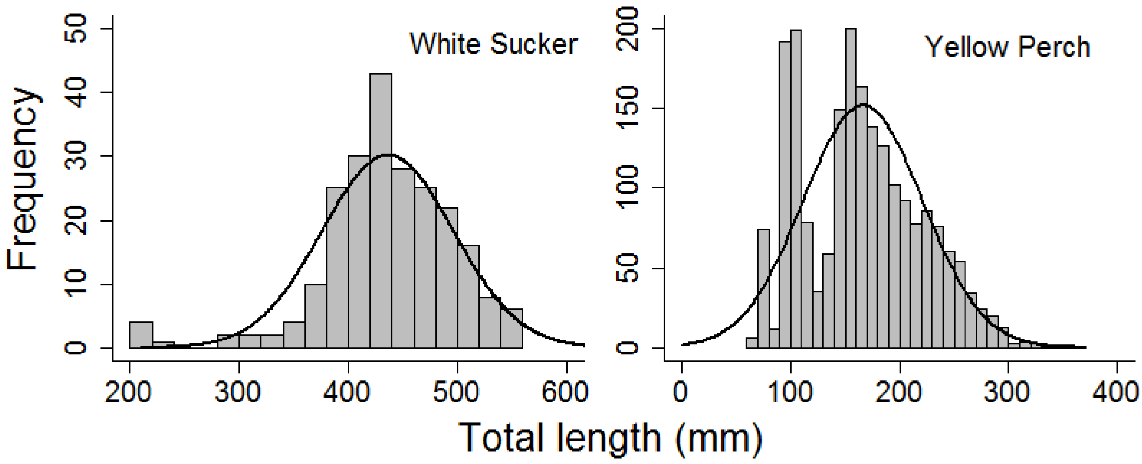

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CHAPTER 5.

ESCAPEMENT OF FISHES FROM MODIFIED FYKE NETS WITH DIFFERING THROAT CONFIGURATIONS

Abstract

Information concerning potential fish escapement from modified fyke nets with differing throat configurations is lacking. We performed a paired gear comparison and subsequent density-dependent escapement trials to identify species-specific differences in catch per unit effort, 24-hr retention and escapement, and sizes of collected fish between North American standard modified fyke nets with and without restricted throat configurations. During paired gear comparisons nets with restricted throats yielded higher estimates of CPUE for stock-length fish of the dominant species sampled. Mean total length (TL; mm) of Black Crappie *Pomoxis nigromaculatus* captured with restricted nets was 31 mm larger than unrestricted nets and 21 mm larger for Bluegill *Lepomis macrochirus*. Nets lacking throat restrictions sampled more sub-stock crappies *Pomoxis spp*. Throat configuration did not influence sizes of Black Bullheads *Ameiurus melas* captured. During escapement trials Black Bullhead retention rates were similar between restricted (48.0%) and unrestricted (53.9%) throat configurations. Retention rates were higher for Black Crappie (95.6%) and Bluegill (89.7%) in nets with restricted throats than in nets with unrestricted throats (i.e., 28.3% and 41.6% for Black Crappie and Bluegill, respectively). Mean TL of Bluegills retained in restricted nets was 9 mm larger than stocked fish while mean TL of Black Bullheads retained in unrestricted nets was 12 mm larger than stocked fish. We urge researchers to consider the influence of varying throat configurations on calculated population metrics and recommend inclusion of this feature in gear specifications for North American standard modified fyke nets.

Introduction

Many gears and techniques exist for sampling fishes and currently efforts are underway to standardize gears used to sample North American freshwater fishes to improve comparability of data (Bonar and Hubert 2002). Passive entrapment gears are common for sampling fishes in lotic and lentic systems and numerous studies have sought to identify differences in selectivity between these gear types by species (Hubert 1996). Modified fyke nets are among the most commonly used gears used to sample fishes lentic systems and have been recommended as a standard gear when sampling lentic systems (Miranda and Boxrucker 2009; Pope et al. 2009). Modified fyke nets are commonly used to capture active fish (e.g., Centrarchids, Ictalurids, Esocids, and Percids) in littoral areas of lakes and reservoirs by intercepting them with a mesh lead attached to shore and directing them towards progressively narrower mesh funnels of the net towards a terminal, or cod, end from which escape is difficult (Hubert 1996; Pope et al. 2009). However, minor differences in bar mesh size and frame diameters (Willis et al. 1984; Gritters 1997; Fischer et al. 2010) and throat diameter (Shoup et al. 2003) are known to produce bias. Information concerning the bias produced by differing throat configurations designed to reduce escapement is lacking for modified fyke nets (Porath et al. 2011).

For fish to be sampled by entrapment gear they must encounter the net, become trapped, and retained until the gear is checked (Hubert 1996). Varying levels of throat restriction can influence the ability of a net to retain fish (Hansen 1944; Porath et al. 2011). Retention and escapement of trapped fish from modified fyke nets have been quantified for several species (e.g., Brown Bullhead *Ameiurus nebulosus*, Bluegill, and

Largemouth Bass *Micropterus salmoides*) and higher escape rates were attributed to fish size and behavioral attributes (Latta 1959; Patriarche 1968). However, escapement from modified fyke nets resulting from varying throat configurations including restricted and unrestricted forms remains an often un-quantified source of bias.

Restricted throats in hoop nets reduce fish escapement by creating a physical barrier to fish trying to swim out of the cod end (Hansen 1944; Porath et al. 2011). Several common varieties of throat restrictions are used in hoop nets including a restricted form that looks like a cone constructed of twine strings that begin at the end of the throat and taper back to a ring that is secured to the terminal hoop forcing the apparatus to remain taught when the net is set (see Porath et al. 2011 for more detailed description).

Fish escapement rates may also be influenced by the presence of a predatory fish in the net. Counter intuitively, some prey fish species (i.e., Banded Killifish *Fundulus diaphanus*, Bluntnose Minnow *Pimephales notatus*, and Round Goby *Neogobius melanostomus*) are less likely to leave a net stocked with a single predator fish (i.e., Bowfin Amia calva) than a net without a predator (Breen and Ruetz III 2006). Escapement may also be influenced by density of conspecifics in the net (Patriarche 1968). Researchers in Nebraska found Channel Catfish *Ictalurus punctatus* escapement from hoop nets was largely unaffected by fish density in nets with restricted throats but without throat restrictions, escapement doubled at low fish densities and tripled at high fish densities (Porath et al. 2011).

Presence or absence and specific throat restrictions in modified fyke nets have not been specified in pre-eminent texts on freshwater sampling (e.g., *Fisheries Techniques*, Murphy and Willis 1996; *Standard Methods for Sampling North American Freshwater Fishes*, Bonar et al. 2009) leading to potential confusion. To quantify this largely unexplored source of bias associated with modified fyke nets, we performed a field experiment that compared differences in catch per unit effort (i.e., CPUE), retention and escapement, and potential size-selective bias of North American Standard modified fyke nets with and without restricted throat configurations.

Methods

Study Area – Sampling was completed at five eastern South Dakota lakes including: Pickerel Lake (June 2013), South Buffalo (June-July 2014), Mitchell (July 2014), Enemy Swim (July 2014), and Clear Lake (September 2014). Four of these study lakes are of natural glacial origin (i.e., Pickerel, South Buffalo, Enemy Swim, and Clear) and are located in northeastern South Dakota and one (i.e., Lake Mitchell) is an impoundment located in south-central South Dakota. Study lakes vary in size from 192 to 868 ha and are generally shallow and eutrophic with fish communities variously dominated by fishes of the families Percidae, Ictaluridae, Esocidae and Centrarchidae (Table 1; Stukel 2003).

Paired gear comparisons - Paired gear comparisons were performed between North American Standard modified fyke nets with and without restricted throat configurations but otherwise constructed to the specifications described in Bonar et al. (2009). The recommended North American standard modified fyke net has two frames 0.9-m by 1.8-m with four hoops of 0.77-m diameter all constructed of 10-mm rolled steel and bar mesh of 13-mm with a single throat between hoops one to three tapering to an opening of 165-mm. Restricted nets were given restricted throat configurations constructed of 24 lengths of #15 (i.e., 1.32-mm diameter) twine approximately 380-mm long while additional nets were left without this modification and identified as unrestricted (Figure 1).

Restricted nets were set adjacent to unrestricted nets at a distance of approximately 100 m within similar habitat. Effort was approximately equal between gear types on all lakes but total effort varied between lakes depending on surface area (Table 1). Nets were fished for 24 hr, lifted to remove fish and moved to a new sampling site each day for two to three consecutive days, resulting in 10-18 net nights of effort per throat type in each lake. All fish captured in either net type were measured for total length (TL; mm) then given a day-specific fin clip and placed in a net pen for use in escapement trials.

Escapement trials- During initial sampling on Pickerel Lake during 2013 re-stocking rates were not controlled for by density but rather fish were removed from the net, marked and measured, then returned to the same net at a different location. Recaptured fish were released to reduce stress-induced mortality. During 2014, restricted and unrestricted nets were set in pairs and stocked with equal densities of known length fish of several species at varying densities. We identified three ranges of density (i.e., low, medium, and high) for stocking each species commonly sampled in eastern South Dakota lakes. Density ranges were calculated from the range of non-zero North American Standard modified fyke net catches from 16 commonly sampled lakes in eastern South Dakota during 2013. Catches corresponding to the 25th percentile were judged to be low, values between the 25th and 75th percentile were medium, and catches above the 75th percentile were high. In the case of medium density we generally used the median value. These fish were randomly assigned to be stocked into restricted or unrestricted nets at prescribed densities (i.e., low, medium, high) and each net pair was stocked at the same rate. After all nets had been retrieved each day, the paired gears were re-set at new locations and stocked. At each lake, replicates of all three densities were sought for each species though small sample sizes limited replication of high density treatments in several lakes. After 24 hr all nets were lifted and fish were removed, measured, weighed, and inspected for marks and nets re-set and stocked with newly marked fish. Previously marked fish were released to reduce stress-induced mortality.

Data Analysis – Mean catch per unit effort (CPUE) was calculated for all fish captured (Total) and stock-length fish (Stock) as the number of fish captured per 24 hr set for each species and net type where at least 30 fish were sampled between both net types. Comparisons of CPUE between net types for Total and Stock data sets were performed using analysis of variance (ANOVA) and for species sampled in multiple lakes we used lake as a blocking factor. Differences in size selectivity between gears was assessed by comparing mean TL of all fish captured between net types for the three most abundant species (i.e., Black Bullhead *Ameiurus melas*, Black Crappie *Pomoxis nigromaculatus*, and Bluegill) using ANOVA with lake as a blocking factor. Retention was evaluated on a species-specific basis and was calculated as the proportion of fish marked the day before remaining in the net after 24 hr while escapement was calculated as the proportion of fish marked the day before that were absent from the net 24 hr later. Differential retention rates between net types for the three most abundant species (i.e., Black Bullhead, Black Crappie, and Bluegill) were compared between gear types using analysis of covariance (ANCOVA) with stocked fish as a covariate and recaptured fish as a response variable with individual net sets as replicates. Normality was assessed with Shapiro-Wilk tests and non-normal data were LOG(X+1) transformed. Pearson's product-moment correlation was used to investigate whether species-specific mortality was correlated with stocking density. Size-selective escape and retention were explored by comparing overall mean total lengths of fish stocked into a net to those retained in the same net the following day using an upper-tailed paired t-test. All tests assumed an α of 0.05 and computations were performed using R version 3.0.1 "Frisbee sailing" (The R Foundation for Statistical Computing, 2013).

Results

Paired Gear Comparison - Catches in both net types were dominated by Black Bullhead, Black Crappie, and Bluegill (Table 2). Channel Catfish and White Crappie were sampled only in Lake Mitchell (Table 2). Restricted nets captured significantly more stock-length Black Bullhead, Black Crappie, Bluegill, Channel Catfish, and Smallmouth Bass than unrestricted nets. In no instance did unrestricted nets yield significantly higher CPUE than restricted nets for stock-length fish. When total catch was analyzed, restricted nets still yielded higher CPUE for Black Bullhead, Bluegill, and Channel Catfish but unrestricted nets had higher CPUE for Black and White Crappies. No difference in mean TL was detected between net types for captured Black Bullhead but unrestricted nets selected for smaller Black Crappie and Bluegill (Table 3). Sample sizes of Channel Catfish, Northern Pike *Esox lucius*, Rock Bass *Ambloplites rupestris*, Walleye *Sander vitreus*, Smallmouth Bass *Micropterus dolomieu*, and White Crappie *Pomoxis annularis* were too small to warrant comparisons of size structure.

Escapement trials - Rates of 24-hr retention and escapement could only be estimated for Black Bullhead, Black Crappie, and Bluegill due to low sample sizes of other species. Combined mortality of stocked Bluegill and Black Crappie ranged from zero in Pickerel Lake to 46% in Lake Enemy Swim with higher mortality of Bluegill in restricted nets ($t = -1.89$, $df = 11$, p-value $= 0.042$) and no difference between net types for Black Crappies ($t = -0.89$, $df = 6$, $P= 0.204$). Mortalities were not correlated with stocking density for Black Crappies in restricted ($r = 0.629$, $t = 1.40$, $df = 3$, $P = 0.256$) and unrestricted ($r = -0.395$, $t = -0.744$, $df = 3$, $P = 0.511$) nets but positively correlated with stocking density for Bluegill in both restricted ($r = 0.919$, $t = 6.17$, $df = 7$, $P < 0.001$) and unrestricted ($r = 0.874$, $t = 4.401$, $df = 6$, $P = 0.005$) nets. Stock-retention relationships were plotted (Figure 2) with mortalities in the net treated as retained (i.e., Unadjusted; left panels) and where mortalities were removed from analysis altogether (i.e., Adjusted; right panels). These plots indicated that regardless of inclusion or exclusion of mortalities the same trend was observed for all three species so we used unadjusted data for further analyses. We assumed that mortalities were related to stress from handling and warm water temperatures exacerbated by inability to escape from the net. Throat configuration did not significantly influence retention rates of Black Bullhead and overall approximately half of stocked Black Bullhead escaped regardless of throat configuration. Plots of empirical Black Bullhead data show a curvilinear relationship between conspecific stocking and recapture rates for both throat configurations (Figure 2). Unlike Black Bullhead, escapement rates for Black Crappie and Bluegill were highly influenced by throat configuration (Table 4). Overall retention of Black Crappie in restricted nets was 95.6% with only 4.4% escapement while in unrestricted nets the opposite trend was observed with 28.3% retention and 71.7% escapement and this difference was significant (Table 5). Inspection of plotted data showed that nearly all Black Crappies escaped from unrestricted nets regardless of stocking density (Figure 2). A similar pattern was observed for Bluegill where restricted nets had retention rates of 89.7% with 10.3% escapement compared to unrestricted nets where only 41.6% were retained and 58.4% escaped. Smaller Bluegill tended to escape restricted nets leaving behind larger individuals and the same was true of Black Bullhead in unrestricted nets (Table 6).

Discussion

I found that modified fyke nets with restricted throats generally produced higher CPUE, selected for larger size structure, and had lower escapement rates than nets without a throat restriction. Failure to account for this bias resulting from a difference in gear construction would likely influence calculations of CPUE and potentially management decisions if throat configurations were not standardized.

Differences in CPUE between stock-length and total catch data produced conflicting results for Black and White Crappies whereby, CPUE was higher for these species in restricted nets when considering just stock-length fish, but the opposite was true when all fish captured were included. The smallest crappies (<130 mm TL) appear less likely to pass through restricted throats and more likely to swim through unrestricted throats. We caution that this observation was heavily influenced by several large catches from a few unrestricted nets in Lake Mitchell and that White Crappies were only sampled in Lake Mitchell.

Previous comparisons of varying throat configurations concluded that addition of restricted throats reduce fish escapement, though most studies have focused on Channel Catfish captured in hoop nets (Guy et al. 2009; Porath et al. 2011). Similar to these results, we found that inclusion of a restricted throat lowered escapement of several dominant fish species from North American Standard modified fyke nets. Analogous escapement rates between throat configurations for Black Bullhead were unexpected because we captured them at a higher rate in restricted nets and Porath et al. (2011) found increased escapement of ictalurids from unrestricted nets with increasing conspecific density. Black Bullheads used in escapement trials had already been in the nets overnight and may have been more adept at escapement given the extra 24-hr period after re-stocking. Our escapement trials for this species may have been improved by using a different gear for initial capture.

Lower escapement rates for Black Crappie and Bluegill from restricted nets may indicate that once these cover-seeking fish became trapped they were less willing or less able to leave than their counterparts in unrestricted nets. This interpretation is corroborated by results from a Michigan study that found fish escapement rates declined at increasing densities of conspecifics (Breen and Ruetz III 2006). Researchers have long speculated that fish are attracted to aggregations of conspecifics making passive gears particularly effective (Munro 1974). Our finding that smaller Bluegills selectively escape from restricted nets leaving behind larger individuals verifies earlier studies indicating escapement of smaller centrarchids from fyke nets (Latta 1959; Patriarche

1968). Failure to detect a similar finding for unrestricted nets was likely due to the open throat that allowed for high escapement of all Bluegills.

Due to the paired nature of our study design we are confident that differences in CPUE, escapement, and retention were due to differences in throat configurations. Our study investigated only two potential throat configurations but others exist (e.g., fingered). Future studies should investigate effectiveness of other throat configurations with different fish communities. Due to limited sample size of many species we were only able to perform in-depth analyses for Black Bullhead, Black Crappie, and Bluegill but these results may differ for other species. Miranda and Boxrucker (2009) noted that crappies and fishes of the genus *Lepomis* are among the most commonly targeted fishes when using modified fyke nets. We conclude that managers and researchers should be cognizant of the effects that varying throat configurations have on catch dynamics when sampling with the North American Standard or other modified fyke nets. When publishing gear specifications, we urge reporting of the presence or absence of throat configurations including throat diameter because all of these features have the potential to bias catches. This study demonstrates the need to not only standardize overall net dimensions but throat configuration as well when sampling freshwater fish with the North American standard modified fyke net.

Acknowledgements

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Table 1. Description of eastern South Dakota lakes sampled using restricted and unrestricted North American Standard modified fyke nets.

Lake	Surface area (ha)	Max depth (m)	Trophic state	Effort (net nights)		Sample Period	
				Restricted	Unrestricted	Month	Year
Clear	192	6.7	Mesotrophic-eutrophic	17	18	September	2014
Enemy Swim	868	7.9	Mesotrophic-eutrophic	12	13	July	2014
Mitchell	271	8.8	Eutrophic	11	11	July	2014
Pickerel	397	12.5	Eutrophic	12	12	June	2013
South Buffalo	724	4.3	Eutrophic	16	18	June-July	2013

Table 2. Number of fish captured and mean Catch Per Unit Effort (CPUE) for stock-length (Stock) and all fish (Total) captured with restricted and unrestricted modified fyke nets. Results of analysis of variance (ANOVA) comparing mean CPUE between restricted and unrestricted nets for all fish captured (Total) and stock sized fish (Stock) are shown. Lake was used as a blocking factor for all species except Channel Catfish and White Crappie. All fish were sampled in five eastern South Dakota lakes during June 2013 and June-October 2014. Asterisks denote significant differences.

		Catch		Mean CPUE					
	Species	Restricted	Unrestricted	Restricted	Unrestricted	F-value	df	Pr > F	
Stock	Black Bullhead	1937	940	52.35 ± 15.75	22.59 ± 10.97	20.35	73	< 0.001	*
	Black Crappie	385	100	6.62 ± 0.97	1.60 ± 0.24	32.30	119	< 0.001	*
	Bluegill	697	469	10.72 ± 2.08	6.20 ± 1.02	13.38	129	< 0.001	*
	Channel Catfish	51	8	10.20 ± 3.02	1.40 ± 0.87	12.20	9	0.008	*
	Northern Pike	22	16	0.92 ± 0.18	0.58 ± 0.15	2.06	47	0.159	
	Rock Bass	20	22	1.25 ± 0.37	1.38 ± 0.52	0.02	31	0.877	
	Smallmouth Bass	30	11	1.20 ± 0.17	0.44 ± 0.22	17.19	49	< 0.001	*
	Walleye	15	22	0.58 ± 0.22	0.96 ± 0.19	3.35	47	0.074	
	White Crappie	5	9	0.60 ± 0.40	1.60 ± 0.4	2.70	9	0.139	
Total	Black Bullhead	1937	942	52.35 ± 15.75	22.65 ± 10.97	19.84	73	< 0.001	*
	Black Crappie	464	601	7.29 ± 1.06	9.41 ± 3.95	4.48	125	0.036	*
	Bluegill	773	570	11.71 ± 2.40	7.15 ± 1.13	6.83	130	0.010	*
	Channel Catfish	51	8	10.20 ± 3.02	1.40 ± 0.87	12.20	9	0.008	*
	Northern Pike	22	17	0.88 ± 0.18	0.60 ± 0.14	1.41	49	0.241	
	Rock Bass	20	24	1.25 ± 0.37	1.50 ± 0.58	2.10E-03	31	0.964	
	Smallmouth Bass	38	44	1.15 ± 0.20	1.22 ± 0.36	0.36	64	0.551	
	Walleye	15	27	0.58 ± 0.22	1.04 ± 0.20	3.71	49	0.061	
	White Crappie	13	71	1.38 ± 1.02	3.75 ± 1.00	6.71	15	0.021	*

Table 3. Comparison of mean total length (TL; mm) between restricted and unrestricted modified fyke nets for Black Bullhead, Black Crappie, and Bluegill sampled in five eastern South Dakota lakes. Results of analysis of variance (ANOVA) blocked by lake are shown with asterisks denoting significant differences.

	Mean TL (mm) ± Standard error					
Species	Restricted	Unrestricted	df	F-value	Pr > F	
Black Bullhead	291 ± 6	287 ± 6	58	0.01	0.920	
Black Crappie	254 ± 7	223 ± 11	110	8.03	0.006	*
Bluegill	190 ± 4	169 ± 6	125	12.30	< 0.001	*

Table 4. Results of analysis of covariance (ANCOVA) tests identifying potential differences in slope and intercept between restricted and unrestricted forms of modified fyke nets used to sample Black Bullhead, Black Crappie, and Bluegills in five eastern South Dakota lakes. Stocking rate was the covariate and recapture rate was the response variable. Black Bullhead data was LOG(X+1) transformed due to strong deviation from normality. Asterisks denote significant differences.

Species	Parameter	df	F-value	Pr > F	
Black	β	29	3.04	0.092	
Bullhead	α	30	1.46	0.236	
Black	β	42	116.61	< 0.001	*
Crappie	α	43	15.31	< 0.001	*
Bluegill	β	56	37.59	< 0.001	*
	α	57	27.63	< 0.001	*

Table 5. Total number of fish stocked into restricted and unrestricted modified fyke nets with subsequent recaptures and associated mortalities. Escapement and retention rates for each species captured by each net type were calculated without adjustment for mortalities. Escapement trials were performed on five eastern South Dakota lakes during June 2013 and June-October 2014.

		Number				
	Species	Stocked	Retained	Mortalities	Escapement (%)	Retention (%)
Restricted	Black Bullhead	419	201	0	52.0	48.0
	Black Crappie	206	197	13	4.4	95.6
	Bluegill	341	306	72	10.3	89.7
	Channel Catfish	21	9	0	57.1	42.9
	Northern Pike	4	4	1	0.0	100.0
	Rock Bass	10	8	2	20.0	80.0
	Smallmouth Bass	36	25	5	30.6	69.4
	Walleye	7	5	0	28.6	71.4
Unrestricted	Black Bullhead	425	229	0	46.1	53.9
	Black Crappie	92	26	7	71.7	28.3
	Bluegill	305	127	37	58.4	41.6
	Channel Catfish	21	14	0	33.3	66.7
	Northern Pike	12	10	2	16.7	83.3
	Rock Bass	11	8	1	27.3	72.7
	Smallmouth Bass	19	8	3	57.9	42.1
	Walleye	9	6	1	33.3	66.7

Table 6. Mean total length (TL) of marked and retained Black Bullhead, Black Crappie, and Bluegill in restricted and unrestricted modified fyke nets. Results of upper-tailed paired t-tests using individual nets as replicates are shown with asterisks denoting significant differences.

		Mean TL (mm) ± SE		Mean of				
	Species	Marked	Retained	difference (mm)	df	t	Pr > t	
Restricted	Black Bullhead	288 ± 6	290 ± 6	2.25	15	0.60	0.279	
	Black Crappie	272 ± 5	272 ± 4	0.77	23	0.26	0.399	
	Bluegill	184 ± 5	193 ± 5	8.99	30	2.84	0.004	*
Unrestricted	Black Bullhead	284 ± 9	296 ± 10	12.30	14	3.25	0.003	*
	Black Crappie	247 ± 16	258 ± 15	11.71	12	1.00	0.168	
	Bluegill	181 ± 7	182 ± 8	0.30	20	0.04	0.483	

List of Figures

Figure 1. Depiction of restricted and unrestricted throat configurations for modified fyke nets used to compare catch, retention, escapement, and potential size-selective bias in modified fyke nets with and without restricted throats.

Figure 2. Relationship between number stocked and number of fish retained for Black Bullhead (Top), Black Crappie (Middle), and Bluegill (Bottom) sampled with restricted (i.e., solid lines, open circles) and unrestricted (i.e., dashed lines, open triangles) fyke nets. Stocking and recapture rates were not adjusted (Left) and adjusted (Right) for mortalities. Black Bullhead data was best explained by a quadratic fit while Black Crappie and Bluegill data was best explained by a linear fit. Equations are shown adjacent to their respective lines of best fit.

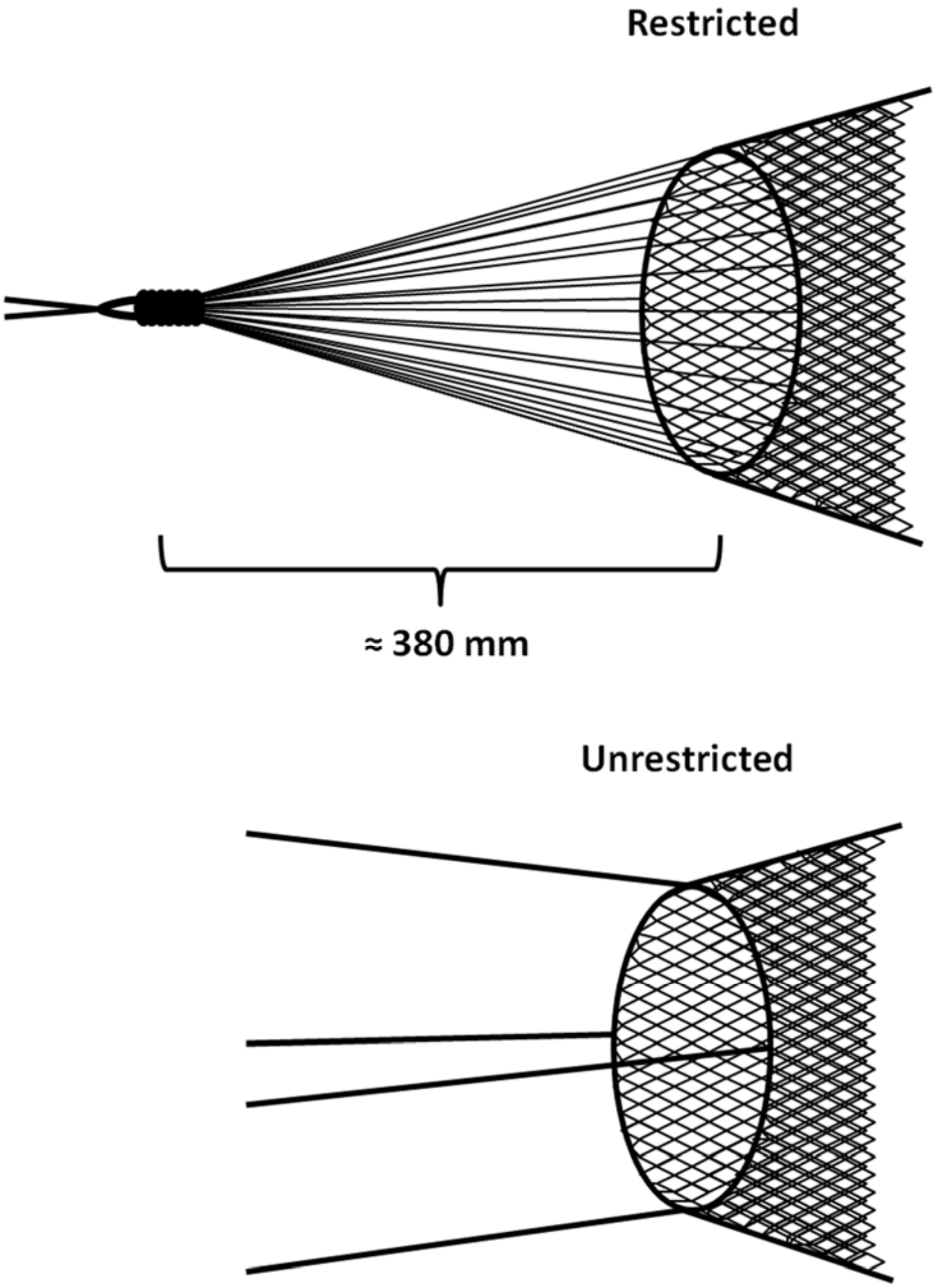

Figure 1. Smith et al., 2014

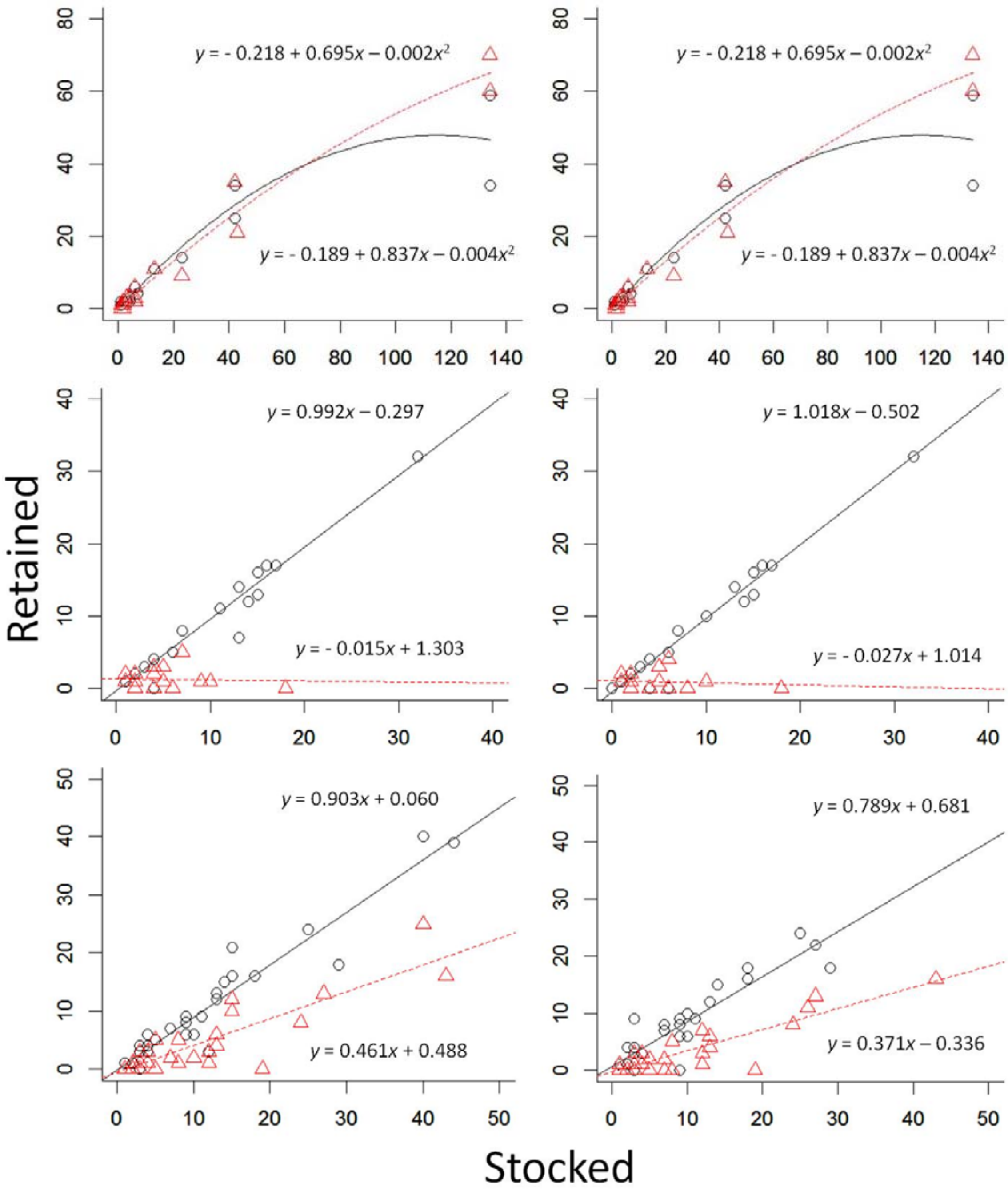

Figure 2. Smith et al., 2014

CHAPTER 6.

SUMMARY AND RESEARCH NEEDS

Comparisons between gill nets and modified fyke nets described in *Standard Methods for Sampling North American Freshwater Fishes* (Standard; Bonar et al. 2009) and current South Dakota Department of Game, Fish and Parks (SDGFP) gill nets and modified fyke nets provided the necessary information to allow for a transition to Standard gears statewide. Current SDGFP gill nets used on Missouri River (MR) and non-Missouri River (non-MR) systems were longer than Standard gill nets resulting in higher catch per unit effort (CPUE) and larger sample sizes for most species. Additional large bar-mesh panels on Standard gill nets resulted in selectivity for larger individuals of most species commonly indexed using gill nets. Walleye and Yellow Perch are most commonly indexed with gill net catch data and for these species CPUE was higher in SDGFP nets while Standard nets selected for larger individuals of both species. Measures of species diversity and evenness were similar between Standard and SDGFP gill nets used in MR and non-MR systems. Monofilament was more efficient at catching fish than current multifilament used in MR systems. Gill net CPUE data yielded reliable conversion factors for MR and non-MR systems.

Bias between Standard and SDGFP modified fyke nets was largely influenced by differences in bar-mesh size. Modified fyke nets are most commonly used in South Dakota to index abundance and size structure of Black Crappie and Bluegill. Estimates of CPUE were higher for Black Crappie and analogous for Bluegill when using Standard nets relative to SDGFP nets. Standard nets selected for larger individuals of both species despite having smaller bar-mesh size. Both net types sampled similar measures of fish diversity. Conversion factors for CPUE were most reliable for species comparisons with high adjusted r^2 values.

Selectivity of Standard gill nets is now well understood for commonly collected species. Most species exhibited bi-modal mesh-specific selectivity curves indicating capture by wedging or gilling and tangling. Most species commonly indexed using gill nets in South Dakota had bi-modal selectivities including Black Bullhead, Channel Catfish, Northern Pike, Sauger, Walleye, White Bass, and Yellow Perch. Peak modal efficiencies were approximated for each species by individual bar-mesh allowing managers to better understand mesh-specific selectivity. Mini-mesh add-ons were most useful for capture of sub-stock Gizzard Shad and Yellow Perch though capture of Yellow Perch in these mini-meshes was infrequent.

Escapement from modified fyke nets was unacceptably high in nets lacking restricted throats. Black Crappie CPUE was higher in restricted nets and they were most adept at escapement with nearly all stocked individuals managing to escape from nets lacking restricted throats. Bluegill CPUE was also higher in restricted nets and Bluegills readily escaped from unrestricted nets. Black Bullheads were caught in greater abundance using restricted nets but escapement was analogous between restricted and unrestricted nets. No consistent bias in size structure was detected between nets of differing throat types. When using modified fyke nets I recommend inclusion of a restricted throat to reduce escapement.

Conversion to standardized gears and methods was identified as a strategic goal by South Dakota Department of Game, Fish and Parks that would improve quality of annual sampling data allowing for improved fisheries management (Statewide Components Work Group 2014). Knowledge of bias between North American Standard and SDGFP gears and appropriate conversion factors for lakewide CPUE should allow for transition to North American Standard sampling gears statewide.

Several logical conclusions follow from analyses and interpretation of data collected during this study that provide an overview of what South Dakota Department of Game, Fish and Parks can expect if they transition to Standard gears. The largest difference would be lower lakewide gill net CPUE for most species due to shorter length of Standard gill nets; as a result, management objectives for CPUE would need to be modified. Simultaneously, we would expect higher estimates of PSD and PSD-P for most species sampled with gill nets. For modified fyke net data, little would change except for slightly increased CPUE and estimates of PSD and PSD-P for Black Crappie and lower CPUE for Black Bullhead. Conversion factors would allow continued use of historic data in long-term analyses. However, despite thorough examination of likely trends, there are several research questions that still need to be addressed.

Research needs:

1.) Future studies should investigate differences in precision of CPUE estimates between SDGFP and Standard gears. When Kansas Department of Wildlife, Parks, and Tourism transitioned to North American Standard methods they found poor precision of Standard nets and recommended increasing effort to index CPUE for several species (Koch et al. 2014).

2.) Related to estimates of precision there should be investigation of potential changes in effort needed to provide adequate sample sizes to calculate PSD and PSD-P, especially for gill nets used in Missouri River and non-Missouri River systems statewide.

3.) Gill net comparisons for Lake Trout and Rainbow Trout in Pactola and other Black Hills reservoirs should continue for several years to allow lake-years to be used as replicate units leading to higher confidence in regression analyses used for conversion factors.

Addressing these research questions should provide the last pieces of information necessary to facilitate a transition to Standard gears. I anticipate that information and analysis provided in this study will prove useful to researchers and managers should South Dakota Department of Game, Fish and Parks decide to adopt Standard methods.

Literature Cited

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