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Stock Density Indices: Development, Use, and Limitations

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ABSTRACT: The purposes of this paper are to review the development and assess the utility of stock density indices. Stock density indices, specifically proportional stock density (PSD) and relative stock density (RSD), were developed to quantify length-frequency data. Length categories for standardized determination of stock density indices were based on percentages of world-record length for each fish species; five-cell length categories have been proposed for many warm- and coolwater fishes, but few coldwater fishes. Both seasonal patterns in sampling data and gear-related biases can affect length-frequency data used to determine stock density indices. Stock density indices have been correlated with population dynamics (recruitment, growth, and mortality), relative abundance, and condition for many fish species; coefficients of determination typically are low, and much of the variability in the relations is unexplained. Stock density indices for predator and prey fish populations tend to be inversely related; however, inverse relations are more likely to be present in small (<50 ha) impoundments. We recommend that development of five-cell length categories for additional fish species continue to be based on established percentages of world-record length.

KEY WORDS: Proportional stock density, relative stock density, population assessment.

I. INTRODUCTION

Stock density indices, specifically proportional stock density (PSD) and relative stock density (RSD), quantify length-frequency data. Both PSD and RSD were introduced to the fisheries profession during the 1970s, and their use has proliferated. For example, in a 1985 survey undertaken by the Fisheries Management Section, American Fisheries Society (Gabelhouse et al., 1992), 34 states and 1 Canadian province reported using PSD/RSD as a standard assessment tool for at least one species of fish (Table 1). In addition, two other states used their own fish quality indices to document size structure. Despite widespread application, questions remain as to the appropriate use of these indices. The purposes of this paper are to review the history/development of stock density indices, document assessments of the indices, discuss their use and limitations, and recommend research needs.

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TABLE 1
Number of State and Provincial Conservation Agencies Reporting Use of Proportional Stock Density (PSD) or Relative Stock Density (RSD) As a Standard Tool for Assessment of Length-Frequency Data

	States or provinces using	
Species	**PSD/RSD**	**Similar index**
Warmwater fishes		
Largemouth bass	33	2
Bluegill	25	2
Smallmouth bass	20	2
Crappies	17	2
Channel catfish	8	2
Striped bass	5	0
White bass	5	2
Coolwater fishes		
Walleye	13	2
Northern pike	7	2
Yellow perch	7	2
Muskellunge	4	0
Coldwater fishes		
Rainbow trout	6	2
Brown trout	5	2
Brook trout	4	2
Lake trout	1	2

From Gabelhouse et al., 1992.

II. HISTORY/DEVELOPMENT

A. DEFINITIONS

Proportional stock density (PSD; Anderson, 1976) was defined as:

$$\text{PSD} = \frac{\text{Number of fish} \geq \text{quality length}}{\text{Number of fish} \geq \text{stock length}} \times 100$$

Relative stock density (RSD) was developed by Wege and Anderson (1978) and is calculated as:

$$\text{RSD} = \frac{\text{Number of fish} \geq \text{specified length}}{\text{Number of fish} \geq \text{stock length}} \times 100$$

1. Proportional Stock Density

Gabelhouse (1984a) summarized the early development of PSD and other stock density indices. The first uses of PSD, not yet named, can be seen in Johnson and Anderson (1974) and Anderson (1975). Anderson (1976) coined the term PSD for this size structure index and also defined "stock" length. Stock length has been variously defined as the approximate length at maturity, minimum length effectively sampled by traditional fisheries gear, and the minimum length of fish that provide recreational value. "Quality" length was defined by Anderson (1978). PSD is quite similar to the A_T value suggested by Swingle (1950). The primary difference between the two indices lies in the fact that PSD is calculated from numbers of fish, whereas A_T is determined by weight.

Stock and quality lengths were first proposed for warmwater fishes such as largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*). Anderson and Weithman (1978) defined stock and quality length as percentages of world-record fish lengths, and also recommended application to coolwater fishes such as yellow perch (*Perca flavescens*), walleye (*Stizostedion vitreum*), smallmouth bass (*M. dolomieu*), northern pike (*Esox lucius*), and muskellunge (*E. masquinongy*). The percentage ranges were based on a fish quality index developed by Weithman (1978; Figure 1). Stock length was the point at which the fish quality index came off the x-axis, and thus represents the point where a fish first has any recreational value to the angler. Quality length was the inflection point at which the fish quality index starts to climb steeply.

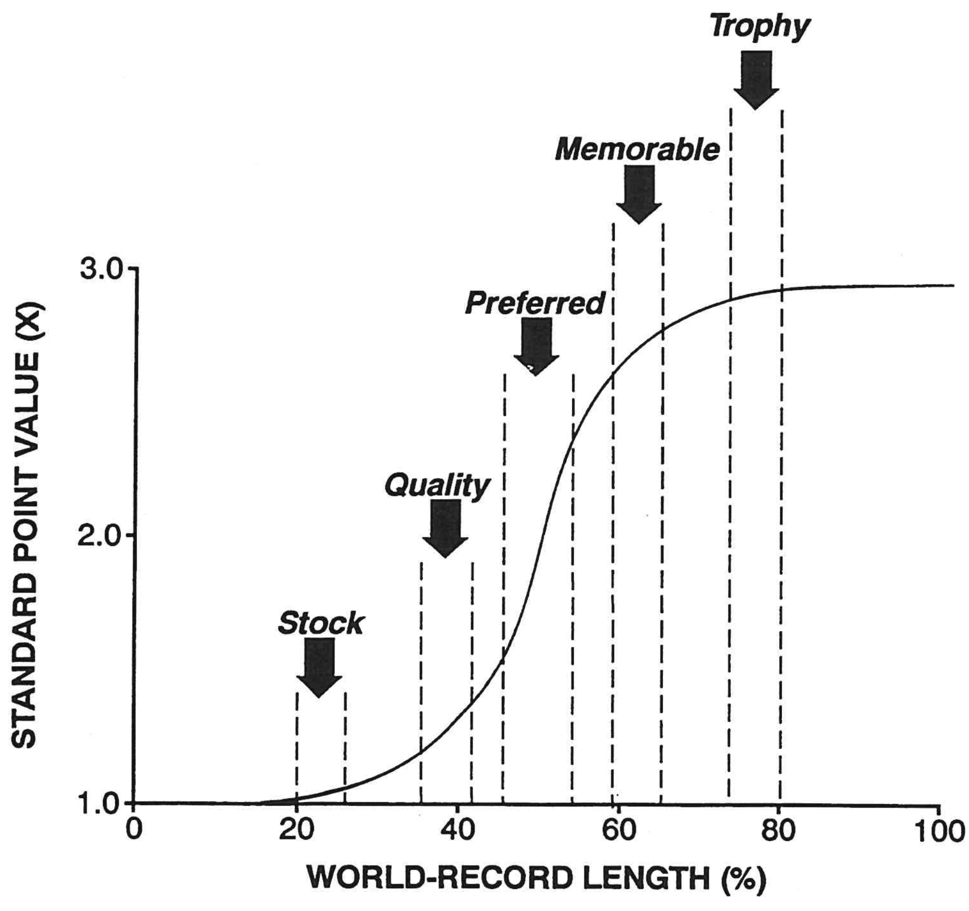

FIGURE 1. Weithman's fish quality relationship adopted by Gabelhouse to identify length ranges for his five-cell length-categorization system. The dashed lines indicate the ranges from or near which minimum stock, quality, preferred, memorable, and trophy lengths should be chosen. (Adapted from Gabelhouse, 1984a.)

For largemouth bass, minimum stock and quality lengths are 20 and 30 cm (total length). The PSD for a largemouth bass sample is the percentage of 20-cm and longer fish that also are longer than 30 cm. Anderson (1980) summarized suggested stock and quality lengths for 26 species of fish. Both PSD and RSD are unitless measures (Anderson, 1980; Anderson and Gutreuter, 1983).

Biologists need to be careful when applying stock density indices to data collected in English or metric units. Anderson and Gutreuter (1983) listed minimum lengths for metric units. However, confusion can occur during "rounding" when conversion between metric and English units occurs. For example, minimum stock length for white crappie (*Pomoxis annularis*) is 5 in. (Gabelhouse, 1984a). Stock length in metric units is standardized as 130 mm (Anderson and Gutreuter, 1983; Gabelhouse, 1984a), not 125 mm. Thus, we encourage biologists to note and use the already established values in both English and metric units, rather than converting from English to metric units by various methods of rounding.

2. Relative Stock Density

RSD was first used for largemouth bass; the "specified" length was 15 in. (38 cm), and the percentage of stock-length fish that also were 15 in. long came to be known as RSD-15. Gabelhouse (1984a) noted the need for more than a two-cell (stock and quality lengths) model for size structure analysis. His example involved discussion of two bluegill populations. Both populations had a PSD of 60, meaning that 60% of stock-length (8 cm) bluegills also were longer than quality length (15 cm). However, one population contained no bluegills over 18 cm, whereas the other contained numerous bluegills over 20 cm and a few that even exceeded 25 cm. Thus, Gabelhouse (1984a) developed a five-cell length-categorization system, again based on percentages of world-record length using Weithman's (1978) fish quality index (Figure 1).

Gabelhouse (1984a) defined the length ranges from which stock (S), quality (Q), "preferred" (P), "memorable" (M), and "trophy" (T) lengths should be chosen for 70 species of fish (the 70 include 2 hybrids and 1 family). Quality length had been defined as the size of fish most anglers like to catch (Anderson, 1980). Gabelhouse (1984a) suggested that although anglers may like to catch a fish of Q length, they would prefer to catch a larger fish (P). "Memorable" was defined as a size of fish most anglers remember catching, and T was a size considered worthy of acknowledgment. He then recommended minimum S, Q, P, M, and T lengths for 27 species (including 1 hybrid) of warm- and coolwater fish. Adoption of these five standard-length categories would facilitate communication within the fisheries profession.

Gabelhouse (1984a) did not propose five-cell length categories for coldwater fishes, although he did provide the length ranges from which appropriate categories should be chosen. Anderson and Gutreuter (1983) also did not include length categories for coldwater fishes. However, Anderson (1980) included stock and quality lengths for landlocked Atlantic salmon (*Salmo salar*), lake trout (*Salvelinus namaycush*), rainbow trout (*Oncorhynchus mykiss*), and brown trout (*Salmo trutta*); plus separate lengths for brook trout (*Salvelinus fontinalis*) in lakes and streams. We have summarized the standard length categories proposed by Gabelhouse (1984a), as well as recently proposed categories, in Table 2. All lengths recommended in this table are based on the technique originally proposed by Gabelhouse (1984a). Again,

TABLE 2

Length Categories That Have Been Proposed for Various Fish Species

	Stock		Quality		Preferred		Memorable		Trophy		
Species	**E**	**M**	**E**	**M**	**E**	**M**	**E**	**M**	**E**	**M**	**Ref. or Developer**
Freshwater drum	8	20	12	30	15	38	20	51	25	63	Gabelhouse (1984a)
Walleye	10	25	15	38	20	51	25	63	30	76	Gabelhouse (1984a)
Sauger	8	20	12	30	15	38	20	51	25	63	Gabelhouse (1984a)
Walleye × sauger	9	23	14	35	18	46	22	56	27	69	Flammang et al. (in press)
Yellow perch	5	13	8	20	10	25	12	30	15	38	Gabelhouse (1984a)
Largemouth bass	8	20	12	30	15	38	20	51	25	63	Gabelhouse (1984a)
Smallmouth bass, spotted bass	7	18	11	28	14	35	17	43	20	51	Gabelhouse (1984a)
White crappie, black crappie	5	13	8	20	10	25	12	30	15	38	Gabelhouse (1984a)
Rock bass, redear sunfish	4	10	7	18	9	23	11	28	13	33	Gabelhouse (1984a)
Bluegill, green sunfish, warmouth, pumpkinseed	3	8	6	15	8	20	10	25	12	30	Gabelhouse (1984a)
Striped bass (landlocked)	12	30	20	51	30	76	35	89	45	114	Gabelhouse (1984a)
White bass × striped bass	8	20	12	30	15	38	20	51	25	63	Gabelhouse (1984a)
White bass	6	15	9	23	12	30	15	38	18	46	Gabelhouse (1984a)
Yellow bass	4	10	7	18	9	23	11	28	13	33	Anderson and Gutreuter (1983)
White perch	5	13	8	20	10	25	12	30	15	38	Gabelhouse (1984a)
Blue catfish	12	30	20	51	30	76	35	89	45	114	Gabelhouse (1984a)
Channel catfish	11	28	16	41	24	61	28	71	36	91	Gabelhouse (1984a)
Flathead catfish	14	35	20	51	28	71	34	86	40	102	Quinn (1989)
Black bullhead	6	15	9	23	12	30	15	38	18	46	Gabelhouse (1984a)
Yellow bullhead	6	15	9	23							Anderson (1980)
Common carp	11	28	16	41	21	53	26	66	33	84	Gabelhouse (1984a)
Muskellunge	20	51	30	76	38	97	42	107	50	127	Gabelhouse (1984a)
Northern pike	14	35	21	53	28	71	34	86	44	112	Gabelhouse (1984a)
Chain pickerel	10	25	15	38	20	51	25	63	30	76	Gabelhouse (1984a)
Chinook salmon (landlocked)	11	28	18	46	24	61	30	76	37	94	Hill and Duffy (1993)
Rainbow trout	8	20	13	33							Anderson (1980)
Lake trout	12	30	20	50	26	65	31	80	39	100	Hubert et al. (submitted)
Brook trout (streams)	5	13	8	20							Anderson (1980)
Brook trout (lakes)	8	20	13	33							Anderson (1980)
Brown trout (streams)	6	15	9	23	12	30	15	38	18	46	C. L. Milewski, Minnesota DNR
Gizzard shad	7	18	11	28							Anderson and Gutreuter (1983)
Paddlefish	16	41	26	66	33	84	41	104	51	130	Brown and Murphy (1993)

Note: All measurements are total length, except for paddlefish (body length = anterior edge of eye to fork of tail). E = English (in.); M = metric (cm).

we recommend that biologists use the proposed lengths rather than creating minor variations caused by "rounding."

B. ***TRADITIONAL VS. INCREMENTAL RSD***

Gabelhouse (1984a) discussed two systems of RSD calculation: traditional and incremental. Traditional RSD values are calculated as the percentages of stock-length fish that also are longer than the defined minimum lengths for size categories. Thus, traditional RSDs are PSD [which actually is the relative stock density of quality-length fish (RSD-Q)], and relative stock density of preferred-length (RSD-P), memorable-length (RSD-M), and trophy-length (RSD-T) fish. Preferred length for largemouth bass is 38 cm; therefore, RSD-P is equivalent to the RSD-15 of Wege and Anderson (1978). Incremental RSDs determined the percentage of stock-length fish consisting of individuals between the minimum lengths for size categories. Thus, incremental RSDs are relative stock density of stock- to quality-length (RSD S-Q), quality- to preferred-length (RSD Q-P), preferred- to memorable-length (RSD P-M), memorable- to trophy-length (RSD M-T) fish, plus RSD-T. See Gabelhouse (1984a) for further information on the calculation of traditional and incremental RSDs.

A common mistake in the reporting of stock density indices involves incremental RSDs. We remind biologists that S length is a minimum length, and includes all fish of that length and longer. Thus, RSD S-Q correctly identifies the percentage of stock-length fish that are from stock to quality length, not RSD of S fish. The latter actually infers all stock-length fish and is always equal to 100. Similarly, RSD-Q is the percentage of stock-length fish that also are longer than quality length; this is *not* equivalent to RSD Q-P (and is actually the same as PSD).

When a biologist undertakes long-term monitoring of a single water body, the ability to recognize variable year-class strength is important. The use of incremental RSDs will allow the biologist to see the effects of strong or weak year classes on length-frequency data. Gabelhouse (1984a) suggested that traditional RSDs are best used for among-lake comparisons, such as an assessment of the relationship between population density and PSD, where lessening the effects of variable year-class strength would be helpful. In addition, we suggest that traditional RSDs would be more useful for one-time or first-time assessments of a particular fish population. Again, effects of variable year-class strength on stock density indices would be lessened, and comparison of the indices to desired objective ranges could be made.

III. ***USE OF STOCK DENSITY INDICES***

As mentioned in Section I, 34 states and 1 Canadian province reported using PSD or RSD for at least 1 species in a 1985 survey (Gabelhouse et al., 1992). The most frequent use of PSD was for largemouth bass and bluegills (Table 1). This is not surprising because the indices were developed, and the first assessments were completed, for those species. For the warmwater species in Table 1, an average of 18 states and provinces used PSD or a similar index. Despite recommendations by Anderson and Weithman (1978) that PSD could be used for evaluation of coolwater populations, only an average of ten states and provinces applied PSD for coolwater assessments. For coldwater species, the average number of states or provinces using PSD declines even further to six.

At present, we seem to encounter two schools of thought on the use of stock density indices. At one extreme, some biologists are firmly convinced that stock density indices reflect both the fish population structure (form) and the dynamics or function (recruitment, growth, and mortality). In some cases, those biologists believe that stock density indices alone can be used to reliably assess populations and communities. At the other extreme are biologists who are just as firmly convinced that stock density indices have no utility whatsoever. We hope to demonstrate that a "middle-of-the-road" approach to use and interpretation of stock density indices would be in the best interest of our profession. Thus, we have chosen to discuss factors that contribute to the proper use of stock density indices as a fisheries assessment tool.

IV. SAMPLING CONSIDERATIONS

Unbiased length-frequency samples are an assumption of many standard analysis techniques used by fisheries biologists. Ideally, such tools as age structure, mortality rates, size (length) structure, and stock density indices would best be calculated from a random sample of the entire population. In reality, many factors affect sampling data. Three of the more important size-related biases result from seasonal patterns in sampling data, gear-related length selectivity, and selection of sampling sites.

A. SEASONAL INFLUENCES

Seasonal patterns in size structure indices for warmwater fishes in impoundments follow a bimodal pattern, with "peaks" in the spring and fall and a "trough" in summer. Carline et al. (1984) in Ohio, Gilliland (1985) in Oklahoma, and Bettross and Willis (1988) in South Dakota reported this pattern for largemouth bass electrofishing PSD from spring to fall, as did Jakes (1987) from spring to late summer in Georgia. Bettross and Willis (1988) also observed a bimodal pattern in PSD for bluegills collected by electrofishing and trap netting. Boxrucker and Ploskey (1988) reported that size structure of white crappie was appropriately represented by spring and fall fyke net samples in Oklahoma. However, McInerny (1988) reported that RSD of black crappie caught in trap nets was higher in spring than fall. An obvious question is whether the peaks or troughs depict the true size structure of fish populations. Van Den Avyle (1976), Reynolds and Simpson (1978), Simpson (1978), Brenner and Noble (1982), Carline et al. (1984), Gilliland (1985), and Mesa et al. (1990) all inferred that spring or fall peaks reflect the true size structure of populations.

Serns (1985) noted that the PSD of spawning walleye (*Stizostedion vitreum*) populations collected by fyke nets would be low early and late in the spawning period because of the abundance of small males. During the height of the spawn, PSD would be higher because females would be more abundant at that time. Mero and Willis (1992) used experimental gill nets to obtain monthly samples of walleyes and saugers (*Stizostedion canadense*) in Lake Sakakawea, North Dakota. Both PSD and RSD-P were highest in spring and fall and lowest during summer samples. We are aware of no work concerning seasonal patterns in size structure for coldwater fishes.

B. GEAR-RELATED BIASES

Size-related biases in data also can result from gear selectivity. Reynolds and Simpson (1978) reported that electrofishing was progressively more effective as the length of largemouth bass increased. However, Reynolds (1983) noted that the overestimation was slight when only stock-length (200 mm) fish were considered. Electrofishing also underestimates the size structure of bluegill (Reynolds and Simpson, 1978) and smallmouth bass (Milewski and Willis, 1991) populations.

Laarman and Ryckman (1982) found that trap nets were selective for larger sizes of rock bass (*Ambloplites rupestris*), walleye, black crappie (*Pomoxis nigromaculatus*), bluegill, yellow perch (*Perca flavescens*), and pumpkinseed (*Lepomis gibbosus*). They did not find significant size selectivity for smallmouth bass and white sucker (*Catostomus commersoni*).

Mesh-size selectivity of gill nets causes small fish to be less effectively sampled than larger fish (Hamley, 1975). Thus, size structure is likely overestimated for most fishes that are effectively sampled with gill nets. However, biases in length frequency due to mesh-size efficiency (i.e., the length range of fish effectively sampled by a particular mesh size) of gill nets will vary depending on the complement of mesh sizes chosen to sample a fish population (Willis et al., 1984).

Size structure is underestimated for most species of fish collected by cove rotenone sampling (Hayne et al., 1967). However, that bias is probably due to the typical late summer sampling time for the technique. Larger individuals of many species are no longer near shore during late summer. Barwick (1984) showed that more representative samples would be collected in May than in August. Bayley and Austen (1988) reported that retrieval efficiencies for marked fish increased with length for both rotenone and detonating cord in ponds and cove enclosures. Thus, the typical underestimation in size structure during cove samples in late summer is likely due to fish behavior and movement patterns.

Use of angler-collected data for making management decisions is becoming more popular and prevalent (Guthrie et al., 1991). Again, length-related biases must be considered before interpretation of any type of length-frequency data, including stock density indices. Data from bass tournaments are a readily available source of information (Shupp, 1978; Durocher, 1978; Van Horn and Birchfield, 1981; Chapman and Fish, 1983; Duttweiler, 1985; Willis and Hartmann, 1986; Dolman, 1991). Gabelhouse and Willis (1986) found that tournament anglers in Kansas selected for larger sizes of largemouth bass; stock density indices calculated from angler-collected data were overestimated compared to electrofishing samples. Angler diaries also have proven to be a useful technique for collecting fisheries data (Green et al., 1984). Ebbers (1987) reported that largemouth bass data supplied by anglers keeping diaries had a size structure similar to electrofishing samples. Anderson (1985) listed objective ranges for PSD of largemouth bass and bluegill caught by angling for various pond management strategies that could be used by Missouri pond owners.

C. SELECTION OF SAMPLING SITES

Biologists often choose subjective sampling sites based on the likelihood of capturing target species. One justification for such a technique is that greater sample size generally can be obtained with less effort. However, Hubbard and Miranda (1986) found that PSD and RSD of largemouth bass samples were overestimated when electrofishing took place in subjectively selected sites compared to randomly selected sites. Therefore, biologists should balance the need for sufficient sample size at lowest necessary effort with the potential for resulting size structure bias.

The biases we have discussed do not preclude the proper use of stock density indices. Many other assessment tools used by fisheries biologists also can be affected by biased samples. A good example would be mortality rates. Length-related biases due to sampling gear or seasonal influences would result in overestimation or underestimation of mortality rates. Biologists should be aware of these biases, deal with as many as possible by selection of appropriate sampling gear and date, and carefully interpret their data with consideration of the biases. Similarly, biased length-frequency data can be useful as trend data over time, as long as a biologist properly interprets these data.

D. SAMPLE SIZE

Sample size is an important consideration when using stock density indices to quantify length-frequency data and assess fish populations. In our opinion, people often calculate stock density indices from insufficient sample sizes. For example, few biologists would think of showing a length-frequency histogram from a sample of 13 fish — especially in a refereed publication. However, biologists are often willing to calculate, report, and use a PSD from that sample of 13 fish. Two methods are available to easily determine whether sufficient sample size has been obtained to reliably calculate stock density indices. Weithman et al. (1979) reported a method by which sequential samples of a fish population could be assessed for reliability using confidence intervals. Once the sample was deemed reliable, sampling could stop. Management biologists may not have the time available to sequentially assess their samples and determine whether more effort is needed. Often, a certain effort is allotted to a body of water, and the resulting data must be assessed. Thus, we suggest that biologists under such constraints use the tables provided by Gustafson (1988) to obtain confidence intervals for stock density indices. Weithman et al. (1979) described the calculation of confidence intervals, and Gustafson (1988) provided tables for simple estimation of 80 or 95% confidence intervals that can be used for PSD or any other RSD. Biologists using these confidence intervals would at least know how much confidence to place in their data and what type of change would have to occur to statistically indicate a change in the population size structure.

V. STOCK DENSITY INDEX CORRELATIONS

A. SINGLE SPECIES CORRELATIONS

An appropriate question concerning the use of stock density indices is whether they reflect the density and dynamics of fish populations. In some situations, the answer is certainly yes (Table 3). As the density of a population increases, the PSD tends to decrease — especially after the population reaches carrying capacity. However, low PSD also can occur at low population density because of problems with poor habitat, food supply, or angler overharvest (Gabelhouse, 1984a). As growth increases, there is a tendency for PSD to increase. As total annual mortality increases, there is a tendency for PSD to decrease. In situations where recruitment is high enough to result in overpopulation, PSD values will be low. Where recruitment is low enough that populations remain below carrying capacity, PSD can be high. These relationships are most likely to be found in similar environments in single geographic areas. Good examples are provided by the Central States Small Impoundment Work Group (formerly Central States Pond Management Work Group) studies on largemouth bass and bluegills (Novinger and Legler, 1978; Reynolds and Babb, 1978) and largemouth bass and crappies (Gabelhouse, 1984b). Those studies were completed in similar environments (small impoundments) in a specific region of the U.S. (midwest). Guy and Willis (1990) noted that largemouth bass PSD ($r = 0.86$, $p = 0.0002$) and RSD-P ($r = 0.70$, $p = 0.009$) were correlated with mean length of largemouth bass in South Dakota ponds.

Variations in factors such as productivity and growing season also can preclude establishment of a clear relationship between stock density indices and population parameters. In fact, these factors also may help explain the wide variability found in the relationships reported in Table 3. Coefficients of determination typically are low, and much variability in the relationships is unexplained.

Based on modeling results, Carline et al. (1984) suggested that PSD increased linearly with survival, but increased curvilinearly with growth. Willis and Scalet (1989) found that curvilinear regressions provided a better fit for PSD and growth of northern pike; however, the improvement in correlation coefficients was slight.

B. PREDATOR-PREY RELATIONSHIPS

Another question concerning the use and interpretation of stock density indices revolves around the possible inverse relationship between size structure of predator and prey populations. We have summarized the correlations between predator and prey size structure that we are aware of in Table 4. All the examples deal with largemouth bass as the predator species. In small impoundments, largemouth bass PSD tends to decline as bass density increases. As largemouth bass density increases, predation on "panfish" tends to increase. Therefore, panfish PSD tends to increase as largemouth bass density increases and an inverse relationship between PSD of predator and prey species results.

Carline et al. (1984) suggested that the likelihood of an inverse relationship declined as impoundment size increased and fish community complexity increased.

TABLE 3

Correlation Coefficients (r) between Proportional Stock Density and Density, Relative Abundance, Condition, or Rate Functions for Single Species as Reported by Various Authors

Species	Density	CPUE[a]	Wr[b]	Recruitment	Growth	Mortality	Ref.
Largemouth bass	Inverse[c]					-0.64	Reynolds and Babb (1978)
		-0.85					Gabelhouse (1984b)
		-0.70					Guy and Willis (1990)
		-0.98					Saffel et al. (1990)
					0.69[d]	-0.52[d]	Miranda (1983)
			-0.75[e]				Wege and Anderson (1978)
		-0.79					Boxrucker (1987)
Bluegill				-0.85	0.87		Novinger and Legler (1978)
Crappies			0.90				Gabelhouse (1984b)
Northern pike			0.59[f]		0.96[g]		Willis and Scalet (1989)
Walleye			0.36				Murphy et al. (1990)
Sauger			0.38				Guy et al. (1990)
Yellow perch			0.27[h]		0.85[i]		Willis et al. (1991)
Brook trout	-0.76		0.81				Johnson et al. (1992)

[a] *CPUE = catch per unit effort.*

[b] *Wr = relative weight.*

[c] *Correlation coefficient not reported.*

[d] *The coefficient of determination for a two-variable multiple regression model with PSD as the dependent variable and growth and mortality as independent variables had $R^2 = 0.71$*

[e] *This correlation was reported for relative stock density of stock- to quality-length fish, which is the complement of PSD (the two always add to 100).*

[f] *The correlation coefficient increased to 0.75 for spring samples only.*

[g] *Correlation coefficients ranged from 0.78 to 0.96 for correlations between PSD and length-at-age data.*

[h] *The correlation coefficient increased to 0.80 for fall samples only.*

[i] *Correlation coefficients of PSD with various growth data ranged from 0.11 to 0.85.*

TABLE 4

Summary of Correlation Coefficients (*r*) between Stock Density Indices of Predator or Prey Species and Other Parameters

Predator		Prey			
Species	**Parameter**	**Species**	**Parameter**	***r***	**Ref.**
Largemouth bass	CPUE	Bluegill	PSD	0.71	Guy and Willis (1990)[a]
	PSD		PSD	–0.83	Guy and Willis (1990)
	RSD-P		Growth	–0.64	Guy and Willis (1990)
Largemouth bass	PSD	Crappie	PSD	–0.85	Gabelhouse (1984b)[b]
	RSD-P		PSD	–0.84	Gabelhouse (1984b)[b]
Largemouth bass	PSD	Crappie	CPUE	0.73	Boxrucker (1987)[c]
	RSD-P		CPUE	0.88	Boxrucker (1987)[c]
	CPUE		PSD	0.56	Boxrucker (1987)[c]
	PSD		PSD	–0.56	Boxrucker (1987)[c]
Largemouth bass	CPUE	Yellow perch	PSD	0.81	Guy and Willis (1991a)[d]
	PSD		PSD	–0.82	Guy and Willis (1991a)[d]
	PSD		Growth	–0.95	Guy and Willis (1991a)[d]
Largemouth bass	PSD	Black bullhead	Mean length	–0.81	Saffel et al. (1990)[e]

Note: *PSD = proportional stock density; RSD-P = relative stock density of preferred-length fish; CPUE = catch per unit effort*

[a] *Impoundment size 1.2–5.1 ha.*
[b] *Impoundment size 0.6–10.5 ha.*
[d] *Impoundment size 3–106 ha.*
[d] *Impoundment size 0.9–27.9 ha.*
[e] *Impoundment size 1.3–6.1 ha.*

In one of their assessments, they used 15 ha as the breakpoint at which expected inverse relationships between size structure of largemouth bass and bluegills could be expected. Gabelhouse (1984c) documented a case history in 34-ha Cowley State Fishing Lake (an impoundment), Kansas, where the fish community was dominated by a high-density largemouth bass population with low PSD and a bluegill population with high PSD. Willis and Guy (1991) reported similar case histories for a largemouth bass/bluegill community in 55-ha Lake Louise, South Dakota, and for a largemouth bass/yellow perch community in 28-ha Perch Lake (both waters are impoundments).

The bottom line on most of the correlations we have presented is that most have quite a bit of unexplained variability. We contend that these correlations indicate that stock density indices are useful tools not only to reflect size structure, but also to reflect density and the rate functions. However, because of the inherent variability and possible confounding factors, stock density indices should be used in combination with other assessment tools to properly evaluate a fish population or community. Such tools might include simple indices such as catch per unit effort (CPUE; Hubert, 1983) and fish condition (e.g., relative weight; Murphy et al., 1991), or more time-consuming analyses such as growth assessment and population or biomass estimates.

VI. INTERPRETATION OF STOCK DENSITY INDICES

Fishery managers often wish to evaluate fish populations by comparison of stock density indices to generally accepted objective ranges for balanced populations. Anderson and Weithman (1978) indicated that "balanced populations have a structure that is intermediate between the extremes of a large number of small fish and a small number of large fish. For the structure of a fish population to be balanced, the rates of reproduction, growth, and mortality must be satisfactory." We have summarized objective ranges for balanced fish populations in Table 5. In most cases, these objective ranges were obtained from simple models that used characteristic rates of recruitment, growth, and mortality to predict population size structure.

We wish to stress that not all populations are managed for "balance." In some situations, managers may determine that stock density index values outside the balanced range are appropriate. For example, Gabelhouse et al. (1982) suggested that largemouth bass and bluegills in small impoundments may be managed for balance, or for the "panfish option" or "big bass option" (Table 6). In the panfish option, the quality (size) of largemouth bass is sacrificed to produce a higher quality bluegill population. A high-density, slow-growing largemouth bass population preys upon bluegill reproduction, and surviving bluegills have faster growth rates and reach sizes of interest to anglers. In such communities, largemouth bass PSD should be 20 to 40 and bass RSD-P should be 0 to 10; bluegill PSD should be 50 to 80 and RSD-P should be 10 to 30. In the big bass option, the management strategy is to produce fewer, larger largemouth bass, resulting in less predation on bluegills. Bluegill size structure then shifts toward smaller fish. Largemouth bass PSD should be 50 to 80 (RSD-P = 30 to 60) and bluegill PSD 10 to 50 (RSD-P = 0 to 10) in impoundments managed under this option.

Stock density indices provide more interpretative information when populations are relatively "steady-state," i.e., where recruitment, growth, and mortality remain somewhat constant. If density is high, recruitment is moderate to high, growth is relatively slow, and mortality is high (at least at a certain age), then PSD will be low. If density is low, growth is moderate to fast, recruitment is low, and mortality is low to moderate, then PSD will be high. These scenarios obviously assume no angler overharvest and a desirable habitat.

In other situations, the indices provide less information. As one example, a low-density, fast-growing population may consistently have a low PSD if angler harvest is excessive. To discern whether a low-PSD population is overharvested or over-populated, other assessment tools are necessary. Again, such tools could include CPUE, condition, or growth assessment. As another example, PSD will provide little interpretive information on population rate functions when recruitment is inconsistent. Populations with inconsistent recruitment are common in the shallow glacial lakes of eastern South Dakota. Guy and Willis (1991b) sampled black crappies monthly during 1990 in Lake Madison, South Dakota, using trap (modified-fyke) nets. They expected to see peak CPUE and PSD during spring and fall samples, as noted by Boxrucker and Ploskey (1988). The expected seasonal pattern in CPUE was present; catches were highest in spring and fall, and lower in mid-summer. However,

TABLE 5
Generally Accepted Stock Density Index Ranges for Balanced Fish Populations

Species	PSD	RSD-P	RSD-M	Ref.
Largemouth bass	40–70	10–40	0–10	Gabelhouse (1984a)
Bluegill	20–60	5–20	0–10	Anderson (1985)
Crappies in midwestern ponds	30–60	>10		Gabelhouse (1984b)
White crappies in Kansas reservoirs	40–70	10–40	0–10	Willis (1984)
White bass	40–70	10–40	0–10	Willis (1984)
Walleye	30–60			Anderson and Weithman (1978)
Northern pike	30–60			Anderson and Weithman (1978)
Yellow perch	30–60			Anderson and Weithman (1978)

Note: PSD = proportional stock density; RSD-P = relative stock density of preferred-length fish; RSD-M = relative stock density of memorable-length fish.

TABLE 6
Stock Density Index Objective Ranges for Largemouth Bass and Bluegills under Three Different Management Strategies

	Largemouth bass			Bluegill	
Option	PSD	RSD-P	RSD-M	PSD	RSD-P
Panfish	20–40	0–10		50–80	10–30
Balance	40–70	10–40	0–10	20–60	5–20
Big bass	50–80	30–60	10–25	10–50	0–10

Note: The largemouth bass objective ranges were provided by Gabelhouse (1984a). The bluegill objective ranges for balanced populations were provided by Anderson (1985), while bluegill objective ranges for the panfish and big bass options are proposed here after consultation wtih D. W. Gabelhouse (personal communication, Kansas Department of Wildlife and Parks, Emporia).

no such bimodal pattern was observed for PSD (Figure 2). Further investigation indicated that nearly all stock-length (≥13 cm) black crappies were from the 1988 year class. Thus, PSD in the spring was 3 and mean length was 181 mm. By fall, PSD had increased to 100 and mean length has increased to 244 mm. The large increase in PSD was due to growth of the single cohort in the adult population.

VII. SUMMARY AND RESEARCH NEEDS

At the least, stock density indices can be used to quantify size structure for fish populations. Acceptance of the five-cell length categorization model proposed by Gabelhouse (1984a) would ease communication within the fisheries profession. At the most, stock density indices reflect the population rate functions of recruitment, growth, and mortality. However, these interpretations have been most successful in populations with relatively consistent recruitment and those without angler over-exploitation. Where recruitment is inconsistent or populations overharvested, PSD

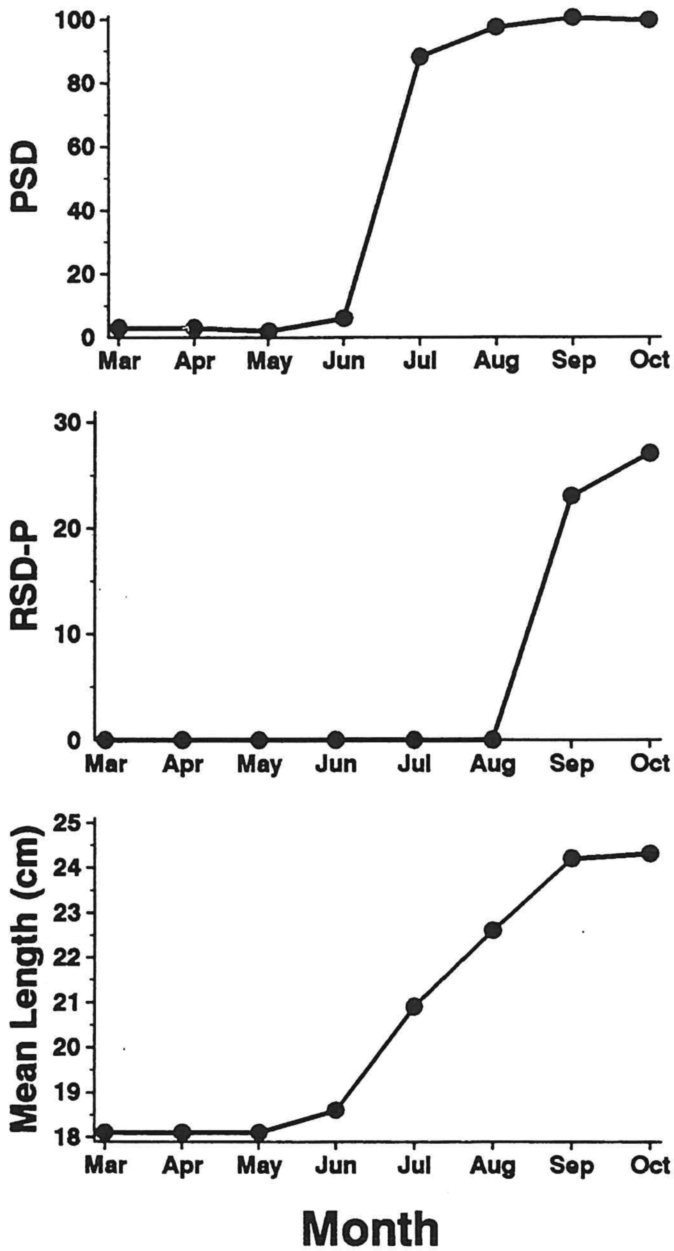

FIGURE 2. Changes in proportional stock density (PSD), relative stock density of preferred-length fish (RSD-P), and mean length for stock-length (≥13 cm) black crappies in Lake Madison, South Dakota, 1990. The 1988 year class represented nearly the entire adult black crappie population. Sample size each month ranged from 158 to 979 fish, and was based on 17 to 20 trap net nights of effort each month.

alone will provide little interpretive information on density, growth, and mortality. Therefore, fishery managers should use stock density indices as only one of the assessment tools in their "arsenal." By combining size structures indices with other tools such as CPUE, fish condition, and growth assessment, population and community analyses will be more reliable.

We see two primary research needs involving stock density indices. First, there is a need to apply stock density index assessment to coldwater populations and assess the interpretive value. Work with brook trout in small Wyoming beaver ponds has been quite encouraging (Johnson et al., 1992). The application to coldwater populations may be a complex task, as tremendous differences among coldwater populations can occur as habitat changes from small streams, to larger rivers and lakes, and to the ocean for anadromous species. Gabelhouse (1984a) did provide the ranges from which stock, quality, preferred, memorable, and trophy lengths might be chosen for salmonids based on percentages of world-record lengths. However, he did not recommend standardized lengths within these ranges. We believe that Anderson (1980) suggested an appropriate technique to allow further development of stock density indices for coldwater populations when he recommended different stock and quality lengths for book trout depending on whether fish were sampled from lakes or streams.

Second, there is a continuing need to assess the utility of stock density indices by collecting regional databases and determining the relationships between stock density indices and population density, recruitment, growth, and mortality. To date, such assessments have indicated that stock density indices are most likely to reflect population density and the rate functions in small waters, simple rather than complex fish communities, and waters that have not been overexploited.

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