THESIS

THE EXTENT OF FISHING WITHOUT A LICENSE IN COLORADO

Submitted by

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In partial fulfillment of the requirements

for the Degree of Master of Science

Colorado State University

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COLORADO STATE UNIVERSITY

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WE HEREBY RECOMMEND THAT THE THESIS PREPARED UNDER OUR SUPERVISION BY DAVID ROSS SMITH ENTITLED THE EXTENT OF FISHING WITHOUT A LICENSE IN COLORADO BE ACCEPTED AS FULFILLING IN PART REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE.

Committee on Graduate Work

Adviser

Department Head

ABSTRACT OF THESIS

THE EXTENT OF FISHING WITHOUT A LICENSE IN COLORADO

I organized this thesis into 2 sections. In the first section I documented the extent and covariates of fishing without a license that occurred in Colorado during the summer of 1988. I based the analysis on records of anglers contacted by a volunteer selection of Division of Wildlife officers. I discussed limitations of these data, especially potential bias and restrictions on inference. The extent of fishing without a license taken over all available data was not sizable, almost surely less than 8%. The following observed relationships were offered as hypotheses. Fishing without a required license was strongly related to age. Anglers under 20 years old were much more likely to be in violation than older anglers and they contributed disproportionately to the total number of violations. For the most part, gender and Colorado residency were unrelated to rates of violation. On a regional basis violation rates varied widely and were positively correlated with human population density.

In the second section of the thesis I described the use of randomized response methods to examine further the relationship between age and prevalence of illegal fishing without a license. Used in sensitive topic surveys, randomized response is an interview technique designed to reduce response bias. I adapted the method for group interviews of a convenience sample of hunter education classes. These classes

were attended by roughly 400 students. Approximately 64% of the students responded; however, 9 out of 10 nonrespondents were either not anglers or too young to need a fishing license. Thus, cooperation with the survey was high. Age was strongly associated with fishing license violators among the respondents. That is, anglers under 25 years of age were much more likely than older anglers to have fished at least once without a license during 1988.

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I can not leave nameless the Division of Wildlife officers who provided data for my analyses. I am indebted to Rick Adams, Alex Chappell, Lauren Childers, Mark Cousins, Paul Creeden, Beth Dillon, Barry Dupire, Glen Eyre, Joe Gumber, Jim Hicks, Doug Homan, Dave Kenvin, Tom Kroening, Laurie Kuelthau, Jim Leiwer, Rich Lopez, Tom Lynch, Jeff Madison, Jim Miller, Ron Oehlkers, Brad Petch, Tom Rauch, Mike Reid, Jay Sarason, Bruce Sigler, Rick Spowart, Bob Thompson, Pat Tucker, John Wagner, Scott Wait, Richard Weldon, Perry Will, Kevin Wright, and Steve Yamashita. Also, I must mention my gratitude to the many energetic and concerned hunter education instructors who let me interview their classes: Dean and Kay Derby, Paul Gresky, Elias Huerta, Irene and Ricky Kettle, Donald Lenhart, Michael Proctor, Raymond Scherbarth, David Tudor, and William Ward.

I am most appreciative of Jeff Laake, Eric Rexstad, and Ken Wilson, my office mates, who played a large part in my education. Through an impressive array of experiences and knowledge they helped me solve my problems in education and research. Besides which they were fun to be around.

Above all I thank my family for their unwavering love and support. Especially my wife, Mary, who tolerated me, loved me, and straightened me out when I needed it (which was surprisingly often).

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DEDICATION

In memory of Bruce Wright Smith -

essayist, poet, taxi driver, grandfather.

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THE EXTENT OF FISHING WITHOUT A LICENSE IN COLORADO DURING MAY THROUGH AUGUST 1988

In Colorado a significant commitment of time and effort is directed to enforcement of fishing license requirements. Between 1983 and 1986, for example, approximately 25% of all citations issued included fishing without a license (J. F. Smeltzer, Colo. Div. of Wildl., pers. commun.). However, little besides total annual citations is known about the extent or nature of this infraction.

Dunning and Hadley (1978) concluded via mail and telephone surveys that approximately 25% of the anglers in Erie County, New York, fished illegally without a license. Martin (1977) estimated that about 40% of anglers in each state are nonlicensed, but he did not distinguish between legal and illegal nonlicensed anglers. In Colorado for example, anglers under 15 years old are not required to purchase a license to fish and are therefore legal nonlicensed anglers. The violation-simulation method (see Vilkitis 1968) was used by Stork and Walgenbach (1973) to study compliance with fishing regulations including license regulations. However, the data were inadequate to examine compliance for separate regulations. Although license compliance was not studied, Paragamian (1984) estimated the proportion of anglers who complied with minimum length limits for smallmouth bass.

Characteristics of conservation law violators are studied to provide information of potential use in reducing violations (Glover and Baskett 1984). For example, education and enforcement programs can be directed towards those resource users most likely to be in violation. Research in this area has focused

largely on big game law violators (Vilkitis 1968, Shafer et al. 1972, Kesel 1974, Beattie and Giles 1979, Ayeni 1980, Glover and Baskett 1984). Typical covariates of crime include age, gender, and population density (Hagan 1987). In addition, whether or not an angler is a state resident where he fishes may be associated with license purchase. Directing education or enforcement programs toward population segments that demonstrate high rates of violation would be an efficient use of limited time and money.

The objective of this paper is to assess the extent of fishing without a license in Colorado and to examine some sociologic characteristics which may help direct efforts of law enforcement and education programs to reduce illegal nonlicensed angling.

METHODS

Data for this study were collected by District Wildlife Managers (DWMs) during May through August 1988. The DWMs voluntarily participated in this study. Of the 114 wildlife management districts administered by the Colorado Division of Wildlife (CDOW), 27 were included in this study.

Two types of data were collected by the districts; not all districts provided both types. Routine law enforcement contacts were made in 21 of the districts and systematic contacts were made in 13 of the districts. That is, on 2 to 4 days per month anglers were contacted systematically on these districts. The sampling rate varied on any day and the selection of which day to make contacts was governed by convenience, for the most part. On 7 districts both types of data were recorded.

Figure 1.1 shows the distribution of the participating districts around the state. For the purpose of analysis, I adopted from the Colorado Commission on Higher Education a scheme to divide the state into 8 multi-county regions which

are relatively homogeneous in population characteristics (Knop 1984). These multi-county regions are also shown on Figure 1.1.

License possession, age, gender, and Colorado residency was noted for each systematically contacted angler. Age was missing for 5 contacts and residency for 1 contact. The daily proportion of illegally nonlicensed anglers was the only data generated from the routine contacts.

Measures of compliance are often expressed as a rate; the proportion of resource users who comply with some regulation. This should not be confused with the proportion of events (e.g., fishing trips) that are in compliance. Because the term compliance can not differentiate between these quantities, I prefer to work with the complement of compliance, say occurrence. Then we can examine the proportion of resource users who have violated a regulation, i.e., violator rate. Or we can look at the proportion of events which result in a violation, i.e., violation rate. In this study, fishing trips are sampled, thus violation rates are estimated. Because licensed anglers may fish more or less frequently than nonlicensed anglers. violator rate does not necessarily equal violation rate and may have a distinctly different interpretation (see Appendix). Violation rate is a good measure of the extent of fishing without a license in Colorado. It can not be transformed directly into revenue loss. For that, an estimate of violator rate is needed. Hereafter, violation rate refers to the proportion of fishing trips illegally taken without a license.

I approached estimation of a "statewide" violation rate and its variance in accordance with the multi-stage nature of the data collection. Let $a_j = \sum_{u=1}^{k_j} y_{ju}$,

where y_{ju} is 1 for no license and 0 otherwise, and k_j is the total contacts on the j^{th} day. Then take

$$\hat{p}_{hi} = \frac{\sum_{j=1}^{m_{hi}} a_{hij}}{\sum_{j=1}^{m_{hi}} k_{hij}}, \tag{1.1}$$

to be the estimated proportion of licensing violations for the i^{th} district in the h^{th} month, where m_{hi} is the number of days sampled. Ignoring the finite population correction (fpc), Cochran (1977:305) gives the appropriate estimator of the sampling variance,

$$\hat{v}(\hat{p}_{hi}) = \frac{\sum_{j=1}^{m_{hi}} k_{hij}^2 (\hat{p}_{hij} - \hat{p}_{hi})^2}{\bar{k}_{hi}^2 m_{hi}(m_{hi}-1)}, \tag{1.2}$$

where $\bar{k}_{hi}$ is the mean number of daily contacts and $\hat{p}_{hij} = a_{hij}/k_{hij}$.

First calculate the violation rate for each month,

$$\hat{\bar{r}}_h = \frac{\sum_{i=1}^{n_h} \hat{p}_{hi}}{n_h}. \tag{1.3}$$

Then the overall violation rate per district per month is

$$\hat{\bar{r}} = \sum_{h=1}^{L} W_h \hat{\bar{r}}_h, \tag{1.4}$$

where L is the number of months (i.e., strata), n_h is the number of participating districts, and W_h the fraction of sampling units in the h^{th} month (i.e., the proportion of districts in each month: in this study $W_h = W = \frac{1}{4}$). Then an approximate variance can be calculated (Cochran 1977:279),

$$\hat{v}(\hat{\bar{r}}) = \sum_{h=1}^{L} W_h^2 \left[\left(\frac{N_h - n_h}{N_h} \right) \frac{\sum_{i=1}^{n_h} (\hat{p}_{hi} - \hat{\bar{r}}_h)^2}{n_h(n_h-1)} + \sum_{i=1}^{n_h} \left(\frac{M_h - m_{hi}}{M_h} \right) \frac{\hat{v}(\hat{p}_{hi})}{N_h n_h} \right], \tag{1.5}$$

where M_h is the number of days and N_h the number of districts in the h^{th} month. The estimated standard error was calculated as $\hat{se}(\hat{\bar{vr}}) = \sqrt{\hat{v}(\hat{\bar{vr}})}$ and an approximate 95% confidence interval, $95\%CI = \hat{\bar{vr}} \pm 2\left[\hat{se}(\hat{\bar{vr}})\right]$.

A "detection rate" was calculated for each district where routine contacts were recorded, $dr_i = a_i/r_i$. Here again $a_i = \sum_{j=1}^{r_i} y_{ij}$, y_{ij} is 1 for no license and 0 otherwise, and r_i is the number of routine contacts in the i^{th} district during the period of interest. Expansion to a "statewide" estimated detection rate was computed as

$$\hat{\bar{dr}} = \frac{\sum_{i=1}^{\tilde{n}} dr_i}{\tilde{n}}, \tag{1.6}$$

where $\tilde{n}$ is the number of districts that provided a record of routine contacts. An estimate of the variance of $\hat{\bar{dr}}$ was calculated by (Cochran 1977:35)

$$\hat{v}(\hat{\bar{dr}}) = \left(\frac{N-\tilde{n}}{N}\right) \frac{\sum_{i=1}^{\tilde{n}} \left(dr_i - \hat{\bar{dr}}\right)^2}{\tilde{n}(\tilde{n}-1)}. \tag{1.7}$$

Unfortunately, these procedures required assumptions to be simultaneously made and violated. First, for Equations(1.1 and 1.2), I assumed that sampled days and contacts within days were simple random samples; this was not true as days were selected by convenience and contacts were systematic. By ignoring the fpc in Equation(1.2) this problem was alleviated somewhat. To expand district estimates to a statewide basis (Equations[1.4-1.7]) I assumed that participating districts were a simple random sample; again, this was not true and the variance formulae may not be conservative.

In addition to model bias caused by violation of model assumptions (e.g., erroneously assuming simple random sampling), these data are likely to suffer from systematic biases. It is unreasonable to expect that violators do not evade being contacted by DWMs; no special effort was made to prevent this. Thus, I expect

estimates based on systematically contacted anglers to be negatively biased. Further, as Cowles et al. (1979) indicate, estimates of compliance based on routine contacts can be very misleading. I expect DWM's are more efficient at detecting violators than would be predicted by chance. While the magnitude of bias on estimates based on routine contacts for any given district is difficult to assess, in general, the tendency is probably toward a positive bias.

I tested for associations of hypothesized covariates (i.e., geographic region, age, gender, state residency) and violation rate. For this purpose contingency table analysis was used assuming that each attribute of the covariate represented an independent sample (Steel and Torrie 1980: Chap. 22).

Colorado population estimates from 1986 (Lin 1986) were used in conjunction with the multi-county scheme of the Colorado Commission on Higher Education to compare violation rates geographically and in relation to observed population density. Population totals and area of land by county were combined to calculate the population density (persons per square mile: PPSM) for each multi-county region where angler contacts were recorded. I examined patterns of enforcement in relation to incidence of violations by comparing the systematic contacts from May through August 1989 with tickets issued in 1986.

RESULTS AND DISCUSSION

Extent of Fishing Without a License

The estimated average violation rate per district, $\hat{\bar{v}}_r$, (expressed as a percent) was approximately 3.5% $\left[\widehat{se}(\hat{\bar{v}}_r) \doteq 0.54;\ 95\%CI \doteq 2.4 \text{ to } 4.6\right]$. In comparison, the average detection rate during that same period, $\hat{\bar{d}}_r$, was approximately 5% $\left[\widehat{se}(\hat{\bar{d}}_r) \doteq 1.2;\ 95\%CI \doteq 2.7 \text{ to } 7.4\right]$. Thus, with the available data, my best estimates show that the average violation rate was less than 8%.

Relationship Between Violation Rate and Detection Rate

The implication for detection rate to be used as an index to violation rate is obvious. Although there are several limitations to the use of official statistics, criminologists have made progress in the study of crime by use of police records, e.g., the Uniform Crime Report (Hagan 1982, Flanagan and Jamieson 1987). For detection rate to be a useful index it must accurately reflect violation rate. In that case, sample survey techniques such as ratio estimation and double sampling can be used to calibrate or scale the index (e.g., detection rate) to the parameter of interest (e.g., violation rate) (Cochran 1977, Eberhardt and Simmons 1987).

In ratio estimation the detection rate must be known for all districts, not estimated. In double sampling, however, the more easily obtained detection rate is estimated from a large sample of districts while violation rate is estimated concurrently on a subsample of those districts. Ratio estimation is then used to calibrate the detection rate estimates with the more accurate violation rate estimates. These are promising techniques if basic requirements of ratio estimation hold.

Ratio estimation would be most valid if the relationship between violation rate and detection rate is linear through the origin and the variance of violation rate is proportional to detection rate (Scheaffer et al. 1986). The data from this study suggest that ratio estimation and double sampling may be appropriate. The estimates for violation rate and detection rate were very close (i.e., roughly 4% versus 5%). There was a positive linear association between the detection rates and violation rates as calculated from the 7 districts that provided both types of data (Pearson correlation coefficient [r] = 0.91, P = 0.0046). For any given day, either detection rate or violation rate was calculated. Thus, dependence was limited to the within district relationship of the 2 rates. Figure 1.2 shows that this

relationship appears approximately linear. Simple regression analysis indicated that the intercept did not differ from the origin ($t = 0.12$, $df = 1$, $P = 0.91$). And regression with no intercept parameter resulted in a significant fit of a linear model ($F = 53.98$, $df = 6$, $P = 0.0003$). It is difficult to conclude much about residual variance because of the small sample; however, examination of the residuals plotted against the detection rate suggests that variance may be proportionate. It is important to note that similarities among those 7 DWMs who volunteered to participate could explain the strong correlation and regression results rather than an inherent relationship between the detection and violation rates. Therefore, although these data do not support inference from double sampling analysis, I suggest that further study along these lines has promise in the development of an efficient estimator of violation rate. Further study should include random selection of districts in a double sampling scheme with subsequent estimation of detection and violation rates.

Covariates of Violation Rate

Age

Figure 1.3 shows the violation rates for 6 different age groups (Table 1.1). There was a strong association between violation rate and age of the anglers ($\chi^2 = 156.8$, $df = 5$, $P < 0.001$). Most noticeable is the high rate of violations among anglers 15 to 19 years old (18.5% when combined). Those over 20 years old show a much reduced rate of violation. While the younger anglers fished less often (6.8% of the contacts were of the 15 to 19 year olds), their relative contribution to total violations was still high (33.6% of the violations were by 15 to 19 year olds). In contrast, another third (32.7%) of the violations are contributed by those anglers 20 to 34 years old and the final third (33.6%) by those 35 years old and older. By

all measures, anglers under 20 years old committed a disproportionately large share of the violations.

Gender

Figure 1.4 shows violation rates for males and females (Table 1.2). There was no difference between male and female violation rates ($\chi^2 = 0.11$, df = 1, P = 0.74). However, these data corroborate that fishing is a predominately male activity (81.7% of the contacts were male anglers). Thus, males contributed the vast majority of total violations (82.9% of the violations).

Table 1.1. Numbers and percentages of licensed and nonlicensed anglers for 6 age groups from systematic contacts made during May through August 1988 in 13 CDOW districts in Colorado.

Age group	Licensed	Percent licensed	Nonlicensed	Percent nonlicensed	Total	Percent of total
15	19	67.9	9	32.1	28	1.0
16 to 19	144	83.7	28	16.3	172	5.8
20 to 24	234	94.7	13	5.3	247	8.4
25 to 34	759	97.1	23	2.9	782	26.6
35 to 49	904	97.0	28	3.0	932	31.7
50 +	772	98.9	9	1.1	781	26.5
Total	2832	96.3	110	3.7	2942	100

Table 1.2. Numbers and percentages of licensed and nonlicensed anglers by gender from systematic contacts made during May through August 1988 in 13 CDOW districts in Colorado.

Gender	Licensed	Percent licensed	Nonlicensed	Percent nonlicensed	Total	Percent of total
Male	2315	96.2	92	3.8	2407	81.7
Female	521	96.5	19	3.5	540	18.3
Total	2836	96.2	111	3.8	2947	100

Residency

Figure 1.5 shows violations for Colorado residents and nonresidents (Table 1.3). Nonresidents had a higher violation rate, although the degree of association is weak ($\chi^2 = 3.92$, df = 1, P = 0.048). However, the residents far out number the nonresidents in these data. Thus, residents contributed the majority of total violations (73.9% of the violations were by residents).

Table 1.3. Numbers and percentages of licensed and nonlicensed anglers by Colorado residency from systematic contacts made during May through August 1988 in 13 CDOW districts in Colorado.

Colorado residency	Licensed	Percent licensed	Nonlicensed	Percent nonlicensed	Total	Percent of total
Resident	2307	96.6	82	3.4	2389	81.1
Nonresident	528	94.8	29	5.2	557	18.9
Total	2835	96.2	111	3.8	2946	100

Region

Figure 1.6 shows the violation rates for the multi-county regions ranked by population density (Table 1.4). The approximate persons per square mile (PPSM) for each region in 1986 were (Knop 1984, Lin 1986):

Region	PPSM
Metro	193
West Energy	11
North Mountains	9
Southwest Mountains	7
San Luis Valley	5

Table 1.4. Numbers and percentages of licensed and nonlicensed anglers for 5 regions (out of 8) from systematic contacts made during May through August 1988 in 13 CDOW districts in Colorado. The boundaries of the multi-county regions were devised by the Colorado Commission on Higher Education.

Multi-County region	Licensed	Percent licensed	Nonlicensed	Percent nonlicensed	Total	Percent of total
Metro	584	90.8	59	9.2	643	21.8
West Energy	415	96.5	15	3.5	430	14.6
North Mountain	527	96.9	17	3.1	544	18.5
Southwest Mountain	714	97.9	15	2.1	729	24.7
San Luis Valley	596	99.2	5	0.8	601	20.4
Total	2836	96.2	111	3.8	2947	100

There appears to be a strong association between violation rate and location within the state ($\chi^2 = 72.77$, df = 4, $P < 0.001$). Given the large discrepancy between the violation rate in the Metro region and the rest of the regions where data are available, future surveys should be designed with regions and perhaps more importantly, population densities as strata. Note that the Metro region includes the metropolitan areas north of Denver and south of Wyoming along the Front Range. As such these results do not strictly refer to Denver. In fact, Denver was rather under sampled considering population size (see Fig. 1).

As well as reducing variance by controlling for between strata differences, stratification allows for assessing how associations may change with region. Although observed sample sizes are not sufficient to support tests of associations within region, exploratory analysis may reveal useful, yet hypothetical, patterns. Figure 1.7 shows violation rates by Colorado residency for each multi-county region where data were available. These data suggest that the association of violation rate and residency may be different between regions. Nonresidents contacted in the Metro region were much more likely to be in violation than nonresident anglers in the other regions. Figure 1.8 shows violation rates by gender for each multi-county

region where data were available. Again there is much local variation of the associations. In the West Energy region female anglers showed a much higher rate of violation than females in the other regions. However, in the Southwest Mountain and San Luis Valley regions violations by female anglers were negligible. Figure 1.9 shows violation rates by age group for each multi-county region where data were available. Data were pooled into 3 age groups (15 to 19, 20 to 34, and 35+) to increase sample sizes. Anglers under 20 years of age were most likely to be in violation for most regions. The North Mountain region was the exception with no violations among the youngest age group; however, only 2.4% of the contacts were of anglers under 20 years old.

Patterns of Enforcement

The relative numbers of tickets written during 1986 was compared to the relative numbers of violations observed during this study (Figs. 1.10-1.12). In 1986, 1097 citations were issued that included a fishing without a license violation. It is important to note that these comparisons are purely exploratory and patterns portrayed are speculative.

The youngest and oldest age groups (15 to 19 and 35+ year olds), it appears, were not cited in proportion to the number of violations they committed. In contrast, the middle age groups (20 to 35 year olds) were cited disproportionately more often (Fig. 1.10). Males and females were cited in nearly exact proportion to observed violations (Fig. 1.11). Residents appeared to be cited more frequently than chance would predict. Thus, nonresidents were necessarily cited less frequently (Fig. 1.12).

The patterns that deviate from observed patterns of violations can be due to 1) reduced citations in a population segment (i.e., fewer contacts and/or more warnings), 2) increased citations in another population segment (i.e., more contacts

and/or fewer warnings), or 3) a combination of 1 & 2. For example, either residents being contacted and cited more or nonresidents being contacted and cited less or a combination of both can explain the pattern in Figure 1.12. These data do not allow for a resolution between these conflicting explanations.

These patterns raised from conjecture have easily imagined justifications. Younger anglers may be cited less often so that they are not discouraged from fishing later in their lives. In addition, older anglers may be given the benefit of the doubt in regards to having a license and not contacted routinely. Alternatively (or simultaneously), the middle age groups may be targeted for contact. When contacted they are expected to know the regulation. Following this argument, they are cited disproportionately often.

Overall, males and females appear to be contacted and cited similarly. This implies that in terms of gender, enforcement is quite equitable. In contrast, tickets among residents and nonresident appear to be not so evenly distributed.

Again I emphasize that these patterns, although interesting to discuss, are speculative. These data are separated by 2 years and it is doubtful that the patterns are stationary over time. However, issues of differential enforcement can be assessed more rigorously given random sampling of resource users and concurrent records of citations. To sort out conflicting explanations for differential enforcement, exact records of routine contacts are necessary and enforcement must not be influenced by the process of record keeping.

CONCLUSIONS

The results presented here are a reasonably focused "snap shot" of violation rates in time and space. Only a subset of potentially relevant sociologic characteristics were examined. Consequently, inference is treacherous. Nevertheless, several conclusions, suggestions, and hypotheses can be advanced.

I conclude that the extent of fishing without a license taken over all available data is not sizable, almost surely less than 10%. Ignoring local variation the rate of violation is probably at a tolerable level. However, certain regions or population groups may be associated with higher than acceptable violation rates.

I suggest that more research be designed to assess the use of double sampling to estimate rates of violations. The results presented here indicate that detection rates can explain much of the variation in violation rates within a district.

Based on these data and analyses I put forward the following hypotheses. Fishing without a license in Colorado is related strongly to age with anglers under 20 years old being much more likely to be in violation. I believe this is robust to local variation. While younger anglers make up a small percent of the fishing activity, they contribute disproportionately to total violations because of their high violation rate. On a statewide basis gender and Colorado residency is of little consequence to violation rate. However, local variation in these relationships may be important. On a regional basis violation rates vary widely and are positively correlated with population density.

Intuitively, methods that may affect violation rates include education and enforcement. While the results presented in this paper can be helpful in making informed policy decisions, the effectiveness and efficiency of policy changes designed to impact violation rates should be assessed (McCormick 1968, Ritter 1975, Beattie et al. 1977 and 1978). For example, a simple agency goal of increased compliance is of little value if compliance is not monitored. Unfortunately, the number of citations is not sufficient to gauge effectiveness or efficiency. Consistent and long term data collection and elements of experimental design in setting policy are required. Increased benefit from research into conservation law enforcement will be realized as the time frame and scope of the research expands.

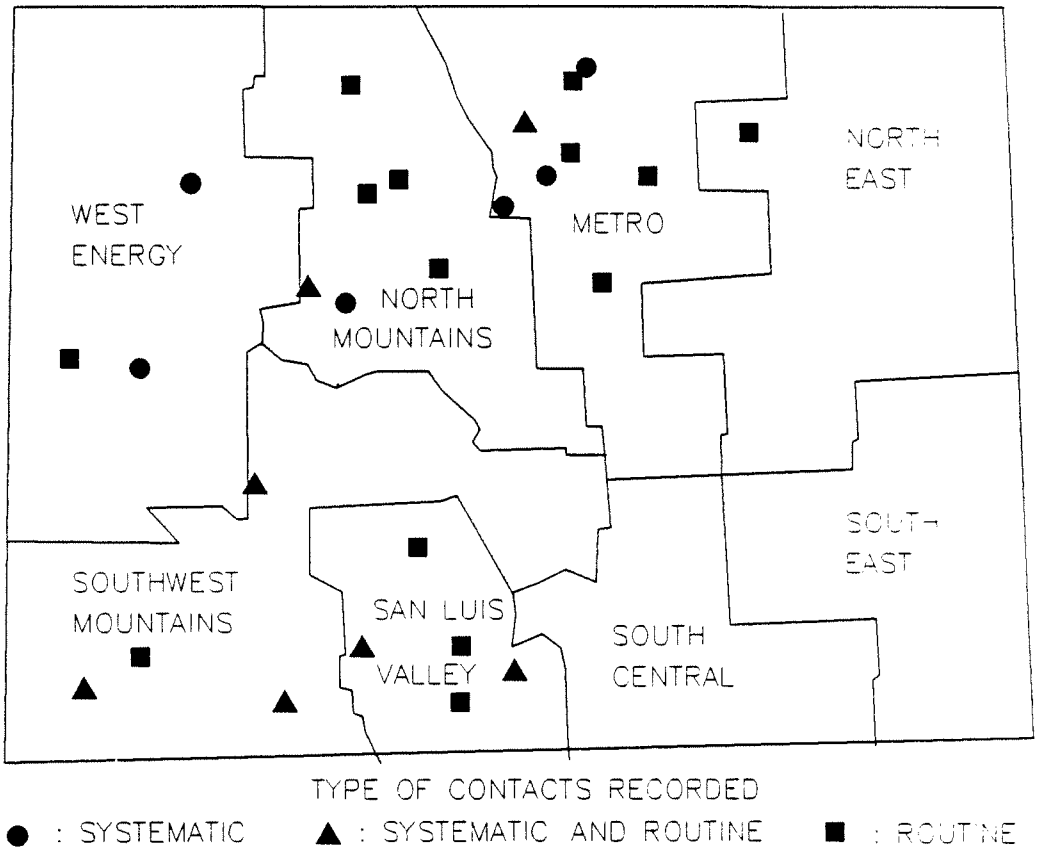

Figure 1.1. Distribution of the districts that voluntarily provided records of angler contacts for May through August 1988.

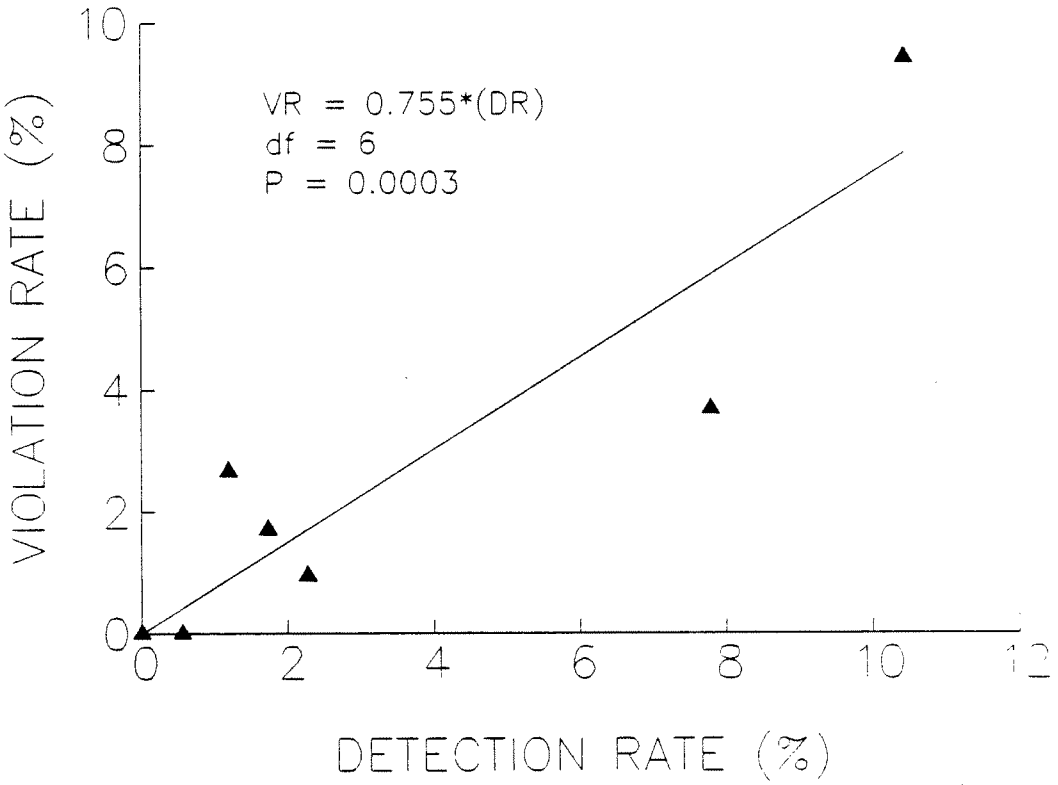

Figure 1.2. Regression of violation rates on detection rates from 7 districts during May through August 1988. Violation rates are calculated from systematic contacts of anglers and detection rates from routine law enforcement contacts. The same DWM made both types of contacts for each district.

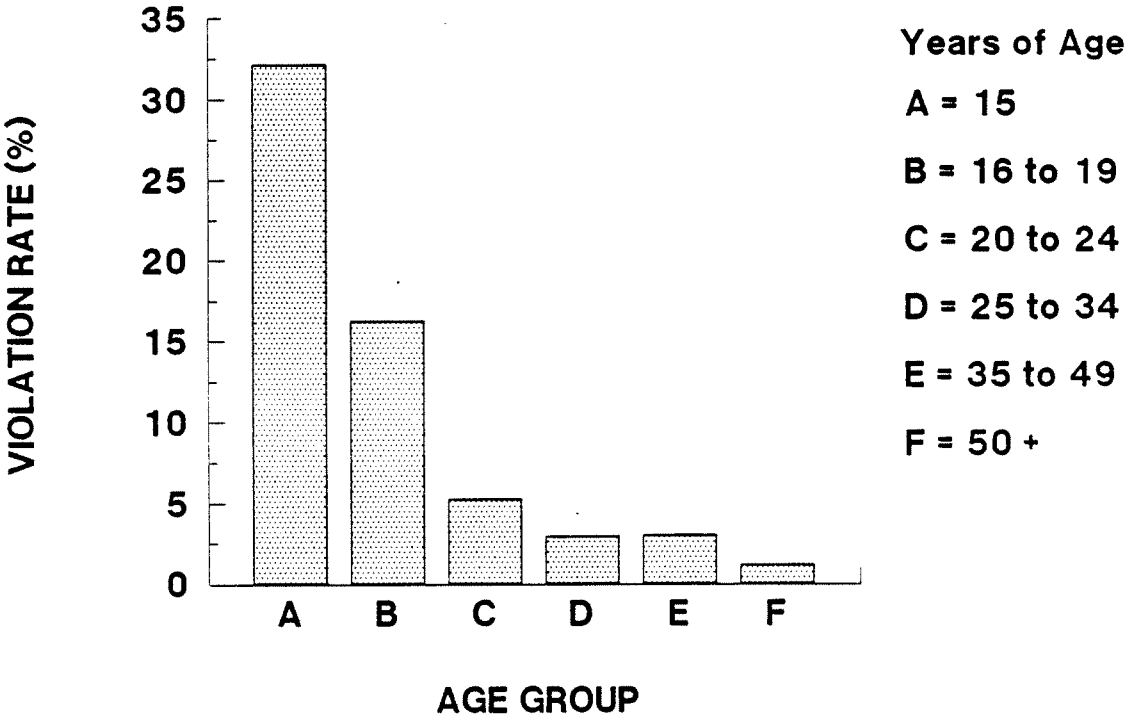

Figure 1.3. Violation rates by age groups from systematic contacts made on 13 districts, May through August 1988.

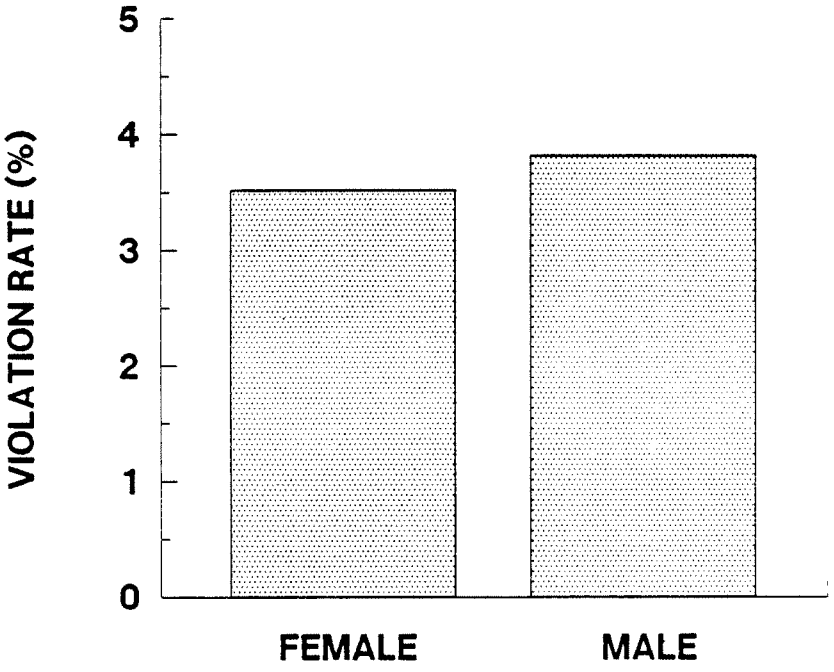

Figure 1.4. Violation rates by gender from systematic contacts made on 13 districts, May through August 1988.

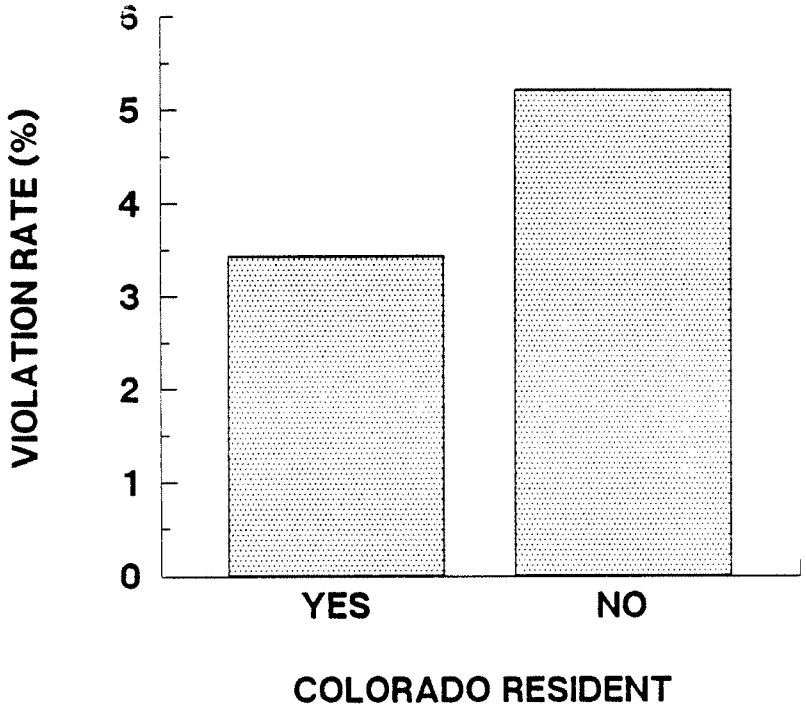

Figure 1.5. Violation rates by Colorado residency from systematic contacts made on 13 districts, May through August 1988.

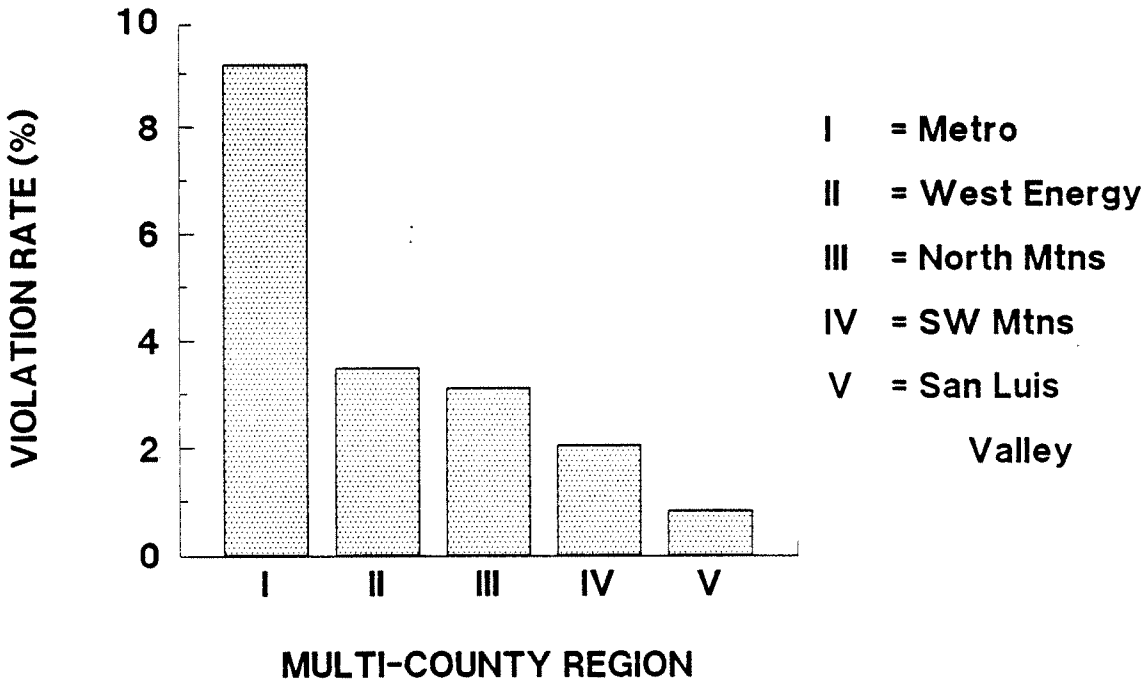

Figure 1.6. Violation rates by multi-county region from systematic contacts made on 13 districts, May through August 1988. The regions are ranked by population density. Approximate persons per square mile for each region in 1986 were: Metro-193, West Energy-11, North Mountains-9, Southwest Mountains-7, and San Luis Valley-5.

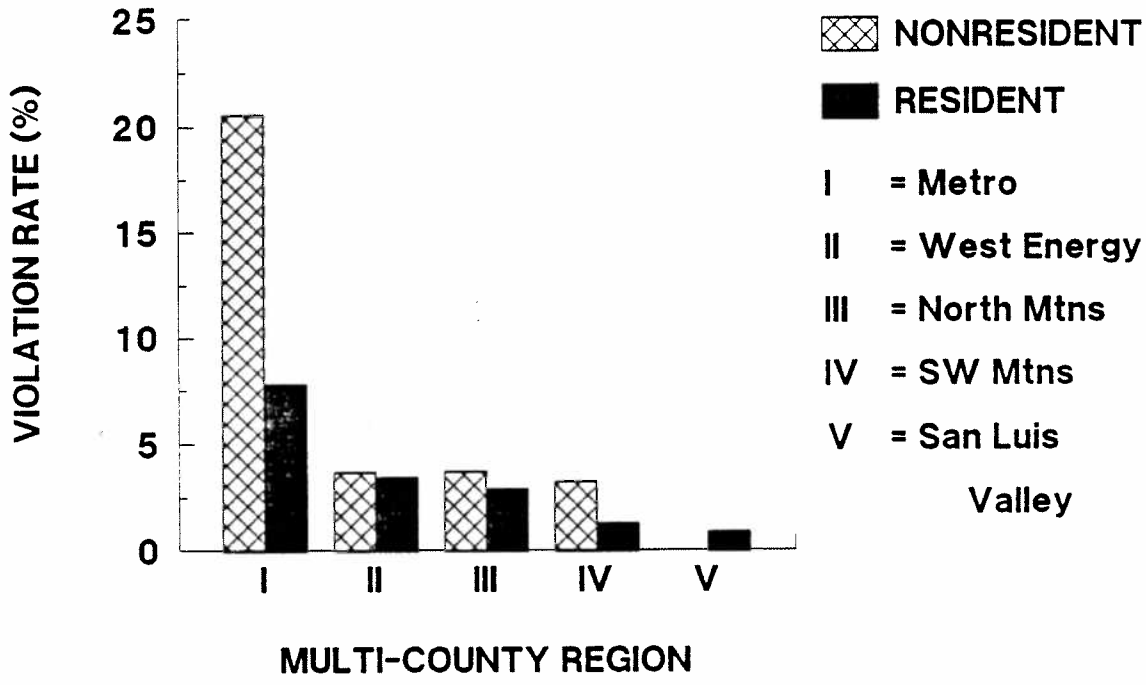

Figure 1.7. Violation rates by Colorado residency for 5 multi-county regions from systematic contacts made on 13 districts, May through August 1988.

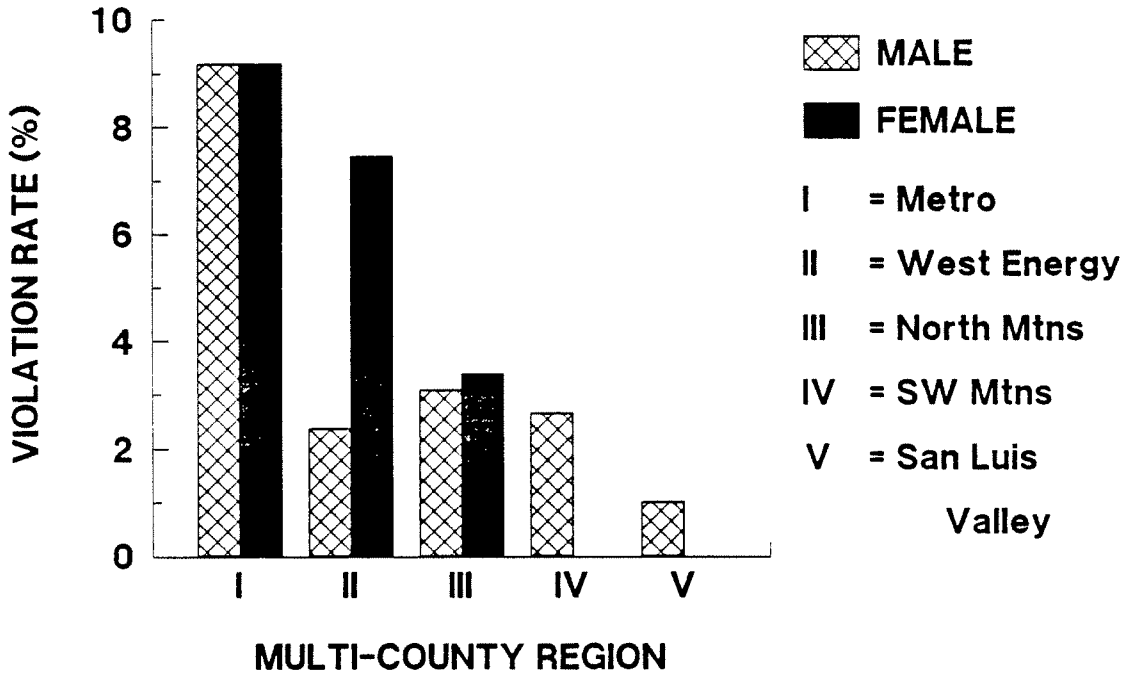

Figure 1.8. Violation rates by gender for 5 multi-county regions from systematic contacts made on 13 districts, May through August 1988.

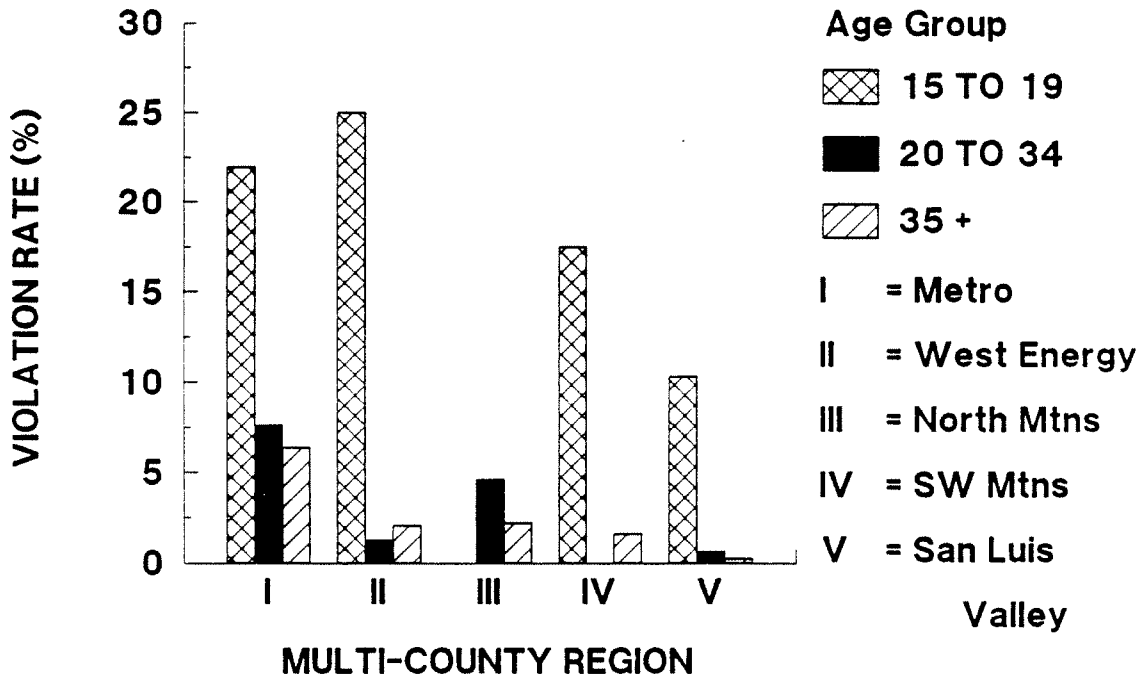

Figure 1.9. Violation rates by age group for 5 multi-county regions from systematic contacts made on 13 districts, May through August 1988.

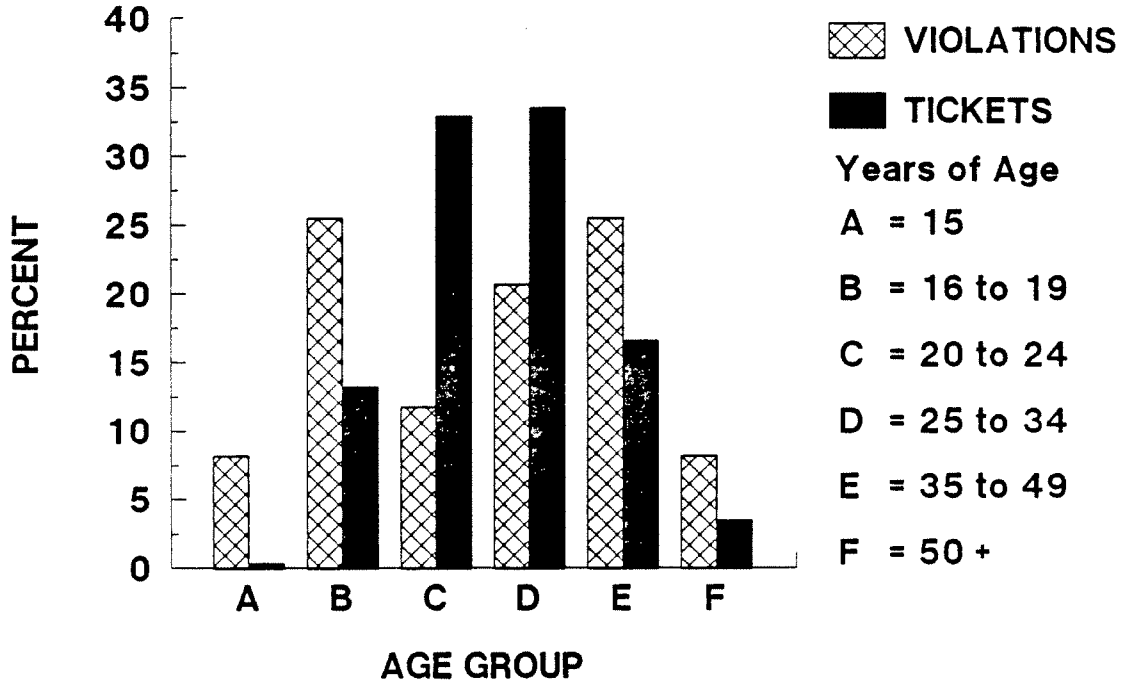

Figure 1.10. Comparisons of the proportion of total violations among systematic contacts made on 13 districts, May through August 1988 and the proportion of total tickets issued during 1986 in Colorado. The proportions were calculated for 6 age groups.

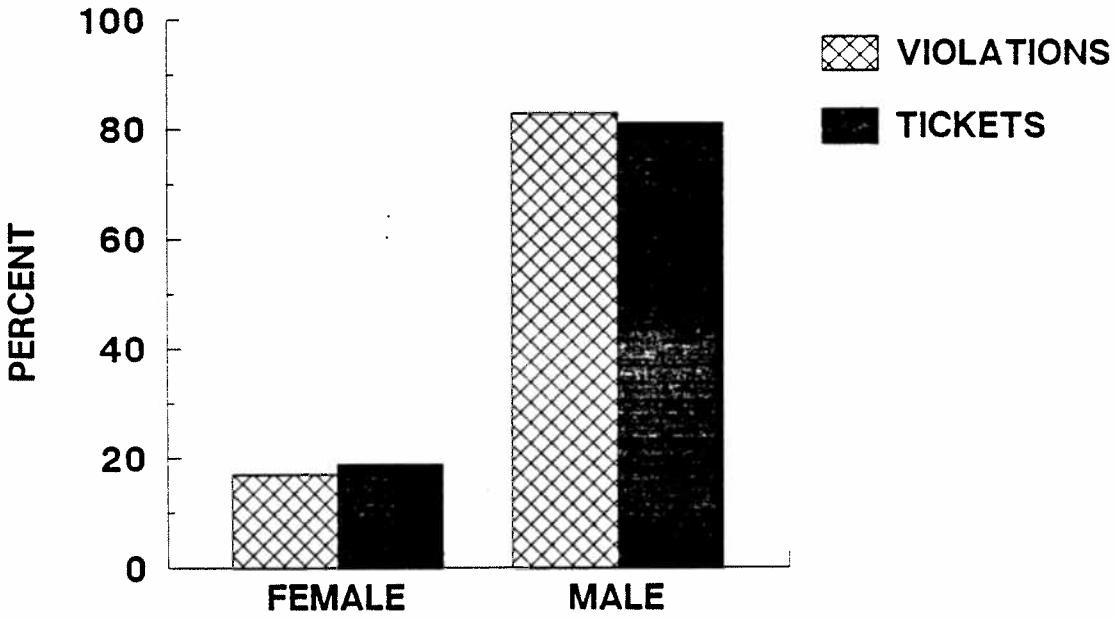

Figure 1.11. Comparisons of the proportion of total violations among systematic contacts made on 13 districts, May through August 1988 and the proportion of total tickets issued during 1986 in Colorado. The proportions were calculated by gender.

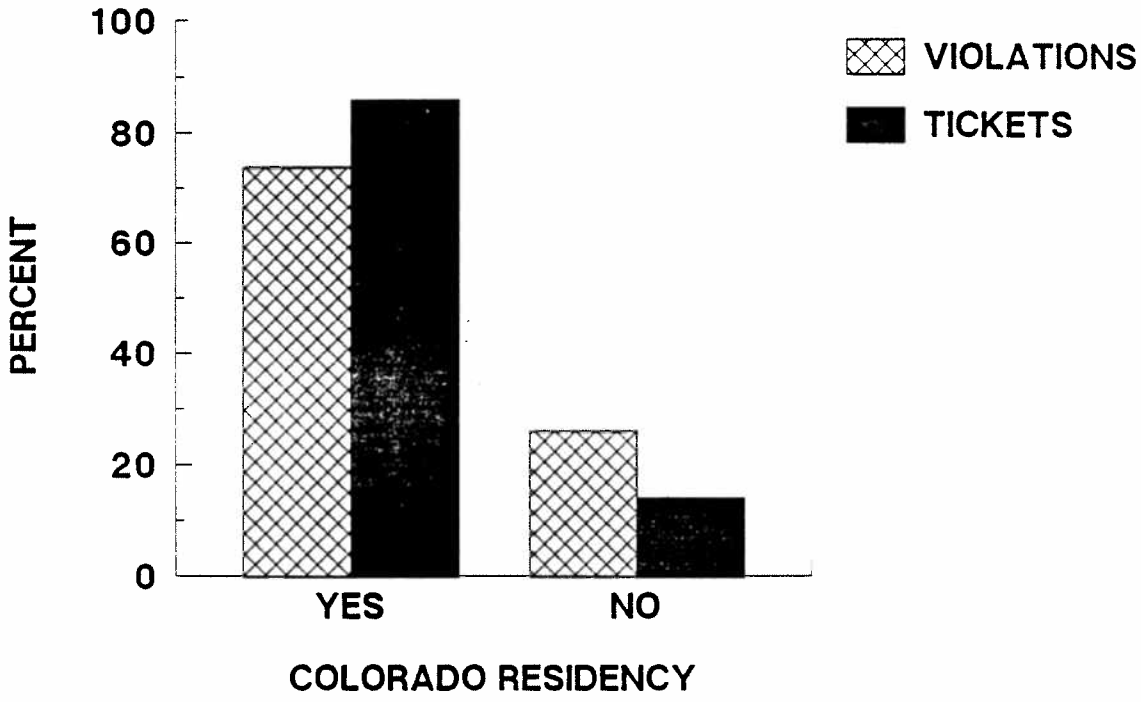

Figure 1.12. Comparisons of the proportion of total violations among systematic contacts made on 13 districts, May through August 1988 and the proportion of total tickets issued during 1986 in Colorado. The proportions were calculated by Colorado residency.

COMPARING AGE OF VIOLATORS AND NONVIOLATORS BY RANDOMIZED RESPONSE

In section 1 of this thesis, data indicated that age was highly correlated with rates of fishing without a license. Approximately 11% of the fishing trips taken by anglers between the ages of 15 and 24 were without a license. In contrast, about 2% of the fishing trips taken by anglers older than 24 were without a license. This large discrepancy in violation rates can be useful in directing education and enforcement programs.

Sources of information on the characteristics of violators are typically official records, e.g., the Uniform Crime Report (Hagan 1982), or self-report questionnaire, e.g., mail survey (Kesel 1974). Wright (1980), however, used the randomized response technique to estimate the proportion of farmers in Iowa who poached at least one deer in a given year. Originally developed by Warner (1965), randomized response is an interview method that encourages truthful responses to questions about potentially embarrassing or stigmatizing topics. In the original method, the respondent is given a sensitive question in its positively and negatively worded form, e.g.,

A. I fished without first buying a license.

B. I did not fish without first buying a license.

The respondent is directed by means of a randomizing device, e. g., roll of a die, to answer only 1 of the 2 questions. The specific result of the randomizing device, known only to the respondent, is withheld from the interviewer. The individual

respondent can not be implicated, because the possible responses to the 2 questions are identical and the interviewer can not be sure which question was selected. For instance, by answering "yes" the respondent can be agreeing that he or she did fish or did not fish without a license; the interviewer can not know for certain. Some investigators have termed this procedure randomized inquiry instead of randomized response (Brown 1975, Bourke and Dalenius 1976) as it is the questions that are randomized rather than the answers. Nevertheless, the probability of the respondents being associated with the sensitive attribute (π) is related to the probability of the total affirmative responses (λ) by

$$\lambda = p\pi + (1 - p)(1 - \pi)$$

where p is the probability of selecting Question A (e. g., $p = 2/3$ for the face of a die less than 5). Or in words

Prob(yes answer) = Prob(yes on Question A) + Prob(yes on Question B)

= Prob(Question A is chosen)Prob(yes | given Question A is chosen)

+ Prob(Question B is chosen)Prob(yes | given Question B is chosen).

Then π is estimated by using the observed proportion of total responses ($\hat{\lambda}$); thus,

$$\hat{\pi} = \frac{(\hat{\lambda} + p - 1)}{(2p - 1)} \qquad \text{for } p \neq 0.5. \tag{2.1}$$

The variance of $\hat{\pi}$ is

$$\hat{\text{Var}}(\hat{\pi}) = \left[\frac{\hat{\pi}(1 - \hat{\pi})}{n}\right] + \left[\frac{p(1 - p)}{n(2p - 1)^2}\right]. \tag{2.2}$$

Many advancements have been made in the past 3 decades that allow flexibility in designing randomized response surveys (Campbell and Joiner 1973, Horvitz et al. 1976, Fox and Tracy 1980, Lai 1982, Chaudhuri and Mukerjee 1988). Greenberg et al. (1969) presented the theoretical framework for the unrelated question model. In this model, rather than offering 2 questions on the same

sensitive topic. 1 question is of a nonsensitve nature while the other regards the sensitive attribute. By substitution the unrelated question model is

$$\lambda = p\pi + (1 - p)\theta$$

where θ is the probability of a yes answer given the unrelated question is chosen. Alternatively, the companion to the nonsensitive question can be a response forced by the randomizing device (Edgell et al. 1982). Using die as the randomizing device, for example, the respondent can be directed to answer the sensitive question if the die comes up 4 or less; otherwise, answer no if the die is 5 or yes if the die is 6. Randomized response was extended to the estimation of quantitative data (e.g., number of crimes committed) by Greenberg et al. (1971). Most recently Bourke and Moran (1988) applied numerical methods to obtain maximum likelihood estimates of proportions where data were collected by randomized response. In addition, Scheers and Dayton (1988) developed a covariate randomized response model that reduces standard errors and allows the relationship of the sensitive characteristic and a continuous covariate to be examined.

Randomized response affords protection to a respondent, but generates additional variation in the process. Compared to a survey that uses direct questioning, a randomized response survey has a larger standard error, therefore it is less efficient. Randomized response is often criticized on this point (Locander et al. 1976, Tracy and Fox 1981, Marquis et al. 1986). However, Scheers and Dayton (1988) note that randomized response is designed to reduce underreporting, a form of response bias associated with sensitive topic surveys especially where direct questioning is used (Sudman and Bradburn 1974, Bradburn and Sudman 1981). Thus, error in direct questioning often includes an unknown (and unaccounted for) bias component that is, in principle, reduced by randomized response.

Efforts to assess the validity of randomized response methods have taken 2 approaches. First, investigators have compared randomized response to other data collection techniques (e.g., direct or self-administered questionnaire). Validity was assumed if the randomized response method returned higher proportions of respondents with the sensitive attribute. These studies cover a wide range of sensitive topics, such as drug use (Goodstadt and Gruson 1975, Reaser et al. 1975, Zdep et al. 1979, Brewer 1981), sexual behavior (Krotki and Fox 1974, Fidler and Kleinknecht 1977), and college exam cheating (Shotland and Yankowski 1982). Most concluded that randomized response methods provided more accurate estimates (Krotki and Fox 1974, Goodstadt and Gruson 1975, Reaser et al. 1975, Fidler and Kleinknecht 1977, Zdep et al. 1979, Shotland and Yankowski 1982). However, Brewer (1981) found admission of marihuana usage to be less by randomized response than by direct questioning. Response rates from randomized response surveys compare favorably to other methods. Although Krotki and Fox (1974) and Goodstadt and Gruson (1975) noted higher response (less refusals) among randomized response interviews, Reaser et al. (1975) conducted a mail survey and found that response rate for randomized response questionnaires were lower than for conventional questionnaires.

At least 3 studies have assessed randomized response in a more rigorous manner; estimates were compared to known values. Locander et al. (1976) examined response bias among 4 data interview methods (i.e., face to face, randomized response, telephone, and self-administered) for 3 levels of sensitive behavior (i.e., library card/voting behavior, bankruptcy, and drunken driving). Although randomized response gave the lowest response bias of the interview methods, there was still a 35% underreporting of drunken driving. Lamb and Stem (1978) compared conventional interview techniques to the quantitative randomized

response method in estimating the number of failing grades per college student. They concluded that randomized response was successful in minimizing measurement error and provided more accurate estimates than conventional methods. Tracy and Fox (1981), again using the quantitative randomized response method, found the method resulted in a substantial reduction in response bias over direct question interviews. Examination of mean squared errors (MSE = variance plus bias squared) of the 2 methods revealed that the relative efficiency (randomized response MSE/ direct question MSE) was less than 1 for sample sizes greater than 80. Thus, response bias became relatively more important than theoretical variance at moderate sample sizes.

While randomized response methods are often applied to personal interviews, telephone and mail surveys have been conducted using randomized response (Brown 1975, Reaser et al. 1975, Shimizu and Bonham 1978, Stem and Steinhorst 1984). However, I know of no application where randomized response interviews were conducted in a group setting. The group setting potentially allows for a greater sense of anonymity compared to face to face of telephone interviews.

The objective of this paper was to use randomized response methods to test the hypothesis that anglers under 25 years old are more likely to fish without a license than older anglers. Randomized response interviews were designed to be conducted in a group setting.

METHODS

In Colorado all hunters born after 31 December 1948 are required to complete a hunter education course. Assuming that the relationship between age and fishing without a license is constant among anglers who do and do not hunt, hunter education students provide a useful and convenient sample population.

In consultation with Colorado Division of Wildlife, I contacted 25 hunter education instructors from the Front Range of Colorado about participating in this study. These 25 were selected for their perceived willingness to participate. Nine instructors gave me permission to interview in their classes. I conducted 15 group interviews between the end of August and mid October 1988; 6 instructors taught 2 classes during the study period. The interviews were dispersed along the Front Range (Table 2.1).

Table 2.1. Location, number, attendance, response, and response rate for each of 15 group interviews conducted at hunter education classes during August through October 1988. Response rate is expressed in percent.

Location and number of class interviews		Attendance	Response	Response rate (%) [a]
Fort Collins	2	90	68	76
Longmont	1	28	15	54
Boulder	2	61	31	51
Brighton	2	36	17	47
Denver	7	145	100	69
Colorado Springs	1	41	26	63
Total/mean	15	401	257	64

[a] Nonrespondents include those not in the population of interest, i.e., nonanglers and anglers under 15 years old.

I adapted the unrelated question model of Greenberg et al. (1969) for this study. The sensitive question asked "Did you fish in Colorado, at least once, during 1988 without first buying a Colorado fishing license?". The unrelated (and nonsensitive) question asked "Were you born in the month of April?". A die inside a 35mm film canister was used as the randomizing device. The die moved freely inside the canister. Because the sensitive question was selected whenever the die showed a face < 5, $p = 2/3$. The probability of being born in the month of April was taken as the proportion of class enrollees born in April; birth dates were available from class rosters.

Fox and Tracy (1986:21) discussed the limitations of using an unrelated question that is part of a respondent's record. In particular, a respondent may suspect that his or her birth month is known and not respond as a result. I interviewed an undergraduate class at Colorado State University by randomized response in the spring of 1987. The last digit of the students' social security number served as the "unrelated question". It is common knowledge that social security numbers are on record. Nevertheless, after the 81 students were interviewed using randomized response, 98% agreed that their response was and would remain completely anonymous. Although observations of college students are not necessarily applicable to the general public, I felt confident that use of an unrelated question taken from public record did not deter response.

Figure 2.1 shows the instructions that each student received. In addition to the instruction sheet, a response card enclosed in an envelope, and the die in the film canister were handed out. I announced that participation in the survey was voluntary. I handed out response cards to all students and attempted to collect all the cards after the survey. I assumed that the total response cards collected was the total in attendance, however it is probable that some cards were not returned.

In Colorado only anglers 15 years old or older are required to purchase a fishing license, and many who attend a hunter education class did not fish in Colorado during 1988. Thus, I instructed those under 15 years old and those who did not fish in Colorado during 1988 not to respond to the survey. During the course of the study I altered the response card to allow those under 15 years old and those who did not fish to indicate this, thereby permitting me to examine possible causes of nonresponse. Prior to my use of the altered response cards, I requested those to whom the survey did not apply to simply return a blank response card.

Those who turned 15 during 1988 and prior to being interviewed could have both legally and illegally fished without a license. I gave verbal instruction that the survey relates only to fishing trips taken after their 15^{th} birthday. However, in retrospect, excluding 15 year olds from the survey would have provided less ambiguous results.

Fox and Tracy (1986) show that subgroup comparisons (e.g., age group of violators versus nonviolators) can be tested by a simple cross tabulation and a chi square test, assuming that survey design and bias are constant across subgroups. I applied this procedure to test for an association between age and prevalence of fishing without a license.

I calculated estimated proportions of violators ($\hat{\pi}$) and associated standard errors of the proportions (SE[$\hat{\pi}$]) by (Chaudhuri and Mukerjee 1988:16)

$$\hat{\pi} = \frac{[\hat{\lambda} - (1-p)\theta]}{p} \tag{2.3}$$

and

$$\hat{SE}(\hat{\pi}) = \sqrt{\frac{\hat{\lambda}(1-\hat{\lambda})}{(n-1)p^2}}. \tag{2.4}$$

Here θ was taken as the proportion of the class rosters who were born in April. I assumed θ was known, not estimated.

RESULTS AND DISCUSSION

Response and Nonresponse

I interviewed a total of 401 students. The median number in each class was 28 with a range of 4 to 53. Fifty percent of the classes were attended by between 15 and 36 people.

The average response rate per class was 64%, as was the response rate overall; 257 responded to the randomized inquiry out of 401 who attended the classes

(Table 2.1). I examined class rosters to compile statistics on the students I interviewed. There were discrepancies in total numbers of students between my counts and the class rosters. The class rosters showed some attendance larger than my counts and some less. This could be due to a combination of the absence of enrolled students and the presence of friends and relatives. Overall the total number of students was 424 according to the class rosters and 401 by my count. In effect, my calculated response rates may be to high (Table 2.1).

I compared the age distributions among survey respondents and those on the original class roster. Survey response did not appear to be related to age group ($\chi^2 = 0.05$, df = 1, P = 0.815). Nearly all (95%) of the respondents indicated their age group. Of those, 34% were between 15 and 24 years old and 66% were 25 years or older. From the class rosters, among those 15 years or older, 35% were between 15 and 24 years old and 65% were 25 years or older.

Most of the observed nonresponse was because the survey did not apply to all students. After the response cards were changed (Fig. 2.1), 8 classes (176 students) were interviewed. One hundred (57%) responded to the randomized inquiry. Among those who did not respond, 45 (59%) indicated that they did not fish in Colorado during 1988, although they were older than 15 years. Twenty five (33%) indicated that they were under 15 years old. Thus, 6 did not provide an explanation for their nonresponse representing 8% of the nonrespondents and only 3% of the 176 students interviewed.

Test of Association

Table 2.2 shows the cross tabulation of observed responses by age group. Even though the power of the test was attenuated by the randomized response process, age was strongly associated with prevalence of violators ($\chi^2 = 6.74$, df =

1, P = 0.009). The young anglers were much more likely to have fished at least once without first buying a necessary license, than older anglers.

I considered the consequences of 15 year olds misinterpreting the survey instructions. According to the class rosters there were 14 students who became 15 during 1988 and before they were interviewed. Because p = 2/3, I expect 9 were asked the sensitive question. The most conservative approach would assume that all 9 answered yes incorrectly; they did fish without a license, but not illegally. Given this scenario no significant association would exist between ages and prevalence of violators (χ^2 = 0.69, df = 1, P = 0.407). As I am not compelled to be so conservative and there is no basis for a middle position, I proceeded with the data as is.

Table 2.2 Cross tabulation of observed responses to a randomized inquiry by the age of respondents for 243 anglers who attended a hunter education class during the fall of 1988. The randomized inquiry included 2 questions: "Did you fish at least once in Colorado without first buying a Colorado fishing license?" and "Were you born in the month of April?".

Response	Age group (years)		Total
	15 to 24	25 or older	
Yes	21	20	41
No	61	141	202
Total	82	161	243

Table 2.3 shows the estimated proportions of violators ($\hat{\pi}$) and associated standard errors ($\widehat{SE}[\hat{\pi}]$) for each relevant age group and all respondents combined. The $\hat{\pi}$ were high compared to the violation rates reported in section 1 of this thesis. I offer three possible explanations. First, the $\hat{\pi}$ are proportions of anglers who fished without a license at least once in 1988. Some of the nonlicensed anglers may have purchased a license later in the year. Second, violator rates (the $\hat{\pi}$) are expected to be higher than violation rates when nonlicensed anglers fish less than

licensed anglers (Appendix). Finally, high violator rates, like violation rates, could be associated with high human population density. Thus, anglers from the Front Range would show higher violator rates than the state as a whole.

Table 2.3. Estimated proportions of violators and associated standard errors for anglers who were interviewed by randomized response. The interviews were conducted in a group setting in hunter education classes. The estimates (in percent) are presented by age group and for all respondents combined.

Age group (years)	Estimated proportion of violators ($\hat{\pi}$)	Estimated standard error ($\widehat{SE}[\hat{\pi}]$)
15 to 24	34	3.2
25 or older	14	1.7
All respondents [a]	22	1.6

[a] 95% of all respondents indicated their age group.

CONCLUSIONS

Application of Randomized Response

The most frequent criticisms of randomized response are that it is inefficient (i.e., requires a larger sample size than direct question surveys to achieve a predefined level of precision) and that the survey is too complicated for the average person to comprehend. Although randomized response is less efficient, it is also less biased (Lamb and Stem 1978, Tracy and Fox 1981). Alternatively, estimates from direct question surveys can suffer from being highly precise, but biased.

In my opinion the mechanics of the randomized response method are easily understood. While I doubt few of the over 400 people I interviewed understood why randomized response works, I believe most were convinced that their response could not implicate them. It is not necessary for the respondent to comprehend randomized response. It is only necessary that they believe the method provides full protection for their answers. My impression is that that occurs readily.

Age as a Covariate of Fishing without a License

These data corroborate earlier findings (see section 1) that anglers under 25 years of age are much more likely to fish without a license than older anglers. If a program is developed to reduce nonlicensed angling (beyond current efforts) then much attention should be directed towards the younger anglers. The exact structure of such a program is beyond the scope of this study. However, consideration should be given to what media can best reach this audience.

STEP 1:

Shake the canister, open the lid and look at the die.

If the die is  then answer question A, truthfully.

If the die is  then answer question B, truthfully.

STEP 2:

Without letting anyone else see, indicate your answer and age group on the response card.

STEP 3:

Put the response card into the envelope and pass the envelope in as instructed.

Question A:

Did you fish in Colorado, at least once, during 1988 without first buying a Colorado fishing license? (answer yes or no)

Question B:

Were you born in the month of April? (answer yes or no)

IF THE DIE IS A 1, 2, 3, OR 4 THEN ANSWER QUESTION (A)

IF THE DIE IS A 5 OR 6 THEN ANSWER QUESTION (B)

☐ YES
☐ NO

PLEASE INDICATE YOUR AGE: ☐ UNDER 15 YEARS OLD ✳

☐ 15 TO 24 YEARS OLD ☐ 25 YEARS OLD OR OLDER

IF YOU ARE UNDER 15 YEARS OLD DO NOT RESPOND TO THIS SURVEY

☐ I DID NOT FISH IN COLORADO DURING 1988. ✳

✳Added midway through the study.

Figure 2.1. Instructions and response card used in randomized response interviews of hunter education classes during the fall of 1988.

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