Sampling Littoral Fish with a Seine: Corrections for Variable Capture Efficiency[1]

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Capture efficiency of a beach seine varies greatly depending on aspects of the littoral zone habitat and fish community. To address this sampling bias, we quantified seine efficiency and several habitat and fish community variables at 26 littoral stations in 10 southern Quebec lakes. We then generated regression models predicting capture efficiencies for total, midwater, and benthic fish. Predictions from these models yield "sliding" correction factors for seine catches. Bottom snags and seine rolling generally reduced capture efficiencies, and higher proportions of benthic fish were associated with reduced capture efficiencies for total fish. Higher macrophyte biomass was associated with increased capture efficiencies. Fish size was a significant predictor of capture efficiency only for benthic fish; smaller fish escaped the seine more readily. Regression models explained 26–73% of the observed variation in capture efficiency. Use of our models will improve the accuracy of abundance estimates from littoral seining with little additional effort.

Le rendement de capture d'une seine de rivage varie énormément selon les caractéristiques de l'habitat riverain et de l'ichtyofaune. Pour corriger ce biais dans l'échantillonnage, nous avons quantifié le rendement de capture d'une seine et plusieurs variables relatives à l'habitat et à l'ichtyofaune à 26 stations riveraines dans 10 lacs du sud du Québec. Nous avons ensuite produit des modèles de régression permettant de prévoir les rendements de capture pour l'ensemble des poissons, pour les poissons nageant entre deux eaux et pour les poissons benthiques. Les prévisions obtenues à l'aide de ces modèles ont donné des facteurs de correction pour les captures variant selon les conditions. Les obstacles rencontrés au fond de l'eau et le fait que la seine roule diminuent généralement les rendements de capture. Quand les rendements de capture pour l'ensemble des poissons étaient bas, la proportion de poissons benthiques était élevée. Par ailleurs, quand les rendements de capture étaient élevés, la biomasse de macrophytes l'était également. La taille des poissons était un bon facteur de prévision du rendement de capture seulement pour les poissons benthiques; en effet, les poissons plus petits peuvent s'échapper du filet plus facilement. Les modèles de régression nous ont permis de rendre compte de 26–73 % de la variation du rendement de capture observée. Nos modèles permettront d'améliorer la précision des estimations d'abondance effectuées au moyen d'un échantillonnage à la seine près de la rive moyennant peu de travail supplémentaire.

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Beach seining is a common method for assessing abundance and species composition of littoral zone fish communities and has been used widely in freshwater, marine, and estuarine studies (Nielson and Johnson 1983). Seining combines several advantages over other assessment techniques: (1) no poisons or explosives are used, (2) the gear is simple and easy to deploy, (3) sampling is rapid, (4) a large area can be sampled, (5) the limits of the sampling area are precisely defined, and thus habitat attributes can be accurately quantified, (6) sampling is active and, in principle, should capture all species equally well, (7) fish are obtained live, with minimal trauma, and are collected soon after capture, enabling accurate assessment of gut contents, temporal distribution patterns, and providing for live release if necessary.

Despite these advantages, a major source of bias presently limits the effectiveness of seining for quantitative sampling. Physical obstructions such as rocks, macrophytes, logs, tree branches, and moorings interfere with the seine and prevent it from passing through the entire water column. The process of snagging and unsnagging from obstructions can provide an escape route for enclosed fish, and dense macrophyte growth can cause the seine to roll up from the bottom into a tight coil. In addition, benthic fish may be more likely to escape than fish higher up in the water column. These problems have been recognized in previous studies (Richkus 1980; Frankiewicz et al. 1986; Lyons 1986; Parsley et al. 1989) and fixed, species-specific correction factors have been proposed. However, variability of habitat and fish community factors results in widely varying degrees of sampling bias and existing corrections are not sensitive to this variation.

The purpose of this study was to quantify relationships of habitat and fish community characteristics with capture efficiency of a beach seine for sampling littoral fish, and to generate predictive models of seine efficiency. Predictions from these models yield correction factors for abundance estimates obtained from seine catches, taking into account the variation in efficiency due to differences in littoral habitats and fish communities.

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TABLE 1. Habitat classifications (M = midwater, B = benthic) and relative abundances of fish species captured in this study (all stations combined).

Species	Habitat	Percent of total catch		Length range (mm)
		Number	Mass	
Perca flavescens	M	27	37	48–269
Notemigonus crysoleucas	M	26	9	51–199
Lepomis gibbosus	M	19	18	32–190
Fundulus diaphanus	B	7	2	49–83
Pimephales notatus	M	4	<1	50–81
Etheostoma olmstedi	B	4	<1	48–82
Catostomus commersoni	B	4	12	50–435
Micropterus dolomieui	M	2	<1	39–199
Semotilus corporalis	M	2	<1	56–178
Ictalurus nebulosus	B	1	2	42–267
Notropis cornutus	M	1	<1	50–126
Ambloplites rupestris	M	1	2	35–224
Esox niger	M	<1	6	88–498
Semotilus atromaculatus	M	<1	<1	50–95
Percina caprodes	B	<1	<1	50–66
Micropterus salmoides	M	<1	<1	47–107
Esox lucius	M	<1	7	106–670
Notropis hudsonius	M	<1	<1	65–83
Osmerus mordax	M	<1	<1	124–142
Moxostoma anisurum	B	<1	1	433 (1)

TABLE 2. Habitat and habitat-related variables at 26 sampling stations included in this study.

Lake	Station	Depth (m)	Mean macrophyte biomass ($g \cdot m^{-2}$)	Bottom	Snags	Seine rolling
Brome	1	0.6	442	Smooth	0	None
	2	0.6	889	Smooth	0	Slight
Bromont	3	0.7	0	Smooth	0	None
	4	1.2	3945	Medium	0	Slight
Brompton						
North end	5	0.9	1379	Medium	0	None
	6	0.8	1083	Smooth	0	None
Boat landing	7	2.5	1437	Medium	3	None
	8	2.0	744	Medium	0	None
Pointe Rocheuse	9	2.2	62	Rough	2	None
	10	2.1	0	Rough	8	None
d'Argent	11	0.7	412	Smooth	0	Slight
	12	0.7	0	Smooth	0	None
Hertel	13	1.4	357	Rough	4	None
	14	1.8	223	Rough	3	None
Magog	15	1.0	2395	Smooth	0	None
	16	1.0	2359	Smooth	0	None
Massawippi	17	1.0	1227	Smooth	0	Slight
	18	1.5	819	Smooth	0	None
Memphremagog						
Macpherson Bay	19	1.7	576	Rough	5	None
	20	1.4	2649	Smooth	1	None
Newport Bay	21	1.0	3026	Smooth	0	Moderate
	22	1.0	4341	Smooth	0	Severe
Roxton Pond	23	0.7	1416	Smooth	0	None
	24	0.9	1331	Smooth	0	None
Waterloo	25	1.2	1705	Smooth	0	Slight
	26	1.0	0	Smooth	0	None

Materials and Methods

Study Sites and Littoral Fish Communities

Our study was conducted in 10 lakes located in the Eastern Townships region of southern Quebec, Canada (45°N, 72°W). Limnological attributes of these lakes are described by Rasmussen (1988) and littoral fish communities are described by Boisclair and Leggett (1989). Yellow perch (*Perca flavescens*), golden shiner (*Notemigonus crysoleucas*), and

TABLE 3. Fish community variables at 26 sampling stations included in this study. — indicates no benthic fish captured.

	Mean fish mass (g wet)			Benthic proportion[a]	
Station	Total	Midwater	Benthic	Density	Biomass
1	5.00	7.45	2.13	0.41	0.18
2	2.44	3.00	2.18	0.65	0.60
3	3.40	4.23	2.63	0.52	0.41
4	46.03	33.87	68.64	0.35	0.52
5	6.56	6.57	3.64	0.003	0.001
6	11.08	11.08	—	0	0
7	10.07	9.97	29.10	0.005	0.01
8	7.29	7.29	—	0	0
9	3.26	3.26	—	0	0
10	2.66	2.66	—	0	0
11	3.87	3.53	15.93	0.03	0.11
12	5.02	5.02	—	0	0
13	10.69	10.69	10.66	0.03	0.03
14	6.61	6.61	—	0	0
15	21.74	14.61	75.01	0.12	0.41
16	31.04	32.98	8.72	0.08	0.02
17	3.13	3.19	3.05	0.46	0.45
18	33.70	42.28	25.58	0.50	0.04
19	1.86	1.86	1.89	0.06	0.05
20	10.51	6.44	16.32	0.41	0.64
21	2.24	2.03	3.54	0.14	0.22
22	3.37	3.36	3.39	0.20	0.20
23	13.75	13.92	8.86	0.03	0.02
24	18.93	15.06	65.44	0.08	0.27
25	7.57	7.11	29.46	0.02	0.08
26	17.74	13.48	113.27	0.04	0.27

[a] Proportion of benthic fish to total fish captured in all seine hauls.

pumpkinseed (*Lepomis gibbosus*) are the dominant littoral fish species in these lakes (Table 1). We sampled at 26 different littoral zone stations varying widely in several habitat and habitat-related variables (Table 2). Substrate conditions at these stations ranged from smooth sand to large rocks, and macrophyte biomass ranged from none to extremely dense. The dominant macrophyte species at most sites were *Vallisneria americana, Myriophyllum spicatum, Elodea canadensis, Potamogeton robinsii*, and *P. crispus*, with several other species occurring less frequently. Maximum sampling depths ranged from 0.6 to 2.5 m. Mean fish size ranged several-fold, and the proportion of benthic fish in communities varied from 0 to over 50% (Table 3). The range of habitats and fish communities included in our study represent most of the conditions encountered in northern temperate zone lakes.

Capture Efficiency Estimates

We estimated capture efficiency of a beach seine at each station in late summer 1987 by repeated removal sampling from an area completely enclosed by a block net. We used a 52 × 2.6 m knotless nylon (6-mm mesh) beach seine, with a continuous lead-core bottom line, plastic floats along the top line, and a 2.6 m^3 bag in the center. The seine was deployed from a small boat in a semicircle extending out from the shoreline, enclosing an area of 430 m^2. Fish generally seemed to ignore the boat until it came to within 2 or 3 m, so we assumed that evasion or other movements into or out of the enclosed area during seine deployment were negligible. We then placed a block net of similar material and construction (but of slightly larger dimensions and without a bag) just outside of and as close to the beach seine as possible. The seine was pulled to shore, capturing a percentage of the enclosed fish, while the block net remained in place and prevented movement of fish between the enclosed and adjacent unenclosed areas. We then replaced the seine just inside the block net and pulled it to shore, repeating this process two or three times depending on how rapidly catches declined with each subsequent haul. Finally, the block net was pulled to shore, constituting the final (fourth or fifth) haul. All fish were put on ice immediately and frozen within a few hours. In the laboratory, fish were identified, measured (TL) to the nearest millimetre, and weighed (wet) to the nearest 0.01 g. We used the Zippin (1958) method to estimate absolute abundance (calculated as both density and biomass) for all fish together (total fish), midwater fish, and benthic fish. (Fish habitat classifications were based on descriptions by Scott and Crossman (1973) and personal observations.) Abundance estimates were not calculated in cases where catch in the first haul was less than 10 individuals. Capture efficiency was then calculated as

$$(1) \quad E_D \text{ or }_B = C_1 \cdot A^{-1},$$

where E is the estimated efficiency (for sampling density or biomass), C_1 is the catch in the first haul, and A is the estimated absolute abundance.

For comparison with these removal estimates, we made simultaneous efficiency estimates based on the percentage of recaptures of marked fish introduced to the enclosed area. Yellow perch, pumpkinseed, and golden shiner were obtained from nearby areas, marked with small fin clips, and 10–20 of each were released inside the seine before the first haul. Capture efficiency for the combined group of marked fish was then calculated as

$$(2) \quad E_R = R_1 \cdot M^{-1},$$

where E_R is the estimated efficiency, R_1 is the number of marked fish recaptured in the first haul, and M is the number of marked fish released inside the seine.

Habitat and Habitat-Related Variables

We quantified littoral habitat and habitat-related variables before and during the seining at each station. Maximum depth was recorded inside the enclosed area. Prior to pulling the seine, a diver sampled submerged macrophytes by taking four 740-cm^2 quadrats at each of three (deep, middle, and nearshore) locations within the enclosed area. Macrophytes were spindried in the laboratory, weighed, and the mean biomass at each station was calculated. While sampling macrophytes, the diver subjectively categorized the bottom as smooth (sand or muck, little or no organic debris), medium (sand or muck mixed with gravel and pebbles, a few cobles and/or tree branches), or rough (numerous cobbles and boulders, tree branches, logs).

We also quantified two habitat-related variables pertaining to the mechanical performance of the seine. As the seine was pulled to shore on the first haul, we recorded the number of times the bottom line became snagged on obstructions and had to be freed by pulling upward on the seine from the boat. Pulling the seine through dense macrophyte stands frequently caused it to roll up from the bottom. We categorized the degree of seine rolling as none, slight (1–25% of the height of the seine), moderate (25–50%), or severe (>50%).

Statistical Analyses

We used linear regression to analyze relationships between capture efficiency and the habitat and fish community variables

TABLE 4. Capture efficiency estimates for total, midwater, benthic, and marked fish. E_D (density) and E_B (biomass) are efficiency estimates derived from removal sampling, and E_R are efficiency estimates derived from recaptures of marked fish. — indicates insufficient data to estimate efficiency.

	Total fish		Midwater fish		Benthic fish		Marked fish[a]
Station	E_D	E_B	E_D	E_B	E_D	E_B	E_R
1	0.86	0.95	0.90	0.98	0.81	0.82	1.0
2	0.42	0.52	0.34	0.57	0.45	0.49	0.90
3	0.53	0.77	0.77	0.90	0.31	0.56	1.0
4	0.59	0.96	0.72	0.95	0.33	0.98	0.89
5	0.91	0.97	0.91	0.97	—	—	1.0
6	0.96	0.99	0.96	0.99	—	—	0.97
7	0.92	0.97	0.93	0.98	—	—	0.64
8	—	—	—	—	—	—	0.88
9	—	—	—	—	—	—	0.77
10	0.10	0.07	0.13	0.08	—	—	0.39
11	0.65	0.68	0.65	0.72	0.91	0.35	0.98
12	0.80	0.70	0.78	0.58	—	—	1.0
13	0.60	0.81	0.62	0.82	—	—	0.65
14	0.92	0.77	0.92	0.77	—	—	0.81
15	0.65	0.97	0.69	0.96	—	—	0.69
16	0.84	0.96	0.90	0.98	—	—	0.86
17	0.75	0.83	0.82	0.88	0.66	0.78	0.82
18	0.81	0.99	0.94	0.99	0.68	0.98	0.88
19	0.56	0.52	0.58	0.55	—	—	0.40
20	0.62	0.89	0.61	0.87	0.64	0.91	0.93
21	0.79	0.78	0.87	0.88	0.17	0.34	0.44
22	0.55	0.58	0.61	0.64	0.17	0.33	0.35
23	0.87	0.96	0.89	0.98	—	—	0.93
24	0.81	0.96	0.80	0.96	—	—	0.93
25	0.91	0.96	0.92	0.97	0.33	0.89	0.85
26	0.83	0.94	0.84	0.97	—	—	0.90

[a] Efficiencies calculated from combined recaptures of yellow perch, pumpkinseed, and golden shiner.

TABLE 5. Predictive models for capture efficiency of a beach seine. E_P = predicted efficiency, R^2 = proportion of variance explained by the model, RMS = residual mean square error.

		Significance (P)				
Group	Model	Coefficient	Model	R^2	RMS	n
	Density					
Total fish	(1) arcsine $E_P = +1.129$	<0.001	<0.001	0.52	0.203	24
	-0.092 Snags	<0.001				
	-0.567 arcsine (Benthic proportion)$^{0.5}$	0.001				
Midwater fish	(2) arcsine $E_P = +0.972$	<0.001	0.011	0.26	0.255	24
	-0.071 Snags	0.011				
	Biomass					
Total fish	(3) arcsine $E_P = +1.348$	<0.001	<0.001	0.73	0.196	24
	-0.107 Snags	<0.001				
	-0.265 Seine rolling	<0.001				
	$+0.075$ $\log_{10}$ Macrophyte biomass	0.003				
Midwater fish	(4) arcsine $E_P = +1.372$	<0.001	<0.001	0.68	0.214	24
	-0.112 Snags	<0.001				
	-0.240 Seine rolling	0.001				
	$+0.069$ $\log_{10}$ Macrophyte biomass	0.011				
Benthic fish	(5) arcsine $E_P = +1.051$	<0.001	0.007	0.71	0.243	11
	$+0.012$ Mean benthic fish mass	0.013				
	-0.223 Seine rolling	0.026				

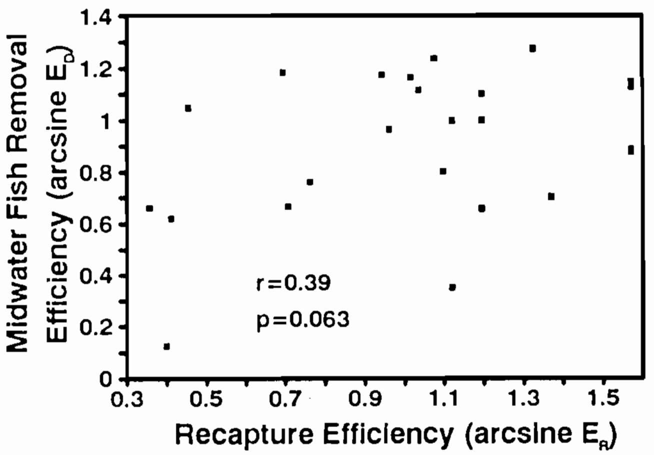

FIG. 1. Relationship of capture efficiency estimates for density of midwater fish with simultaneous estimates from combined recaptures of marked yellow perch, pumpkinseed, and golden shiner.

presented in Tables 2 and 3. Variables were transformed as necessary to conform with assumptions and conventions of linear regression, and only independent variables with significant regression coefficients (H_0: $b = 0$) were retained in the final models. We used the simple arcsine transformation for efficiencies rather than the customary angular transformation (arcsine ($p^{0.5}$)) due to the skewed distribution of the raw efficiency estimates. Seine rolling categories were coded as follows: none = 0, slight = 1, moderate = 2, severe = 3. Correlation coefficients and condition indices (Belsley et al. 1980) were examined to insure that our models contained no serious multicollinearities. All analyses were performed using the REG and CORR procedures of SAS (Luginbuhl et al. 1987).

Results and Discussion

Littoral Habitat and Seine Operation

Habitat conditions varied widely across the 26 stations we sampled (Table 2), resulting in variable mechanical performance of the seine. Snagging was much more frequent at stations with rough bottoms than smoother ones, averaging 4.4 snags per haul compared with 0.6 and 0.06 snags per haul at medium and smooth stations, respectively. Seine rolling was positively related to macrophyte biomass, although single observations in the severe and moderate rolling categories limit this interpretation. Macrophyte biomass averaged 909 and 1635 $g \cdot m^{-2}$ at stations where rolling was scored as none and slight, and was 3026 and 4341 $g \cdot m^{-2}$ at the stations where rolling was moderate and severe, respectively.

Direct observations by a diver during seining confirmed these relationships between the habitat and seine performance. Snagging of the bottom line on rocks, branches, and logs was commonly observed, and it was necessary in a few instances for the diver to assist in unsnagging the seine. Seine rolling occurred when dense, firmly rooted macrophytes bent over in front of the advancing bottom line, forming a thick mat over the bottom. Both snagging and rolling caused the bottom of the seine to lift off the substrate, providing a potential escape route for the entrapped fish. Seine rolling can also pull the top line under the surface, allowing additional opportunity for escape. Extra care is necessary to quantify these factors when working in difficult conditions.

Capture Efficiency Estimates

Catches generally declined rapidly with repeated seining and usually approached zero on the last haul. A previous study in which ponds were repeatedly seined followed by draining has shown that both midwater and benthic species can be reliably depleted in this manner (Forney 1957). Data of this type yield very precise estimates of absolute abundance (Zippin 1958), and coefficients of variation associated with our abundance estimates were generally well under 5%. Therefore, we assumed that these small errors in abundance estimation would have a negligible contribution to error in estimation of capture efficiency.

Capture efficiencies estimated from removal sampling ranged from <10 to nearly 100%, with the majority of estimates >50% (Table 4). Mean efficiencies for midwater fish, 75% (density), and 83% (biomass), were similar to means for total fish, 72% (density), and 81% (biomass), reflecting the dominance of midwater fish at most of our sampling stations. Benthic fish capture efficiencies, which averaged 50% (density) and 68% (biomass), were considerably lower than values for midwater fish. Earlier studies have also shown roughly 20% differences between midwater and benthic fish capture efficiencies (Forney 1957; Lyons 1986; Parsley et al. 1989).

Capture efficiencies estimated from recaptures of marked fish ranged from 35 to 100%, and averaged 80% compared with 75% for removal estimates for density of midwater fish. However, correlation between these estimates was weak (Fig. 1), suggesting that simple efficiency estimates from recaptures of relatively few marked fish do not closely reflect true capture efficiency of the resident fish populations. Better estimates could probably be obtained from recaptures if larger numbers of marked fish were used, and the ambient mixture of species was more closely matched.

Predicting Capture Efficiency

Habitat and fish community variables explained a substantial portion of the variation in capture efficiencies (Table 5). Capture efficiency for sampling total fish density was a negative function of snags and the proportion of benthic fish, with model 1 in Table 5 explaining 52% of the variation in efficiency (Fig. 2a). Model 3 (Table 5) explained 73% of the variation in efficiency of sampling total fish biomass (Fig. 2c) as a positive function of macrophyte biomass, and a negative function of snags and seine rolling. Models 2 and 4 (Table 5) employ similar combinations of variables to explain 26 and 68% of the variation in capture efficiency for midwater fish density and biomass, respectively (Figs. 2b, d). No statistically significant model for benthic fish density was found, but model 5 (Table 5) explained 71% of the variation in efficiency for sampling benthic fish biomass as a positive function of mean benthic fish mass, and a negative function of seine rolling (Fig. 2e).

Frequency of snags and degree of seine rolling were important predictors of capture efficiency, and both had the expected negative effects in all cases. The proportion of benthic fish also had a negative effect on capture efficiency for sampling total fish density. Benthic fish are apparently more likely to escape underneath the bottom line of the seine than midwater species (Table 4; Forney 1957; Lyons 1986; Parsley et al. 1989). The positive effects of macrophyte biomass seen in Table 5 may at first seem counterintuitive, but are consistent with our observations during seining. Fish entrapped in the advancing seine seemed less agitated where macrophyte growth was extensive,

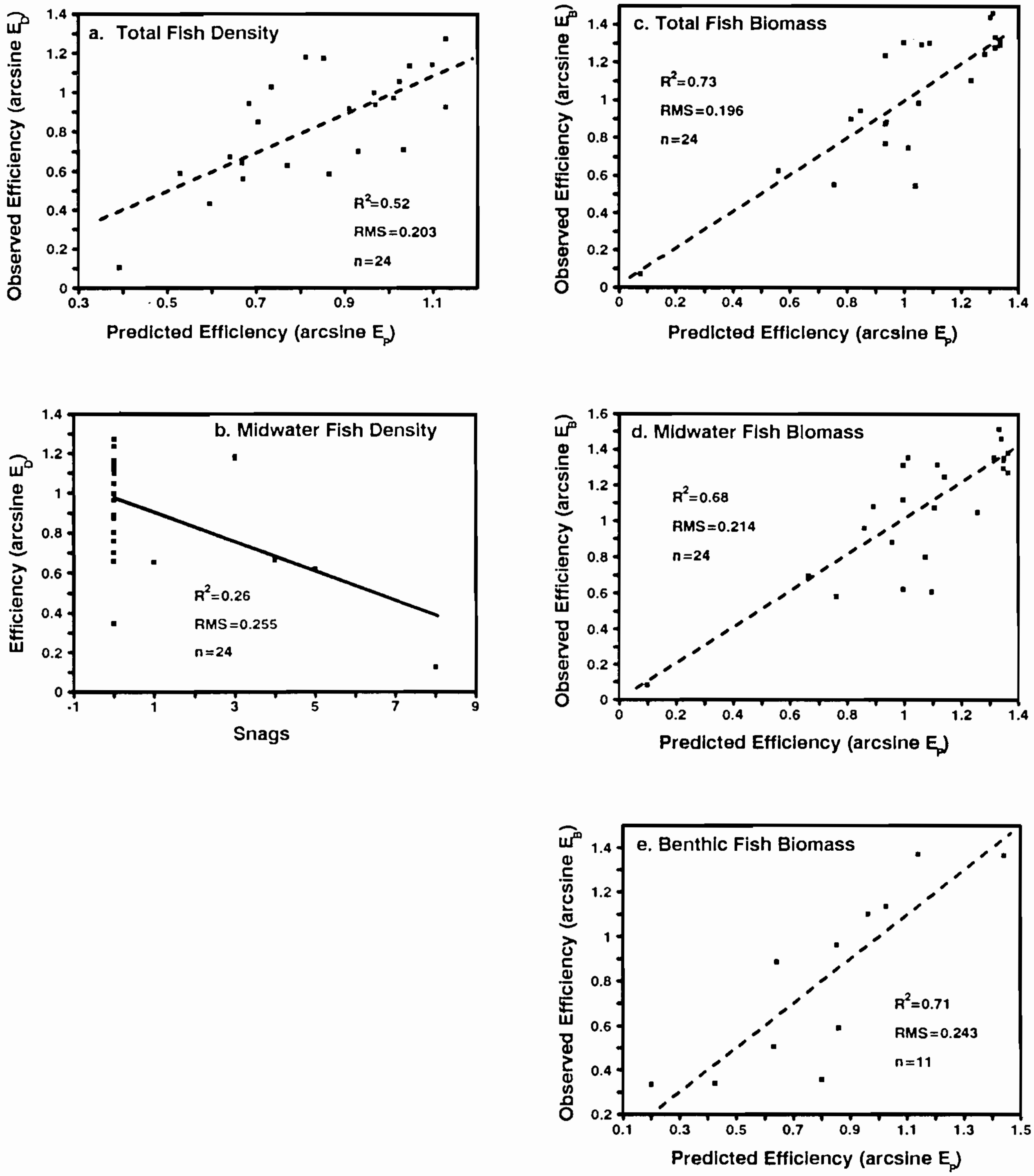

FIG. 2. Observed capture efficiency estimates versus predicted capture efficiency of a beach seine for sampling total, midwater, and benthic fish. (Note: simple bivariate relationship of capture efficiency and number of snags shown in b). Relationships a through e described in Table 5 by models 1 through 5, respectively. Dashed lines are 1-to-1 lines; solid line is a least-squares regression line.

and thus may have been less likely to find escape routes. Fish size was a significant predictor of capture efficiency only for benthic fish; smaller benthic fish were apparently better able to escape underneath the seine than larger fish.

The models in Table 5 provide predictions of capture efficiency based on a few easily measured variables. Predictions from these models can be used as correction factors to convert seine catches to abundance estimates by solving equation (1) for A. Moreover, these predicted correction factors incorporate the variability in capture efficiency inherent in sampling different fish communities from different habitats. Seining can provide quantitative estimates of littoral zone fish abundance under most conditions encountered in temperate lakes, provided that appropriate corrections for variable capture efficiency are made. We recognize that some conditions, such as dense emergent vegetation, flooded stands of timber, and other extreme circumstances may still preclude the use of seines in favor of other methods (e.g. Bayley and Austen 1988). However, our results effectively extend the range of suitable conditions for seining and significantly reduce the uncertainties surrounding abundance comparisons among diverse sites. These improvements can be achieved with very little additional effort. Sampling can be accomplished by two workers if necessary, but it is helpful to have an additional person in a boat freeing the seine from snags while the other two pull it toward shore from the ends. It is useful to have a diver for sampling macrophytes, but this could also be done from a boat with a remote grab or using an echosounder (Duarte 1987).

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