BARKLEY LAKE SYMPOSIUM

COMPARISON OF SECOND-DAY PICKUP WITH NUMBERS ESTIMATED BY POLLUTION COMMITTEE COUNTING GUIDELINES -- BARKLEY LAKE STUDY

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Abstract: Methods proposed in Pollution Committee Guidelines for estimating numbers and values of dead fish in open water are practical under field trial.

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A state fishery biologist often finds it his duty to count the dead fish from a fish kill. He can make a complete count if there are only a few dead fish, but often there are so many that he cannot count and identify them all but must use sampling methods. For this reason, the Pollution Committee of the Southern Divison of the American Fisheries Society has developed guidelines for the application of sampling to the problem of estimating the numbers of dead fish, (Pollution Committee 1970, 1979). When the Reservoir Committee began to plan the Barkley Lake study, it became obvious that this gathering of skilled manpower and equipment presented a unique opportunity for field demonstration of that part of the Guidelines concerned with dead fish on open water.

The objectives of the Pollution Committee's substudy were, first, to demonstrate the practicality of the methods proposed in the Guidelines, second, to compare estimates made at a single point in time with the total pickup of a large number of fish, and third, to acquire a large set of data for examination of the pattern of distribution of dead fish (not reported here).

Summers and Axon (1979) describe the development and execution of the Barkley Lake rotenone study. Early the planners decided that in the early morning of the second day of pickup the Pollution Committee would estimate the number of dead fish using the sampling methods of their Guidelines. This was the only time when large numbers of dead fish would be present, when the number of fish rising to the surface would have been reduced, and when interference with the main objectives of the Barkley Lake study would be minimized. The Pollution Committee carried out this trial of the Guidelines at the planned time. Numerous other personnel helped with the pickup, identification, counting and recording of fish in the sample; the data were incorporated into the file of the overall study.

METHODS

The sampling design and the estimation procedures followed closely the Guidelines of the Pollution Committee (1979), in particular that portion relating to fish kills in lakes and wide streams. In these methods, dead fish are counted on sample areas with counts expanded to totals in direct proportion to area. Lakes are divided into shoreline and open water with different methods of counting. The shoreline includes a counting or "exclusion" zone which extends into open water for some constant width to be chosen at the site to include the principal concentrations of fish along the shoreline. Fish are picked up on a number of "segments" (stretches of shoreline of uniform length) located as a systematic sample with a random start. The total numbers along the shoreline are estimated by multiplying the total picked up by the expansion factor: total length of shoreline divided by total length of the segments counted. In the open water beyond the exclusion zone fish are picked up on transects of known width (measured as distance from the boat); these transects are selected as a systematic sample (with random start) of all possible non-overlapping, parallel transects laid out perpendicular to an imaginary "base line" which ideally lies parallel to the principal axis of the lake. Transects must not overlap the exclusion zone. Total numbers on the open water may be estimated by either Method A or Method B. Method A may be used where a good map of the lake is not available; here the expansion factor is: total length of base line divided by the product of transect width and number of transects counted. Method A takes no account of transect length but the length of the base line must be known; this method is used in the present report. Method B may be used where a good enough map of the lake is available to allow measurement of both the area of the lake and the lengths of the sample transects. Expansion here is in proportion to area, with the expansion factor: area of the lake divided by total area of transects covered. The Guidelines also provide a table of random numbers, instructions for calculating the "gap" (distance between starting points of successive members of a systematic sample) and for selecting a systematic sample with a random start, a suggestion for calculating an approximate standard error, and other information.

The counting of dead fish on sample shoreline segments and open-water transects was carried out early on the second day of pickup. The complex operation was successful because of the planning and the allocation of duties beforehand, guided by a written plan that advised each man of his precise duties. The plan confined the substudy to the three principal open-water areas OW1, OW2 and OW3, with a total sample of 72 shoreline segments and 44 open-water transects, all marked before the first day of pickup. Table 1 shows the characteristics of the open-water areas and the samples.

TABLE 1. Characteristics of the 3 open-water areas OW1, OW2, and OW3 where methods of Pollution Committee guidelines were used to estimate numbers of dead fish on the morning of the second day, Barkley Lake rotenone study.

Characteristics	OW1	OW2	OW3
Area (hectares)	80.67	20.19	19.21
Shoreline:			
Shoreline length (meters)[a]	2,328.1	2,407.0	2,454.2
Shore segment length (meters)	15.24	15.24	15.24
Number of shore segments	23	24	25
Shore segment expansion factor	152.76	157.88	161.04
Open water:			
Base line length less exclusion zone (meters)	628.8	433.4	542.8
Transect width (meters)	3.05	3.05	3.05
Number of transects	18	12	14
Open-water transect expansion factor	206.3	142.2	178.1

[a]Includes block nets treated as shoreline.

The shoreline segments were distributed with a gap (distance from the start of one segment to the start of the next) of 91.4 m; each segment was 15.2 m long and thus smaller, and probably more variable, than the 30.5 m segments suggested in the Guidelines. Numbered plastic jugs marked both ends of each segment. A crew located the ends of the segments by using a line 76.2 m long, measuring from the end of one segment to the beginning of the next. Block nets were treated as shoreline where they formed parts of the boundaries of the three open-water areas (including the outer side of nets forming 6 small enclosures within the open water). Where a block net separated 2 of the open-water areas, the 15.2 m shoreline segments were located at the same point on either side of the net to eliminate the confusion that would have been created by an independent placement of jugs marking segments along both sides of the same block net. In each segment the assigned crew collected the dead fish as they lay on the shore, along the shore or block net, or in the water out to a distance of 6.1 m, the width of the exclusion zone decided upon by the group that morning before any fish were picked up. Each crew judged the width of the exclusion zone by comparison with the known length of their boat.

A crew marked the location of each transect with numbered plastic jugs on stakes, one on the shore at each end. Working from a boat, they first marked transect locations (with a gap of 36.6m) by dropping near each transect end point a conspicuous fishing float or "bobber" anchored by a lead weight. They placed the first float at the randomly-selected starting point and then ran the boat parallel to the base line, trailing a line 36.6 m long with a plastic jug at its end. As the jug passed the float placed last, the crew dropped the next. With the two lines of floats in place, they next located the shore markers and then removed the floats.

Transect width was marked with a rod 3.0 m long fastened horizontally across the bow, perpendicular to the long axis of the boat. During the pickup of fish along the sample transects, one man drove the boat and two others stood at the front with dip nets, retrieving the fish as they were encountered within the limits of the strip as marked by the ends of the 3.0-m rod. This transect pickup required skillful operation of boat and motor to both keep on course and yet proceed slowly enough that all fish could be handled. Collection started and ended at the exclusion zone, 6.1 m from the bank.

Each shoreline segment and open-water transect was assigned to a particular boat crew; each collected several samples. The crew was provided with heavy plastic bags, each prenumbered to correspond to an assigned segment or transect; extra bags were provided. The collected samples were taken to predesignated measuring tables where each was processed and recorded separately.

Expansion of the sample data to estimates for the entire body of water followed the Guidelines but with slightly different arithmetic, used here to make easier the calculations with differing sample sizes. In this study we calculated an expansion factor for shoreline segments (Table 1) as the total length of shoreline divided by 15.2 m (the segment length); this factor was multiplied by the average number (or value) of fish per segment. In the Guidelines, the expansion factor is calculated as the length of shoreline divided by the total length of all sample segments; this factor is multiplied by the total number of fish picked up. The resulting estimates are identical. A similar practice was followed with the open-water transects, calculating the expansion factor in this study (Table 1) as the total baseline length divided by the width of a single transect.

The Guidelines provide different methods for estimating numbers of dead fish along the shore and on the open water; these estimates are then summed for the total. In the tables we have listed the estimates separately for shoreline and for open water. but the only comparison possible between numbers as estimated and as picked up is between the totals.

We have used *Monetary values of fish* (Pollution Committee 1975) in calculating values of dead fish, using the value for the closest equivalent form when a species was not listed. In estimating total values, we first calculated a value for each sample segment or transect, and then estimated the total by expansion; this approach facilitated the estimation of standard errors.

To provide a measure of precision we have calculated an approximate standard error for each estimate and stated it in the tables as proportional standard error, that is, standard error divided by the estimate. We calculated these standard errors by the method of mean square successive difference as described in the Guidelines (Pollution

Committee 1979, pp. 17-18) which emphasize that these are approximations based upon systematic samples; we do not advise that they be used in any definitive statistical testing. When comparing numbers estimated and numbers picked up, we have treated the 3 open-water areas as independent trials and used a standard t test of the proportion estimated, based upon 2 degrees of freedom.

To provide examples of applying the Guidelines in this study, we have estimated total numbers and total values of all species of dead fish and numbers separately for 3 species chosen to represent species comparisons: channel catfish, largemouth bass, and shad (gizzard and threadfin combined because of unresolved questions of records). We also present estimates of numbers by separate size class for the 3 species.

In making these estimates we used all the samples collected in this special study (72 shore segments and 44 open-water transects; Table 1). Only rarely under field conditions could an agency devote so much effort to sampling a fish kill; normally they would use a number closer to the minimum specified in the Guidelines as three shore segments and three open-water transects (Pollution Committee 1979, pp. 8-10).

We have not yet made an analysis of the effect of reduced sample size for this study, but as an example, we estimated the total value of all fish for each of the 3 open-water areas on the basis of this minimum sampling schedule. Although such a sampling plan is closer to a practical level of field operation, it does not duplicate the suggested minimum schedule for shore segments because the 15.2 m lengths used here were probably more variable than the 182.9 m segments suggested. The open-water transects followed the specifications in the Guidelines.

RESULTS

Picking up the dead fish on the sample segments and transects proceeded smoothly without major problems and was completed somewhat before the time allocated. Thus the exercise showed that the field phases of these methods are practical under operating conditions.

Three tables summarize background information for all fish picked up in all Barkley Lake study subareas over all three days. Table 2 lists the total number of fish, total weight, total value, and value per acre for each of the study subareas. Table 3 presents information on total number of fish, total weight, and total value according to species; the greatest number, weight, and value are associated with the gizzard shad, the next greatest with the threadfin shad, closely followed by the white crappie. Table 4 shows the distribution of numbers, weight, and value according to each of the three days of pickup and each of the three large open-water areas. The total number of fish recorded as picked up over the 3 days was 3,073,184, the total weight was 82,959.1 kg, and the total value was $272,315.80.

On the second day, the total number of dead fish of all species in the three open-water areas, as estimated from the early morning pickup on sample shore segments and open-water transects, was about 40% of the 3-day pickup and about half the number on the second day (Table 5). Based upon all samples, this proportion varied over the 3 open-water areas from about one-quarter to two-thirds. The mean proportion was significantly less than unity, in other words, the estimate based upon the early morning pickup was consistently less than the total second day's pickup. The approximate relative precision in each area was quite respectable when based upon the total sample (proportional standard errors of 0.08, 0.12, 0.17). In OW1 and OW2, the estimated number of fish in open water far exceeded the number along the shore while in OW3 these numbers were approximatley the same; usually most fish are on the shore (Pollution Committee 1979).

The estimated total numbers of gizzard plus threadfin shad averaged about half the numbers of those species picked up on the three open-water areas (Table 6), resembling

TABLE 2. Barkley Lake rotenone study -- numbers, weights, and values[a] of fish, by area, for all 3 days.

Area	Area in acres	Number	Weight (kilograms)	Value (total, in dollars)	Value (per acre in dollars)
BN1	0.87	31,181	430.0	1,799	2,068
BN2	0.87	2,817	79.3	310	357
BR1	0.77	11,227	870.4	3,957	5,139
BR2	0.93	9,915	744.3	3,309	3,558
TR1	0.72	7,785	269.0	1,305	1,812
TR2	0.97	8,171	406.6	1,677	1,729
C1	3.95	79,433	1,535.5	5,357	1,356
C2	1.52	26,477	798.0	2,588	1,703
C3	1.02	3,543	168.1	748	734
C4	1.08	18,860	231.4	1,350	1,250
D	0.99	13.935	219.2	837	845
E	1.04	5,844	111.5	782	752
F	0.95	6,557	137.3	825	869
G1	13.31	106,138	3,634.0	13,290.	993
G2	1.50	33,464	685.6	2,990	1,993
G3	0.69	4,636	203.2	646	937
G4	1.02	15,931	243.9	1,185	1,162
H1	1.52	8,512	278.5	1,017	669
H2	0.98	6,880	321.5	1,006	1,027
H3	1.01	9,339	187.1	942	932
I	0.97	5,719	166.2	629	648
OW1	75.78	691,154	27,631.9	76,808	1,013
OW2	49.88	1,198,227	24,406.7	86,526	1,734
OW3	47.47	767,389	19,199.7	62,423	1,315
Total	209.81	3,073,184	82,959.1	272,315	1,297

[a]Values from 1975 revision of *Monetary values of fish* (Pollution Committee 1975).
[b]Mean value (total value/total area).

the situation with all species (Table 5) except that in OW1 the estimated number was about 70% of those picked up. The relative precision by separate area was not quite as good as that for all fish. The estimated total numbers of channel catfish averaged only about one-third of the numbers picked up (Table 7); the relative precision was good considering the relatively low numbers involved, probably reflecting a more uniform distribution in space. The number of largemouth bass estimated was about two-thirds of the number picked up (Table 8) with this proportion more variable, ranging from about one-quarter to a 40% overestimation; relative precision for this species was comparatively poor even though based on all the samples, probably reflecting the low numbers involved.

Details of the distribution of these 3 species by size class, as estimated by sampling and as observed in the fish picked up, are shown in Table 9 for combined shad, Table 10 for channel catfish, and Table 11 for largemouth bass. These data, presented separately for each of the 3 open-water areas, illustrate the fact that even with the relatively large total number of samples involved in this study, estimates of numbers of fish present at the species size-class level are generally of poor precision except where these categories contain large numbers.

TABLE 3. Barkley Lake rotenone study -- numbers, weights, and values (dollars)[a] of fish by species[b], for all 3 days.

Species	Number	Weight (kilograms)	Value (dollars)
Paddlefish (*Polyodon spathula*)	100	659.8	829
Spotted gar (*Lepisosteus oculatus*)	15	3.9	3
Longnose gar (*L. osseus*)	2	0.3	0
Shortnose gar (*L. platostomus*)	2	0.5	1
Bowfin (*Amia calva*)	5	18.5	11
American eel(*Anguilla rostrata*)	7	3.8	5
Skipjack herring (*Alosa chrysochloris*)	1,537	162.2	453
Gizzard shad (*Dorosoma cepedianum*)	1,875,897	24,745.6	90,603
Treadfin shad (*D. petenense*)	785,356	7,229.9	38,102
Hybrid shad (*Dorosoma sp.*)	67	0.8	3
Goldeneye (*Hiodon alosoides*)	14	4.2	1
Mooneye (*H. tergisus*)	47	2.4	3
Grass pickerel (*Esox americanus vermiculatus*)	2	0.0	1
Carpsucker (*Carpiodes sp.*)	92	112.1	41
River carpsucker (*C. carpio*)	346	386.7	143
Quillback (*C. cyprinus*)	159	141.6	49
Highfin carpsucker (*C. velifer*)	29	33.0	12
Spotted sucker (*Minytrema melanops*)	120	202.9	267
Smallmouth buffalo (*Ictiobus bubalus*)	2,617	5,395.8	3,756
Bigmouth buffalo (*I. cyprinellus*)	1,822	6,314.8	5,629
Black buffalo (*I. niger*)	185	658.5	653
River redhorse (*Moxostoma carinatum*)	20	4.1	5
Black redhorse (*M. duquesnei*)	1	0.1	0
Golden redhorse (*M. erythrurum*)	2	0.7	1
White catfish (*Ictalurus catus*)	1	0.1	0
Blue catfish (*I. furcatus*)	2,011	539.3	1,132
Black bullhead (*I. melas*)	565	37.6	62
Yellow bullhead (*I. natalis*)	870	41.0	93
Brown bullhead (*I. nebulosus*)	40	7.2	7
Channel catfish (*I. punctatus*)	18,475	3,970.7	8,169
Tadpole madtom (*Noturus gyrinus*)	3,424	4.2	376
Flathead catfish (*Pylodictis olivaris*)	143	151.6	405
Pirate perch (*Aphredoderus sayanus*)	1	0.0	0
Topminnows (*Fundulus sp.*)	2	0.0	0
Blackstripe topminnow (*F. notatus*)	18	0.0	1
Black spotted topminnow (*F. olivaceus*)	53	0.1	2
Mosquito fish (*Gambusia affinis*)	1	0.0	0
Brook silverside (*Labidesthes sicculus*)	727	1.0	24
White bass (*Morone chrysops*)	8,810	715.7	6,684
Yellow bass (*M. mississippiensis*)	3,221	58.1	1,153
Striped bass (*M. saxatilis*)	4	0.0	5
Bluegill (*Lepomis macrochirus*)	49,960	1,936.6	23,805
Green sunfish (*L. cyanellus*)	307	4.0	79
Longear sunfish (*L. megalotis*)	30,619	537.4	8,591
Redear sunfish (*L. microlophus*)	47	3.1	31
Orangespotted sunfish (*L. humilis*)	236	1.7	50
Redbreast sunfish (*L. auritus*)	16	0.1	3

Warmouth (*L. gulosus*)	3,745	46.3	928
Rock bass (*Ambloplites rupestris*)	2	0.0	1
Hybrid sunfish (*Lepomis sp.*)	4	0.0	1
Largemouth bass (*Micropterus salmoides*)	3,950	516.4	4,965
Spotted bass (*M. punctulatus*)	142	4.8	162
Smallmouth bass (*M. dolomieui*)	2	1.7	15
Crappies (*Pomoxis sp.*)	72	1.0	21
White crappie (*P. annularis*)	69,315	3,468.3	37,632
Black crappie (*P. nigromaculatus*)	663	70.6	532
Sauger (*Stizostedion canadense*)	66	17.6	196
Darters (*Percina sp.*)	2	0.0	0
Logperch (*P. caprodes*)	321	3.6	35
Freshwater drum (*Aplodinotus grunniens*)	190,525	12,733.9	29,958
Carp (*Cyprinus carpio*)	9,125	11,976.1	6,404
Golden shiner (*Notemigonus crysoleucas*)	441	14.6	15
Bluntnose minnow (*Pimephales notatus*)	1	0.0	0
Fathead minnow (*P. promelas*)	1	0.0	0
Bullhead minnow (*P. vigilax*)	1	0.0	0
Miscellaneous minnows	5,811	11.7	186

[a]Values from 1975 revision of *Monetary values of fish* (Pollution Committee 1975).
[b]Common names as designated in AFS list (Bailey 1970).

TABLE 4. Numbers, weights, and values for fish of all species and sizes picked up in the Barkley Lake rotenone study, by day and by the 3 open-water, and all other, areas.

	OW1	OW2	OW3	Other	Total
			NUMBERS		
Day 1	164,112	95,114	74,976	79,119	413,321
Day 2	497,835	1,056,502	679,225	300,122	2,533,684
Day 3	29,207	46,661	13,188	37,123	126,179
Total	691,154	1,198,277	767,389	416,364	3,073,184
			WEIGHTS (kilograms)		
Day 1	13,289.5	7,556.5	7,340.7	4,870.6	33,057.3
Day 2	11,007.7	14,149.4	10,259.3	5,358.2	40,774.6
Day 3	3,334.7	2,700.8	1,599.8	1,491.9	9,127.2
Total	27,631.9	24,406.7	19,199.7	11,720.7	82,959.1
			VALUES (dollars)		
Day 1	31,231	15,732	17,282	14,443	78,690
Day 2	37,580	61,559	40,674	25,272	165,086
Day 3	7,996	9,233	4,466	6,842	28,538
Total	76,808	86,526	62,423	46,588	272,315

TABLE 5. Number of fish of all species estimated by methods of Pollution Committee guidelines based on all samples along shore and in open water, and number picked up, in three open-water areas, second day of Barkley Lake rotenone study.

Area	Portion of area	Number estimated	pse[a]	Number picked up	Proportion estimated
OW1	shore	84,058	0.181		
	open water	249,405	0.080		
	total	333,463	0.075	497,835	0.670
OW2	shore	181,404	0.332		
	open water	368,582	0.057		
	Total	549,987	0.116	1,056,502	0.520
OW3	shore	96,373	0.315		
	open water	95,551	0.138		
	Total	191,923	0.172	679,225	0.282
Total	shore	361,835	0.191		
	open water	713,538	0.044		
	Total	1,075,373	0.071	2,233,562	(0.481)
Mean of 3 area proprotions; does this differ significantly from 1.0?					0.491*

[a]pse = proportional standard error.
* = 0.01 < p ≤0.05 (t test, 2 df).

TABLE 6. Number of shad (gizzard plus threadfin) estimated by methods of Pollution Committee guidelines based on all samples along shore and in open water, and number picked up, in 3 open-water areas, second day of Barkley Lake rotenone study.

Area	Portion of area	Number estimated	pse[a]	Number picked up	Proportion estimated
OW1	shore	75,171	0.201		
	open water	237,383	0.083		
	total	312,554	0.080	440,632	0.709
OW2	shore	172,438	0.349		
	open water	359,861	0.058		
	Total	532,299	0.120	1,019,855	0.522
OW3	shore	86,111	0.351		
	open water	88,516	0.148		
	total	174,627	0.189	647,996	0.269
Total	shore	333,720	0.207		
	open water	685,760	0.046		
	Total	1,019,480	0.074	2,108,483	(0.484)
Mean of 3 area proportions, does this differ significantly from 1.0?					0.500 ns[b]

[a]pse = proportional standard error.
[b]ns = p > 0.05 (t test, 2 df)

TABLE 7. Number of channel catfish estimated by methods of Pollution Committee guidelines based on all samples along shore and in openw ater, and number picked up in 3 open-water areas, second day of Barkley Lake rotenone study.

Area	Portion of are	Number estimated	pse	Number picked up	Proportion estimated
OW1	shore	438	0.126		
	open water	779	0.154		
	Total	1,218	0.109	2,938	0.414
OW2	shore	335	0.169		
	open water	616	0.132		
	Total	952	0.104	2,369	0.402
OW3	shore	303	0.184		
Open water		420	0.169		
	Total	723	0.125	2,44	0.296
Total	shore	1,076	0.090		
	open water	1,815	0.089		
	Total	2,893	0.065	7,751	(0.373)
Mean of 3 area proportions, does this differ significantly from 1.0?					0.371**

[a]pse = proportional standard error.
** = $p \leqslant 0.01$ (t test, 2 df)

TABLE 8. Number of largemouth bass (*Micropterus salmoides*) estimated by mehtods of Pollution Committee guidelines based on all samples along shore and in open water, and number picked up in three open-water areas, second day of Barkley Lake rotenone study.

Area	Portion of area	Number estimated	pse[a]	Number picked up	Proportion estimated
OW1	shore	46	0.386		
	open water	69	0.514		
	Total	115	0.344	404	0.285
OW2	shore	105	0.275		
	open water	142	0.354		
	Total	247	0.234	172	1.436
OW3	shore	232	0.195		
	open water	76	0.387		
	Total	308	0.175	390	0.790
Total	shore	383	0.148		
	open water	287	0.238		
	Total	670	0.132	966	(0.694)
Mean of 3 area proportions, does this differ significantly from 1.0?					0.837 ns[b]

[a]pse = proportional standard error.
[b]ns = $p > 0.05$ (t test, 2 df).

TABLE 9. Shad (gizzard plus threadfin) -- number by size class (2.5 cm) as estimated by methods of Pollution Committee guidelines based on all samples, and as picked up, in three open-water areas, second day of Barkley Lake rotenone study.

Size class (cm.)	OW1 estimate	OW1 pickup	OW2 estimate	OW2 pse[a]	OW2 pickup	OW3 estimate	OW3 pickup
5.1	163	76	315	0.397	595	64	228
7.6	12,374	8,579	18,390	0.153	67,054	32,587	56,273
10.2	277,623	389,700	500,104	0.127	929,869	131,911	569,631
12.7	14.094	23,774	7,818	0.207	9,089	5,122	7,988
15.2	455	508	211	0.291	25	26	6
17.8	832	982	767	0.111	1,426	397	1,163
20.3	2,798	5,383	2,173	0.143	5,025	1,580	4,257
22.9	3,700	10,184	2,040	0.096	5,866	2,418	7,208
25.4	466	1,398	442	0.227	858	533	1,148
27.9	7	41	32	0.538	46	0	92
30.5	46	6	7	1.022	2	0	1
33.0	0	1	0	-	0	0	1
Total no.	312,554	440,632	532,299	0.120	1,019,855	174,627	647,996
Total value[b]	$15,494	$22,365	$26,214	0.121	$49,364	$7,909	$31,153

[a]pse = proportional standard error, here listed only for OW2.
[b]Values from 1975 revision of *Monetary values of fish* (Pollution Committee 1975).

Table 12 compares the total value of fish of all species as estimated by sampling methods and as calculated for the fish picked up. The average value estimated from sampling was a little less than half the value calculated for the fish picked up. The relative precision of the estimates of values seem to be slightly better than for the total number of fish, although no test was made of this point.

As an example of the effect of reduced sample size, we estimated the total value of all fish for the 3 open-water areas on the basis of 3 shoreline segments and 3 open-water transects each (Table 13). The apparent relative precision of these estimates was not good, and the average results deviated from the values estimated from all samples (Table 12), probably as sampling fluctuations.

DISCUSSION

This study has shown that the counting methods described in the Pollution Committee Guidelines are practical to apply under field conditions and provide results that seem reasonable. The field phases proceeded smoothly and provided both a demonstration of the methods, and a data base for making estimates.

We should expect sampling estimates to be less than the total number of fish picked up during an entire day. The estimates refer only to fish available during the pickup of samples, here for a short time during the early morning of the second day. After a fish kill dead fish continue to float up for several days; samples can only measure the status at the time they are collected. Our best conclusion here is that the number of dead fish on the shoreline and floating in the water in the early morning was about half the total number available for pickup during the whole day and about 40% of the number for the 3 days. There is no standard here by which an absolute numerical judgement of the estimates may be made.

The Barkley Lake rotenone study could not provide a direct test of the Guidelines' methods, and, of course, that was not the objective. For a direct test of this estimation procedure, we would have to collect samples by these methods and simultaneously pick

TABLE 10. Channel catfish -- number by size class (2.5 cm) as estimated by methods of Pollution Committee guidelines based on all samples, and as picked up, in three open-water areas, second day of Barkley Lake rotenone study.

Size class (cm.)	OW1 estimate	OW1 pickup	OW2 estimate	OW2 pse[a]	OW2 pickup	OW3 estimate	OW3 pickup
5.1	0	6	0	-	0	6	1
7.6	41	24	12	1.044	7	0	14
10.2	59	63	7	0.722	15	13	10
12.7	145	234	49	0.481	51	32	69
15.2	31	151	20	0.590	171	38	99
17.8	107	279	165	0.224	292	57	257
20.3	56	384	154	0.268	342	58	379
22.9	18	124	25	0.624	144	25	131
25.4	31	87	32	0.420	57	19	76
27.9	31	119	62	0.402	187	51	164
30.5	154	332	122	0.359	291	121	341
33.0	204	332	96	0.307	309	103	329
35.6	113	277	87	0.397	194	51	206
38.1	82	198	67	0.318	141	51	130
40.6	43	112	25	0.441	66	26	75
43.2	25	68	12	1.044	42	45	67
45.7	38	63	0	-	20	13	29
48.3	7	29	7	1.022	19	13	14
50.8	7	18	0	-	8	0	15
53.3	7	14	0	-	5	0	11
55.9	7	12	12	0.738	2	0	8
58.4	11	4	0	-	2	0	4
61.0	0	4	0	-	1	0	9
63.5	0	3	0	-	2	0	3
66.0	0	1	0	-	1	0	1
68.6	0	0	0	-	0	0	1
71.1	0	0	0	-	0	0	0
73.7	0	0	0	-	0	0	1
Total no.	1,218	2,938	952	0.104	2,369	723	2,444
total value[b]	$678	$1,537	$405	0.149	$1,052	$394	$1,279

[a]pse = proportional standard error, here listed only for OW2.
[b]Values from 1975 revision of *Monetary values of fish* (Pollution Committee 1975).

up all of the other fish available at the time. Such an operation would require many more men per unit of water surface than were available at Barkley Lake. In spite of this problem, however, the present study represents the best test that has been carried out; further, it provides a large set of real data based upon a well-conducted field operation.

Results of this study emphasize the fact, stressed in the Guidelines, that the number of dead fish as estimated at any one time will be less than the total number killed. Any estimation method, or any pickup that is less than complete over time as well as space, will only determine the number of fish available at the time. Even if it had been possible to spread the sampling over the entire day, then the estimates would have represented only

TABLE 11. Largemouth bass -- number by size class (2.5 cm). as estimated by methods of Pollution Committee guidelines based on all samples, and as picked up, in 3 open-water areas, second day of Barkley Lake rotenone study.

Size class (cm.)	OW1 estimate	pickup	estimate	OW2 pse[a]	pickup	OW3 estimate	pickup
5.1	0	0	7	1.022	11	6	2
7.6	71	117	125	0.389	44	173	189
10.2	13	63	42	0.445	22	51	53
12.7	0	15	0	-	3	0	12
15.2	7	39	0	-	26	26	39
17.8	18	100	37	0.449	34	52	70
20.3	0	26	12	0.738	6	0	6
22.9	7	8	0	-	3	0	3
25.4	0	7	0	-	3	0	4
27.9	0	3	0	-	2	0	3
30.5	0	5	0	-	2	0	2
33.0	0	6	0	-	2	0	1
35.6	0	4	0	-	2	0	2
38.1	0	1	0	-	2	0	1
40.6	0	3	7	1.022	2	0	0
43.2	0	2	7	1.022	1	0	2
45.7	0	1	0	-	1	0	1
48.3	0	1	0	-	1	0	0
50.8	0	2	12	1.044	4	0	0
53.3	0	1	0	-	1	0	0
Total no.	115	404	247	0.234	172	308	390
Total value[b]	$73	$460	$374	0.458	$255	$181	$303

[a]pse = proprotional standard error, here listed only for OW2.
[b]Values from 1975 revision of *Monetary values of fish* (Pollution Committee 1975).

the average numbers present during the day, and would not necessarily correspond to a total pickup.

The size of the population being estimated influenced the relative precision of estimates. In general, large numbers were estimated with better relative precision than small numbers; a total of all fish was estimated better than numbers of separate species, and a species number was better estimated than the number of fish of a single size class.

This fact may prompt the suggestion that only these larger categories should be estimated; other criteria disagree. In reporting a fish kill it may be mandatory to present estimates for different kinds of fish, and for game fish, estimates according to species and even size classes. Monetary values of fish vary according to size. Each sample collection can be evaluated on the basis of the species and sizes of fish present and then a total value may be estimated on the basis of these sample values. This approach, rather than estimating total numbers by species and size category separately and then evaluating these totals, is the more convenient for calcultion of a variance of the estimated total value; the two methods provide identical estimates.

Possibly the size categories used in recording field data should be broadened, primarily to reduced the labor of measuring and recording in the field, but in small part to facilitate the calculation and reporting of the estimates. Such a departure from the

TABLE 12. Value of fish of all species estimated by methods of Pollution Committee guidelines for counting fish, and monetary values of fish, based on all samples of fish along shore and in open water, and values for all fish picked up in 3 open-water areas, second day of Barkley Lake rotenone study.

Area	Portion of area	Estimated value (dollars)	pse[a]	Observed value (dollars)	Proportion estimated
OW1	shore	6,199	0.132		
	open water	14,482	0.070		
	Total	20,681	0.063	37,580	0.550
OW2	shore	11,487	0.262		
	open water	20,865	0.052		
	Total	32,353	0.099	61,559	0.526
OW3	shore	6,731	0.229		
	open water	5,595	0.119		
	Total	12,326	0.136	40,674	0.303
Total	shore	24,417	0.142		
	open water	40,943	0.040		
	Total	65,360	0.059	139,813	(0.467)
Mean of 3 area proportions; does this differ significantly from 1.0?					0.460*

[a]pse = proportional standard error.
* = $0.01 < p \leq 0.05$ (t test, 2 df).

tradition of using 2.5 cm classes would have to be closely correlated with the determination of monetary value. For example, in the monetary values proposed by the Pollution Committee (1975) large fish are evaluated according to weight; length is not used directly but provides a basis for estimating weight. Further, any consolidation of size classes might reduce the value of the records in the study of population dynamics.

What can be done to improve the precision of estimates, especially those based upon small numbers of samples? The relatively high variance associated with the estimates arises principally from the variability in numbers of fish, especially among shore segments (for example, see Tables 5 and 13). This variability can be reduced by making the shore segments either more numerous or individually longer; either way the sampling cost is increased. To increase the sample segment number may be expected to decrease the standard error (probably by the well-known square root rule, though not necessarily so with systmatic samples in a non-random distribution). To increase segment length should also reduce the standard error, though probably not by the square-root rule because of the correlation between adjacent stretches of shoreline. Although we have no way of demonstrating the fact, the use here of 15.2 m shore segments probably yielded better precision here than use of one-sixth as many segments of 91.4 m (the length suggested in the Guidelines). The open-water transects followed closely recommendations of the Guidelines for Plan A; increasing numbers would increase precision. Further, some gain in precision may be possible when it is possible to calculate estimates according to Plan B of the Guidelines where the counts are weighted according to the length (area) of the transect (Pollution Committee 1979, pp. 8-13).

Under some conditions it would be possible to increase precision by stratifying the open water and shoreline into 2 (or more) strata according to fish density. The details of such an operation must be worked out on the site by someone who understands the methods.

TABLE 13. Value of fish of all species estimated by methods of Pollution Committee guidelines for counting fish, and monetary values of fish, based on sampling three shoreline segments and three open-water transects per area, and values for all fish picked up in 3 open-water areas, second day of Barkley Lake rotenone study.

Area	Portion of area	Estimated value (dollars)	pse[a]	Observed value (dollars)	Proportion estimated
OW1	shore	6,851	0.529		
	open water	12,192	0.274		
	Total	19,043	0.259	37,580	0.507
OW2	shore	1,887	0.823		
	open water	16,822	0.258		
	Total	18,710	0.246	61,559	0.304
OW3	shore	1,412	0.159		
	open water	4,162	0.211		
	Total	5,574	0.162	40,674	0.137
Total	shore	10,150	0.390		
	open water	33,177	0.167		
	Total	43,327	0.57	139,813	(0.310)
Mean of 3 area proportions; does this differ significantly from 1.0?					0.316*

[a]pse = proportional standard error.
*=$0.01 < p \leqslant 0.05$ (t test, 2 df).

It may be possible to increase precision by varying the allocation of sampling effort between the determination of the number of fish along the shoreline and number floating in the open water. Counts along the shoreline and in open water must be made as separate strata in any event because different methods are used. In some cases it might be possible to determine by inspection that, for example, there are more fish in total along the shore than in the open water and that sampling should therefore be increased along the shore and possibly decreased in the open water (although the Guidelines' minimum of 3 shoreline segments or transects should be adhered to). As an approximation in such a case, the sampling effort should be divided in proportion to the total numbers of dead fish in each stratum. This rule conforms with the standard formula for determining optimal allocation (Snedecor and Cochran 1967, p. 523) because with such counts the standard deviation tends to be proportional to the counts per sample.

Finally, administrative officers must give careful attention to the decision of what level of precision is required in estimating numbers or values of fish in the fish kill. This study suggests that high precision will be costly and should not be called for unless information of that quality is really needed.

CONCLUSIONS

1. The methods proposed in the Pollution Committee Guidelines for estimating numbers and values of dead fish in open water are practical under field trial.

2. On the second day of the Barkley Lake rotenone study the estimated numbers of dead fish available in the early morning were about half the total numbers picked up during the entire day and about 40% of the 3-day pickup. Using sampling to estimate the number of fish available at any one time ordinarily will underestimate the magnitude of the total fish kill.

3. To judge from this single study, use of practical sampling methods can provide reasonable precision for estimates of only the most numerous categories of dead fish; less numerous classes can be estimated only with poor precision.

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