ARIZONA GAME AND FISH DEPARTMENT

RESEARCH BRANCH
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EVALUATION OF THE U.S. FOREST SERVICE'S FISH HABITAT RELATIONSHIP SYSTEM IN EAST- CENTRAL ARIZONA TROUT STREAMS

A Final Report

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September 1991
Revised May 1995

FEDERAL AID IN SPORT FISH RESTORATION PROJECT

Arizona Game and Fish Department Mission

To conserve, enhance, and restore Arizona's diverse wildlife resources and habitats through aggressive protection and management programs, and to provide wildlife resources and safe watercraft and off-highway vehicle recreation for the enjoyment, appreciation, and use by present and future generations.

Arizona Game and Fish Department
Research Branch

Technical Report Number 8

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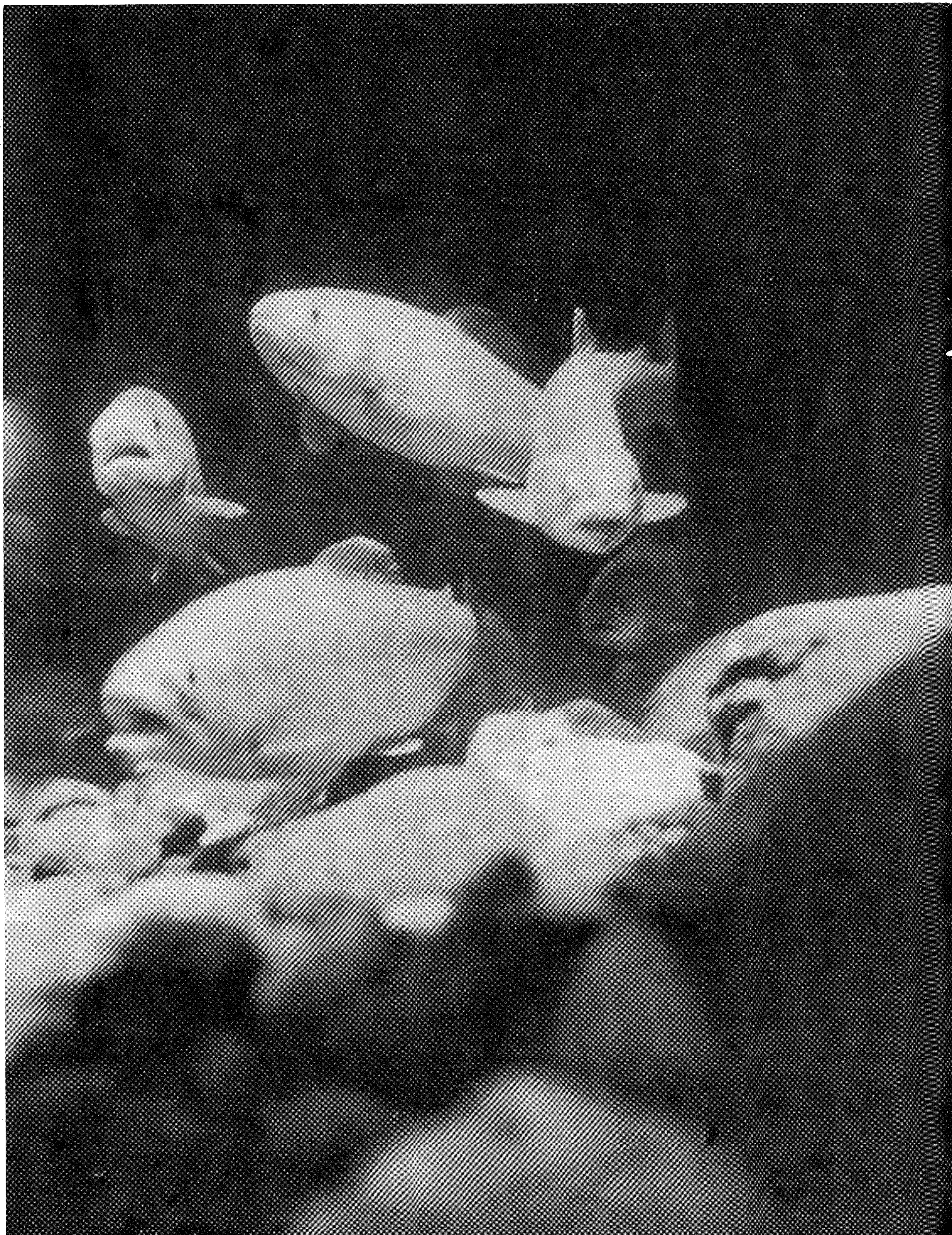

Evaluation of the U.S. Forest Service's Fish Habitat Relationship System in East-Central Arizona Trout Streams

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Abstract: Habitat and fish population data were collected between 1986-1990 from 243 sampling stations among 75 reaches of 21 high elevation trout streams in east-central Arizona to test and evaluate the survey design and predictive models of the U.S. Forest Service's Fish Habitat Relationship System (FHRS). With some modification, the perpendicular-to-flow clustered transect survey design was capable of statistically unbiased habitat and fish population descriptions when rigorously applied. The FHRS Habitat Condition Index model proved to be of little utility for predicting trout populations in Arizona streams, and its use should be abandoned in Arizona. The FHRS Habitat Vulnerability Index could not be objectively tested within our study design, but a Delphi evaluation indicated that it could be misused by land managers if certain guidelines were not established. The FHRS COWFISH model, with additional modifications, showed promise for future applications to Arizona situations. We developed 2 multiple linear regression models that predicted fish and trout standing crops within predetermined precision criteria. These models and logistic regressions demonstrated that a rating of the amount of ungulate damage to stream banks consistently explained the greatest amount of variation in standing crops of fishes. We conclude that better cattle management in many riparian zones in the White Mountains area is necessary for improvement of trout habitats and enhancement of trout populations.

INTRODUCTION

Biologists and land managers have sought an understanding of cause-and-effect relationships between measurable characteristics of the environment and standing crops of stream fishes (number or biomass per unit length, area or volume of stream) since at least the early 1950s (McKernan et al. 1950, Allen 1951). The use of mathematical models to decipher these associations first appeared in the literature in the 1970s (reviewed by Fausch et al. 1988), and met with varied success, in part depending on the application of proper statistical procedures, adherence to model assumptions, incorporation of adequate sample sizes, management of measurement errors, and other factors. To be useful for analyzing land management alternatives, Fausch et al. (1988) concluded that models must be specific for a homogeneous area and include variables that are affected by land management. These models, however, do not necessarily impart an understanding of cause-and-effect relationships between the independent and dependent variables. Manipulation of the habitat and monitoring responses of the fish community in many cases have not been undertaken.

The U.S. Forest Service (USFS), charged with managing thousands of kilometers of riverine habitat that dissect the West's multiple-use national forests, recognized the need for a quantified causal connection among land use practices, stream and riparian habitat quality, and associated fishery resources. Federal legislation such as the Multiple-Use Sustained Yield Act of 1960 (PL 86-517), the Forest and Rangeland Renewable Resources Planning Act of 1974 (PL 93-378), the National Forest Management Act of 1976 (PL 94-588), and the Public Rangelands Improvement Act of 1978 (PL 95-514), provided impetus for funding research to better understand these relationships. The USFS and others examined effects of major land uses such as livestock grazing and silviculture on riparian habitats, stream morphology and fish populations. In the process, standard stream survey routines were developed and refined. The USFS also produced multivariate models to predict relationships between fish standing crop and stream habitat quality.

A result of these continuing efforts was development of the USFS Fish Habitat Relationship System (FHRS), a multi-faceted program with the goal to "integrate fish habitat inventory and evaluation into project and forest level interdisciplinary resource planning and management." The system is designed around the assumption that "streams draining lands that have been formed by similar processes will be similar in fishery production potential and react the same to specific management practices" (Parsons 1984). At the present time, FHRS is intended for application to salmonid streams only. As a whole, FHRS is intended to analyze, integrate and predict compatibility of land use practices with salmonid fishery resources.

FHRS utilizes a transect-based, systematic inventory technique (General Aquatic Wildlife System [GAWS]; USFS 1990) to quantify baseline information on stream and riparian habitats and fish populations. A multiple-pass, block-and-shock depletion technique is used for quantification of fish populations. A land-aquatic classification (Rosgen 1985) attempts to stratify streams into reaches based on physical similarities.

Finally, FHRS predictive models are intended to assess existing and optimal habitat capabilities and species carrying capacities and aid in evaluation and monitoring of Forest Plans. Primary models within FHRS include the Habitat Condition Index (HCI) (USFS 1990), a composite rating of existing trout habitat quality; the Habitat Vulnerability Index (HVI) (USFS 1990), a descriptor of the vulnerability of stream habitat to disturbance from management activities; COWFISH (USFS 1985), a predictor of the effects of livestock grazing on fish standing crops; the Biotic Condition Index (BCI) (Winget and Mangum 1979), a descriptor of perturbations to a stream based on water quality tolerances of the existing macroinvertebrate community; and FISHSED (Stowell et al. 1983), a predictor of sediment yields from different land use practices and their effects on fishes and aquatic habitats. With the exception of the latter two, the data, criteria, and procedures used in formulation of these models have not been published in the peer-reviewed literature, nor are they available for review.

The GAWS survey methodology is intended to summarize stream habitat conditions and estimate standing crops of fishes that occupy those habitats. GAWS accepts certain assumptions that have not been fully evaluated, and a purpose of our study was to test the validity of those assumptions. We attempted to identify the potential biases of the method by examining the following questions:

1) Does stream reach stratification facilitate an understanding of the patterns of variation of habitats and fish populations along a stream course?

2) What are the patterns and magnitudes of variation of habitats and fish populations within a stream, stream reach, or sampling site?

3) Does the GAWS survey design describe patterns of habitat and fish populations in a statistically unbiased manner?

4) Are there other survey designs or techniques more appropriate for fulfilling the objectives of FHRS?

We attempted to develop an experimental design that would answer these questions using objective statistical tests. We made some modifications of the GAWS survey design to aid these analyses.

This report attempts to critique, test, and validate selected major elements of FHRS for utility in Arizona. High elevation trout streams in the Apache-Sitgreaves National Forest and White Mountain Apache Nation in east-central Arizona were surveyed according to FHRS procedures between 1986 and 1990 (Fig. 1, Table 1), and provided the basis for testing and assessment. The objectives of this study were as follows:

1) Determine if the sampling design and data obtained from the GAWS survey methodology (USFS 1990) adequately describe stream conditions.

2) Determine if the land-aquatic classification system used in FHRS (Rosgen 1985) is applicable to lotic ecosystems in Arizona.

3) Test selected FHRS models and outputs using data from Arizona streams, and evaluate their local utility.

4) Modify existing, or develop new, stream habitat models that explain greater variation in fish standing crops than do FHRS models.

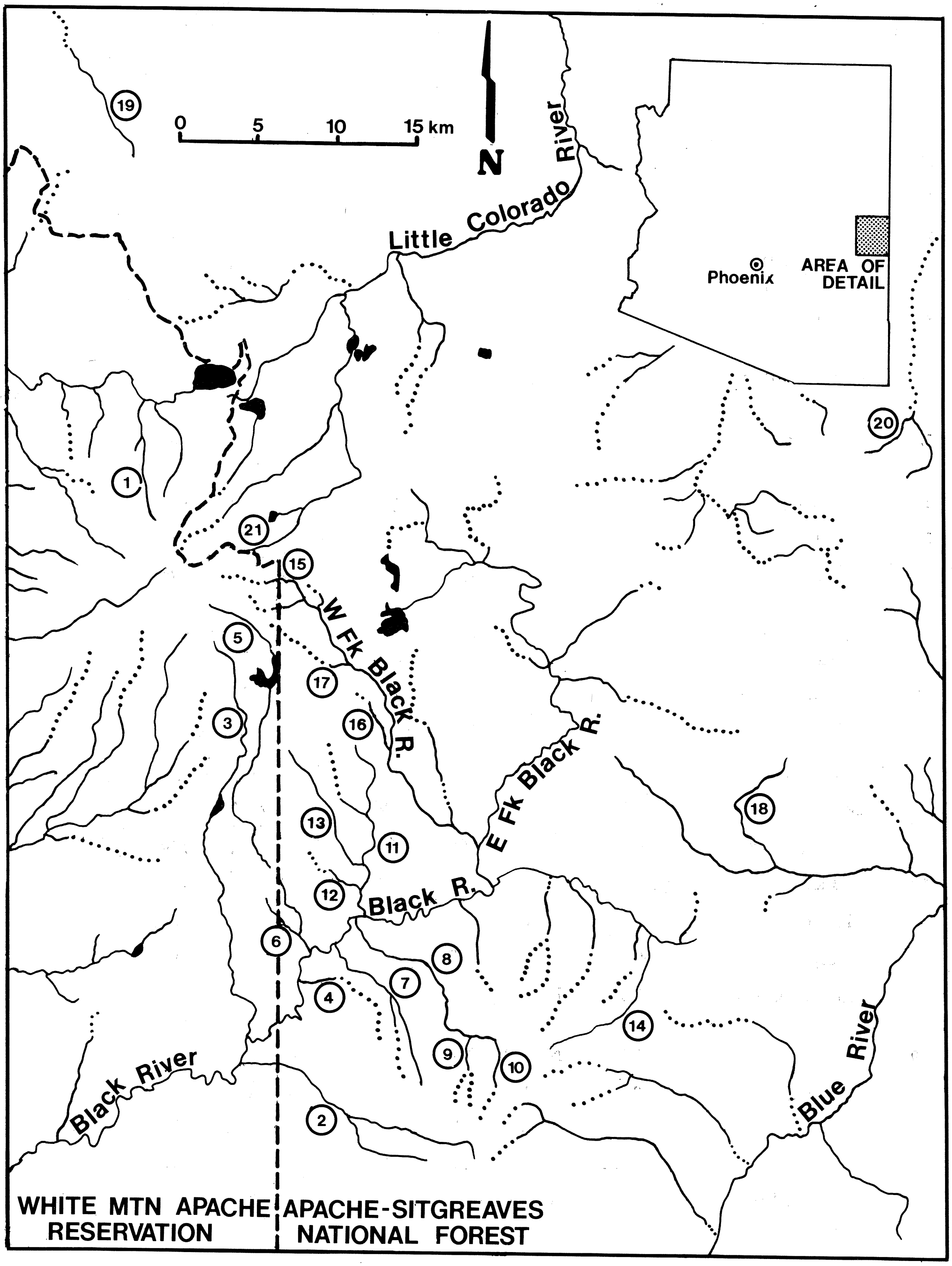


Figure 1. Map of the drainages of the White Mountains area, Apache-Sitgreaves National Forest and White Mountain Apache Nation, showing locations of the study streams. Numbers refer to streams listed in Table 1.

Table 1. Summary data of stream reaches used for testing and validation of FHRS methodologies. Unless otherwise designated, streams are located within the Apache-Sitgreaves National Forest. Stream numbers refer to numbers in Figure 1.

No.	Stream	No. of Reaches-Stations[1]	Sampling Dates	Species Sampled
1	Ord Creek[2]	2-12	AUG 13 - AUG 23, 1990	*O. apache, S. fontinalis*
2	Bear Wallow Creek (North & South Forks)	5-26	SEP 11 - OCT 11, 1990	*O. apache X O. mykiss*
3	Pacheta Creek[2]	13-45	JUL 17 - SEP 6, 1990	*O. mykiss, S. fontinalis, S. trutta, R. osculus*
4	Snake Creek	1-4	JUN 4 - JUN 7, 1990	*O. apache, S. trutta, R. osculus*
5	Reservation Creek[2]	5-20	JUL 16 - AUG 8, 1990	*O. apache, O. mykiss, S. fontinalis, S. trutta*
6	Soldier Creek	3-9	JUL 6 - JUL 9, 1989	*O. apache, S. trutta*
7	Conklin Creek	3-8	JUL 12 - JUL 20, 1988	*O. apache*
8	Fish Creek	4-12	JUL 22 - AUG 18, 1987	*O. apache, S. Fontinalis, R. osculus, P. clarki*
9	Double Cienega Creek	2-5	JUN 24 - JUN 30, 1987	*O. apache, R. osculus*
10	Corduroy Creek	3-5	JUL 9 - JUL 22, 1987	*O. apache, R. osculus*
11	Centerfire Creek	3-8	JUN 2 - JUN 20, 1988	*O. apache, S. trutta, R. osculus*
12	Wildcat Creek	2-6	MAY 18 - JUN 1, 1988	*O. apache X O. mykiss*
13	Boggy Creek	3-5	MAY 14 - MAY 22, 1988	*O. apache, S. trutta, R. osculus*
14	Hannagan Creek	4-13	MAY 12 - MAY 20, 1990	*O. apache X O.mykiss, R. osculus*
15	W Fk Black River	2-10	MAY 7 - MAY 31, 1990	*S. trutta, R. osculus*
16	Hayground Creek	3-8	JUN 23 - JUN 29, 1988	*O. apache X O. mykiss, R. osculus*
17	Stinky Creek	4-12	MAY 31 - JUN 19, 1989	*O. apache X O. mykiss, R. osculus*
18	Coleman Creek	2-8	JUL 1 - JUL 11, 1990	*O. apache, O.mykiss, R. osculus, P. clarki*
19	Mineral Creek	2-5	NOV 17 - NOV 20, 1986	*O. apache*
20	Mamie Creek	2-9	JUN 20 - JUN 26, 1989	*O. apache*
21	E Fk Little Colorado River	7-11	AUG 6 - AUG 19, 1987	*S. fontinalis, S. trutta, R. osculus, P. discobolus*

1 Major (clustered transect) stations only; number of stations used for testing may be less than the number actually sampled.

2 White Mountain Apache stream.

Multiple linear and logistic regression models, which relate measured habitat and geomorphicvariables to fish standing crops, were developed under the latter objective as alternative tools to address some of the goals of FHRS for local uses in east-central Arizona, high-elevation trout streams. Their use in other areas and habitats is discouraged without further testing and validation.

STUDY AREA

Study streams straddle the zone separating the Colorado Plateau and Basin and Range Physiographic Provinces in the White Mountains area, east-central Arizona (Fenneman 1931). They drain the White Mountains Volcanic Field and adjacent areas in the Little Colorado and Gila river basins, the latter consisting of tributaries in the White, Black, and Blue sub-basins (Fig. 1, Table 1). The area is characterized by volcanic, volcaniclastic, alluvial, lacustrine, colluvial, and glacial late Tertiary and Quaternary deposits (Merrill and Pewe 1977). Mount Baldy and Mount Ord, remnants of the Mount Baldy Volcano of middle Tertiary age, represent the highest elevations of the area, rising to 3475 and 3461 m above sea level, respectively. The lower altitudinal limit of the study area is just above 2000 m.

Riparian habitats typically are located within ponderosa pine (*Pinus ponderosa*) and mixed conifer forests. Shrub willows (*Salix scouleriana, S.bebbiana, S. exigua, S. laevigata,* and *S. lasiolepis*) and other shrubs such as red-osier dogwood (*Cornus stolonifera*), shrubby cinquefoil (*Potentilla fruiticosa*), and thinleaf alder (*Alnus tenuifolia*) dominate the riparian scrublands. Aspen (*Populus tremuloides*) and conifer species including ponderosa pine, Douglas-fir (*Pseudotsuga menziesi*) and white fir (*Abies concolor*) are occasionally present, but distinctive riparian tree forms are typically absent. Subalpine wet meadows also occur along high elevation watercourses, and are dominated by grasses such as *Poa pratensis, Muhlenbergia wrightii, Carex* spp. and *Juncus* spp. Willow communities may also be present in these meadows (Minckley and Brown 1982). Some lower elevation riparian habitats consist of mixed broadleaf and cottonwood-willow gallery forest communities. Diverse mixtures of tree species such as Arizona sycamore (*Platanus wrightii*), velvet ash (*Fraxinus pennsylvanica* var. *velutina*), Fremont cottonwood (*Populus fremontii*), Arizona alder (*Alnus oblongifolia*), Arizona walnut (*Juglans major*), and several species of willow, such as *Salix gooddingii*, are present. Boxelder (*Acer negundo*), narrowleaf cottonwood (*P. angustifolia*), and bigtooth maple (*Acer grandidentata*) may also be present (Brown 1982). Szaro (1989) defined and described the vegetative community types of the study area.

The native fish fauna of these high elevation streams was historically composed of the endemic Apache trout, *Oncorhynchus apache*, either alone or in combination with the cyprinid *Rhinichthys osculus*. Gila mountain sucker (*Pantosteus clarki*) and bluehead mountain sucker (*P. discobolus*) penetrated lower reaches of these streams in the Gila and Little Colorado river basins, respectively (Minckley 1973, Minckley et al. 1986).

Today these streams often are occupied by introduced rainbow trout (*O. mykiss*), brown trout (*Salmo trutta*), and brook trout (*Salvelinus fontinalis*), which in many cases has resulted in the displacement, replacement or genetic swamping of *O. apache* (Rinne et al. 1981, Rinne and Minckley 1985, Dowling and Childs 1992, Carmichael et al. 1993). Chemical renovation of many of these streams for removal of non-native trouts and reintroduction of Apache trout and associated native species has progressed since the early 1960s (Rinne and Turner 1991). We avoided such streams in our evaluations unless a minimum of 5 years since renovation and restocking had passed.

METHODS

Steering Committee

A panel of 10 fisheries biologists, representing the Arizona Game and Fish Department, various entities within USFS, U.S. Fish and Wildlife Service, and the University of Arizona, was established in 1989 for the purpose of ensuring multi-agency participation in the design and implementation of the study. The committee and other participants met on March 30, 1989, to discuss FHRS and formulate an outline for the evaluation of the system in Arizona. AGFD then developed a draft study plan that included detailed methods, hypotheses, and statistical tests, which was sent to committee members for review. Comments and criticisms were incorporated into a final study plan and sent to committee members along with a summary of the major comments expressed regarding the earlier draft. Selected members of the committee also participated in a field evaluation of the Habitat Vulnerability Index (see below).

Selection of Study Streams

Selected perennial, coldwater streams in the Apache-Sitgreaves and Coconino national forests in east-central and north-central Arizona, respectively, were to be surveyed and evaluated for compatibility with FHRS methods and models. GAWS survey data acquired from the Coconino National Forest (Schuhardt 1989), however, proved incompatible in terms of fish communities (low fish populations) for testing purposes developed in the approved study plan for this project, and thus were not included in analyses. Trout streams selected for survey in the Apache-Sitgreaves National Forest were those with resident populations of the endangered Apache trout, or with other species of trout designated as high potential coldwater fisheries. Streams (or stream reaches) selected for use in model testing and validation procedures were an unstocked, lightly-fished, first and second order subset of these streams. These criteria were applied in an attempt to limit effects of stocking and fishing pressure on standing crops. Three streams in the White Mountain Apache Nation were chosen because of their "pristine" nature (ungrazed or lightly grazed by cattle) for comparison with the more disturbed streams in the Apache-Sitgreaves National Forest. This was essential for model testing purposes in order to span a larger range of stream conditions. These streams were also chosen because they had a high diversity of reach (channel) types (see below). Streams were surveyed once in the period following ice-out and spring high flows (typically beginning in May) and prior to the onset of heavy snows in autumn (typically November). Discharges at the time of sampling were believed at or near base levels in these ungauged streams. Sampling ceased during rare minor spates caused by summer rains.

GAWS Sampling Design

Three years of stream survey data (1986-1988) were obtained using the standard sampling design and procedures of GAWS. The sampling design of this method stratifies streams into reaches according to channel types of Rosgen (1985). Rosgen divisions are based on differences in gradient, sinuosity, width-depth ratios, substrate composition, channel entrenchment, valley confinement, and landform and soil characteristics. Our surveys did not necessarily classify reaches to homogeneous Rosgen channel types, but our reach classification procedure employed similar concepts and characteristics. Streams were divided into reaches denoted as meadow (mean gradient <2%, mostly fine substrate, poorly confined channel), canyon or headwater (mean gradient >6%, mostly large substrate, highly confined channel), and intermediate channel types. This level of stream classification is analogous to the Landtype of Lotspeich and Platts (1982) and Nelson et al. (1992). Each stream was walked from mouth to headwater, and approximate reach boundaries were identified. Division of a stream course into discrete reaches in this manner was occasionally difficult. The purpose of defining a stream reach was to stratify habitat and fish population variance. Some headwater reaches were excluded from analyses when physical barriers precluded fish access.

Under the GAWS methodology guidelines, we selected "representative" sampling stations within these reaches. We avoided sampling sub-reaches that were not representative of overall reach conditions. This technique likely reduced measurement variance, but introduced bias, because "unrepresentative" portions of the stream were not accounted for when summarizing stream conditions. Unless dimensions of these sub-reaches are quantified, it is impossible to ascertain what portion of the stream reach is "representative."

The newer version of GAWS (USFS 1990) dictated establishment of a minimum of 2 sampling stations per reach if shorter than 1.6 km, a minimum of 3 per reach if between 1.6-16.0 km, and a minimum of 5 per reach if longer than 16 km. Earlier versions allowed sampling of short reaches with only 1 station, and reaches less than 400 m were not to be surveyed at all. Our 1986-1989 surveys occasionally sampled shorter reaches with only a single station because we did not receive the newer edition until 1988. Sampling design was modified during 1989-1990 surveys to facilitate statistical evaluations of the technique.

A standard GAWS sampling station consisted of 5 "clustered" perpendicular-to-flow transects spaced upstream at regular intervals from the station identification point. Sampling stations surveyed in 1986-1987 were 152.4 m (500 ft) long (older English unit GAWS design), those in 1988 were 100 m long, and modified 1989-1990 stations were 50 m in length. Thus, the former stations had transects established at 30.5 m intervals, 1988 stations spaced transects at 20 m intervals, and latter transects were at 10 m intervals. Platts et al. (1983) reported that precision of habitat measurements among transects increased with decreasing distance between transects.

A diagrammatic example of our 1989-1990 survey modifications is illustrated in Fig. 2. Sampling stations were located in a systematic pattern within identified reaches, with 3 stations established in reaches shorter than 500 m in length, 5 within reaches between 500 and 1500 m, and 10 within reaches over 1500 m in length. For reaches less than 500 m in length, the initial station was established 50 m above the lower reach boundary, and for longer reaches, the lowermost station was placed 100 m above the lower reach boundary. Remaining stations were established at regular intervals to embrace the majority of the reach length. The uppermost station never began within 100 m of the end of a reach.

At each station demarcation point, a single perpendicular-to-flow transect was surveyed, hereafter designated "systematic" transects. Within shorter reaches (<500 m), all 3 stations were also surveyed with 5 clustered transects, as described above, beginning 20 m above the systematic transect. Intermediate length reaches (500-1500 m) were surveyed with clustered transects in this manner at odd-numbered stations (1, 3, and 5; illustrated in Fig. 2), and longer reaches (>1500 m) established clustered transects at stations 1, 3, 5, 6, 8, and 10. In text that follows, stations sampled with only a single systematic transect are termed "minor" stations, and those sampled with clustered transects are termed "major" stations (Fig. 2). Each station was classified according to Rosgen (1985) channel type.

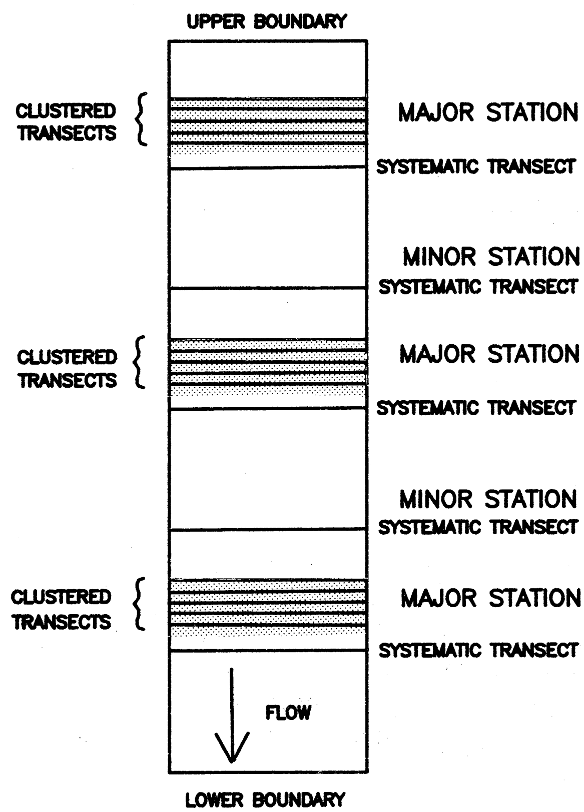


Figure 2. Diagrammatic representation of a stream reach, depicting the 1989-1990 modified sampling design employed to evaluate the GAWS methodology. Minor stations were surveyed with a single systematic transect and major stations were also sampled with a series of 5 "clustered" transects. Stippling represents the areas electrofished and habitat typed. See text for further discussion.

Habitat Measurements

Habitat variables were quantified at each transect or station (Table 2). Most habitat measurement procedures were tested for precision and accuracy by Platts et al. (1983). Variables not conducive to transect evaluation (e.g., channel gradient) were measured or estimated over portions of the station length (Table 2). Station elevations were taken from U.S. Geological Survey topographical maps. Transects that crossed split stream channels were omitted from analyses. All variables with left and right stream or bank measures (shore depth, undercut bank width, bank angle, bank ungulate damage, bank vegetation cover, bank soil stability) were combined to form a single variable representing the mean of both values.

Stream area sampled at each station was calculated from the product of mean stream width (across transects) and station length (50.0, 100.0, or 152.4 m). Stream volume was derived from the product of stream area and mean stream depth (across transects) within a station. These variables were used in estimating numbers and biomass per unit stream area (m^2) and unit stream volume (m^3) of trouts and fishes.

For comparisons with GAWS transect data, and to identify fish habitat utilization patterns, surveys conducted in 1989-1990 also classified instream habitats according to habitat types of Bisson et al. (1981) and McCain et al. (1990) (Table 3). Within each 50 m major station reach (encompassing the clustered transects and area of fish collections), stream habitat units were identified (e.g., low gradient riffle, cascade, etc.), enumerated, and unit dimensions quantified. Length, 4 measurements of width, and maximum depth were recorded for each habitat unit. The numbers and species of fishes collected from within each unit were recorded and summed over electrofishing passes (see below).

Fish Population Surveys

Fish populations were surveyed by electrofishing according to the GAWS methodology (USFS 1990). Upstream and downstream boundaries of each major station (incorporating the 5 clustered transects) were blocked with nets, and 3 separate upstream "passes" were completed (or until no fish were collected) using a 12 volt DC powered inverter with a 200 watt, 115 volt AC output backpack electroshocker. Fish samples were sorted to species, weighed to the nearest gram with an electronic balance, and measured to the nearest millimeter total length.

Fish collection procedures were modified for 1989-1990 surveys to conform to modified station sampling changes for those years (above). Fishes were collected following enumeration of habitat type units, but prior to measurements of habitat variables; otherwise, collection methods were not altered.

Specimens not taken for pathological examinations or museum collections were released below the downstream net. Population estimates for each electrofished section were made using the pass depletion maximum likelihood method of Zippin (1958), incorporated in the PC MicroFish 3.0 software package of Van Deventer and Platts (1989). Missing fish weights, due to equipment breakdowns or windy conditions, were assigned from length-weight regression equations. MicroFish 3.0 computes confidence intervals for populations (numbers) only; biomass upper and lower 95% confidence limits were calculated by multiplying the quotients of population upper and lower limits relative to mean population by total biomass.

FHRS Models

Habitat Condition Index. The various FHRS models are intended to aid decision-makers regarding potential impacts of land use practices on stream fishery resources. When possible, we attempted to evaluate the models using objective statistical tests or consensus expert opinion. The Habitat Condition Index (HCI) is purported to be a rating of trout habitat that is proportionately related to its capacity to sustain trout standing crops. For example, an HCI value of 75 would indicate that the habitat supports only 75% of its potential trout biomass. HCI was calculated according to USFS (1990) from the mean of the following variables, expressed as percent: 1) pool measure; 2) pool structure; 3) streambottom; 4) bank cover; 5) streambank soil stability rating; and 6) streambank vegetation stability rating (Table 2). The HCI model was evaluated by regression of HCI outputs against observed trout standing crops.

Habitat Vulnerability Index. The Habitat Vulnerability Index (HVI) is intended to rate the susceptibility of a stream reach to perturbations

Table 2. Variable designations and descriptions of methods of measurement of variables quantified and rated at sampling stations. Only GAWS and HCI variables were used in multiple regression modeling trials.

GAWS Variables	Description
Channel width	distance (±0.1 m) between banks along a transect at the points where changes in slope, vegetation, and/or substrate material indicated "bank-full" discharge (Platts et al. 1983, USFS 1990)
Stream width	distance (±0.1 m) along a transect between shores, including individual substrate particles above water completely surrounded by water (Platts et al. 1983, USFS 1990)
Mean water depth	sum of depths (±0.01 m) recorded at 1/4, 1/2, and 3/4 the stream width across a transect, divided by either 4 or 3, depending on whether both shore depths were zero, or one or both were greater than zero, respectively (Platts et al. 1983, USFS 1990)
Maximum water depth	deepest point (±0.01 m) along a transect (USFS 1990)
Riffle width	transect width (±0.1 m) accounted by riffle, run, or cascade habitat as defined by Bisson et al. (1981) (Platts et al. 1983, USFS 1990)
Pool width	transect width (±0.1 m) accounted by pool or glide habitat as defined by Bisson et al. (1981) (Platts et al. 1983, USFS 1990)
Channel gradient	slope (±0.5%) between transects, measured with a clinometer and stadia rod (Platts et al. 1983, USFS 1990)
Riparian canopy density	area of sky (%) measured 0.3 m above the water surface of a transect accounted by vegetation, measured with a spherical densiometer, as modified by Strichler (1959) (Platts et al. 1987, USFS 1990)
Periphyton width	transect width (±0.1 m) covered by visible encrusting algae (USFS 1990)
Macrophyte width	transect width (±0.1 m) covered by macrophytes and rooted algae (USFS 1990)
Boulder width	transect width (±0.1 m) accounted by boulder (256-4,096 mm diameter) (modified from Platts et al. 1983, USFS 1990)
Cobble width	transect width (±0.1 m) accounted by cobble (64-256 mm diameter) (modified from Platts et al. 1983, USFS 1990)
Gravel width	transect width (±0.1 m) accounted by gravel (2-64 mm diameter) (modified from Platts et al. 1983, USFS 1990)
Sand/silt width	transect width (±0.1 m) accounted by sand and silt (0.004-2.0 mm diameter) (modified from Platts et al. 1983, USFS 1990)
Other substrate width	transect width (±0.1 m) accounted by other bottom materials (clay, detritus, etc.) (modified from Platts et al. 1983, USFS 1990)
Width:depth ratio	stream width divided by mean water depth at a transect (USFS 1990)
Shore depth	depth (±0.01 m) of water at shoreline or edge of overhanging bank at a transect (Platts et al. 1983, 1987, USFS 1990)
Undercut bank width	transect width (±0.01 m) from furthest point of bank protrusion (shoreline) to furthest point of bank undercut (Platts et al. 1983, 1987, USFS 1990)
Bank angle	angle formed by downward sloping streambank as it meets the water surface, measured with a clinometer and meter stick (Platts et al. 1983, 1987, USFS 1990)
Embeddedness	percent of gravel and larger substrate perimeter covered or surrounded by sand and smaller substrate within the stream 5 m above and below transect, rated as: 5) <5%, 4) 5-25%, 3) 26-50%, 2) 51-75%, 1) >75% (modified from Platts et al. 1983, USFS 1990)
Bank ungulate damage	percent of streambank 5 m above and below transect grazed and trampled by ungulates, rated as: 4) 0-25%, 3) 26-50%, 2) 51-75%, 1) >75% (modified from Platts et al. 1987, USFS 1990)
Bank vegetation cover	class of vegetation on or above streambank 5 m above and below transect, rated as: 4) shrubs dominant, 3) trees dominant, 2) grasses and forbes dominant, 1) >50% of streambank transect line barren of vegetative cover (modified from Platts et al. 1987, USFS 1990)

Table 2. Continued.

GAWS Variables	Description
Bank soil stability	percent of streambank surface 5 m above and below transect covered by vegetation or substrate classes, rated as: 4) >80% covered by vegetation or by boulders and cobble, 3) 50-79% covered by vegetation or by gravel and larger substrates, 2) 25-49% covered by vegetation or by gravel and larger substrates, 1) <25% covered by vegetation or by gravel and larger substrates (modified from Platts et al. 1983, USFS 1990)
Bank vegetation stability	percent of streambank surface 5 m above and below transect covered by vegetation or substrate classes, rated as: 4) >80% covered by vegetation or by boulders and cobble, 3) 50-79% covered by vegetation or by gravel and larger substrates, 2) 25-49% covered by vegetation or by gravel and larger substrates, 1) <25% covered by vegetation or by gravel and larger substrates (USFS 1990)
Discharge	cubic meters per second measured by the conventional current meter method (a minimum of 5 points across transect), measured with an electromagnetic flow meter (1988-1990) (Rantz et al. 1983); or the velocity-headrod method (a minimum of 4 points across transect) (1986-1987) (Wilm and Storey 1944)
Valley bottom width	distance between toe slope to toe slope (relatively unconfined channels) or between "bank-full" channel points (highly confined channels), measured with a rangefinder (±10 m) if >100 m or tape (±1 m) if <100 m (USFS 1990)
Riparian area width	width (±1 m) of valley bottom with distinct vegetative communities occasionally submerged under flood flows, measured with a rangefinder (±10 m) if >100 m or tape (±1 m) if <100 m (modified from Platts et al. 1983, USFS 1990)
Station elevation	estimated from U.S. Geological Survey topographic maps

HCI Variables	Description
Pool measure	sum of all pool widths across transects at station divided by sum of all stream widths at station (x 100). If dividend (d) < 50, rating = 100 -[(50 - d) x 2]; if dividend = 50, rating = 100; if dividend > 50, rating = 100 -[(d - 50) x 2] (USFS 1990)
Pool structure	sum of all pool widths longer or wider than average stream width and greater than 0.6 m deep across transects at station divided by sum of all pool widths at station (x 100) (USFS 1990)
Streambottom	sum of all gravel widths and cobble widths across transects at station divided by sum of all stream widths at station (x 100) (USFS 1990)
Average bank vegetation cover	sum of all bank vegetation cover ratings at station divided by the product of 8 x the number of transects at station (x 100) (USFS 1990)
Average bank soil stability	sum of bank soil stability ratings at station divided by 8 x the number of transects at station (x 100) (USFS 1990)
Average bank vegetation stability	sum of bank vegetation stability ratings at station divided by 8 x the number of transects at station (x 100) (USFS 1990)
Habitat condition index (HCI)	sum of pool measure, pool structure, streambottom, average bank vegetation cover, average bank soil stability, and average bank vegetation stability, divided by 6 (USFS 1990)

HVI Variables	Description
Average valley bottom width	average valley bottom width in reach, rated as: 1) <30 m, 2) 30-100 m, 3) > 100 m (USFS 1990)
Average channel gradient	average channel gradient in reach, rated as: 1) <2%, 2) 2-3%, 3) 3.1-6%, 4) >6% (USFS 1990)
Average side slope gradient	average of valley side slope gradients (±0.5%) in reach, measured with a clinometer and meter stick, rated as: 1) <60%, 2) 41-60%, 3) 30-40%, 4) <30% (USFS 1990)
Bank angle coefficient	number of occurrences in reach of bank angles, rated as follows: 1) undercut (<90°), 2) steep slope (90-135°), 3) gentle slope (>135°). Coefficient computed as sum of frequency of rank 1 (x 3), frequency of rank 2 (x 2), and frequency of rank 3 (x 1), divided by 2 x the sample size (USFS 1990)
Channel stability coefficient	number of occurrences in reach of channel stability ratings (Table 5). Coefficient computed as sum of frequency of rank E (x 4), frequency of rank G (x 3), frequency of rank F (x 2), and frequency of rank P (x 1), divided by 2 x the sample size (USFS 1990)

Table 2. Continued.

HVI Variables	Description
Indicators of potential sediment production coefficient	number of occurrences in reach of each type of indicator of potential sediment production, including pioneer vegetation, V-notch, thick soil over bedrock, and slumping, divided by 8 x the sample size. Percent maximum occurrence (coefficient) rated as 1) >10%, 2) 5-10%, 3) 3-5%, 4) <3% (USFS 1990)
Habitat vulnerability index (HVI)	sum of average valley bottom width, average channel gradient, average side slope gradient, bank angle coefficient, channel stability coefficient, and indicators of potential sediment production coefficient, divided by 22 (x 100)

COWFISH Variables	Description
Percent undercut bank	percent of bank at station with slope <90° (USFS 1985)
Percent vegetative overhang	percent of bank at station with vegetation overhanging stream (USFS 1985)
Percent bank soil alteration	percent of bank at station with soils exposed or trampled (USFS 1985)
Percent embeddedness	as defined above, but not rated (USFS 1985)
Width:depth ratio	as defined above (USFS 1985, 1990)
Percent undercut bank PSI	percent undercut bank at station, rated as: <10%=0, 11-24%=0.1, 25-29%=0.2, 30-34%=0.3, 35-39%=0.4, 40-44%=0.5, 45-49%=0.6, 50-59%=0.7, 60-74%=0.8, 75-84%=0.9, ≥85%=1.0 (USFS 1990)
Percent vegetative overhang PSI	percent vegetative overhang at station, rated as: <10%=0.1, 10-19%=0.2, 20-24%=0.3, 25-34%=0.4, 35-39%=0.5, 40-44%=0.6, 45-54%=0.7, 55-74%=0.8, 75-99%=0.9, 100%=1.0 (USFS 1990)
Percent bank soil alteration PSI	percent bank soil alteration at station, rated as: >98%=0, 96-98%=0.1, 91-95%=0.2, 89-90%=0.3, 86-88%=0.4, 76-85%=0.5, 66-75%=0.6, 51-65%=0.7, 26-50%=0.8, 1-25%=0.9, 0%=1.0 (USFS 1990)
Percent embeddedness PSI	percent embeddedness at station, rated as: >50%=0, 47-50%=0.1, 44-46%=0.2, 41-43%=0.3, 36-40%=0.4, 31-35%=0.5, 26-30%=0.6, 21-25%=0.7, 11-20%=0.8, 1-10%=0.9, 0%=1.0 (USFS 1990)
Width:depth ratio PSI	width:depth ratio at station, rated as: >26=0.1, 26=0.2, 24-25=0.3, 22-23=0.4, 21=0.5, 20=0.6, 19=0.7, 13-18=0.8, 5-12=0.9, <5=1.0 (USFS 1990)
Mean PSI	sum of percent undercut bank PSI, percent vegetative overhang PSI, percent bank soil alteration PSI, percent embeddedness PSI, and width:depth ratio PSI, divided by 5 (USFS 1990)
Habitat suitability index (HSI)	mean PSI at station, rated as: >0.90=1.00, 0.81-0.90=0.75, 0.71-0.80=0.65, 0.61-0.70=0.55, 0.51-0.60=0.45, 0.41-0.50=0.40, 0.31-0.40=0.35, 0.21-0.30=0.25, 0.11-0.20=0.20, 0.01-0.10=0.10, 0=0 (USFS 1990)
Optimum stream width	width:depth ratio PSI x mean stream width at station (ft) (USFS 1990)
Optimum (predicted) trout numbers	optimum stream width x 5 (numbers of trout >154 mm per 300 m of stream) (USFS 1990)
Existing (predicted) trout numbers	optimum (predicted) trout numbers x habitat suitability index (numbers of trout >154 mm per 300 m of stream) (USFS 1990)

Table 3. Habitat types quantified in streams surveyed in the White Mountains area Arizona, 1986-1990. Definitions are based on those provided by Bisson et al. (1981) and McCain et al. (1990).

Habitat Type	Description
Cascade	The steepest riffle habitat, consisting of alternating small waterfalls and shallow pools. Substrate is usually bedrock and boulders.
High gradient riffle	Steep reaches of moderately deep, swift, and very turbulent water. Amount of exposed substrate is relatively great. Gradient is >4%, and substrate is boulder dominated.
Low gradient riffle	Shallow reaches with swiftly flowing, turbulent water with some partially exposed substrate. Gradient <4%, substrate is usually cobble dominated.
Glide	A wide shallow pool flowing smoothly and gently, with low to moderate velocities and little or no surface turbulence. Substrate usually consists of cobble, gravel and sand.
Run	Swiftly flowing reaches with little surface agitation and no major flow obstructions. Often appears as flooded riffles. Typical substrates are gravel, cobble and boulders.
Pool	A broad category of relatively deep habitat types consisting of secondary channel pools, backwater pools, plunge pools, and dammed pools, characterized by slow-flowing currents, no surface turbulence, and small substrates.

from land uses and natural events. HVI is computed by assigning ratings to 6 habitat variables: 1) valley bottom width; 2) stream gradient; 3) gradient of valley side slopes; 4) lower bank angles; 5) channel stability rating; and 6) a summary of indicators of potential sediment production (Table 2). The final HVI is obtained by dividing the sum of these ratings by the maximum possible sum and expressing it as percent (USFS 1990).

Because the HVI does not yield a hypothesis that can be statistically tested from data collected within this study, a Delphi approach to its evaluation was undertaken (Crance 1987). A questionnaire was developed regarding rating criteria of stream reaches for perceived vulnerability to management activity and natural perturbations, and was sent to all steering committee members. Available respondents were taken on a field tour of 2 streams and their watersheds in the Apache-Sitgreaves National Forest by the senior author. Results of the questionnaire were presented and discussed, and each component variable of HVI was applied and evaluated in regard to different stream and reach situations. Consensus conclusions for component variables and the overall index were recorded and discussed. Actual HVI values for the study streams were not computed.

Also evaluated under the Delphi questionnaire format described above were USFS (1990) definitions of Potential Spawning Area (PSA) and Potential Rearing Area (PRA), defined as the proportions of stream area comprised of gravel between 3 and 76 mm (0.125-3.0 in) in diameter, and stream area with current velocities less than 0.3 m/s (1 ft/s), respectively. Potential Overwintering habitat (POW) is another index of habitat quality mentioned in the USFS (1990) handbook, but its definition could not be found. Respondents to the HVI questionnaire were asked to rate existing definitions of these variables for suitability in Arizona trout streams, and modify them as appropriate. Results were reviewed at the HVI field trip, and consensus definitions and opinions recorded.

COWFISH. We also tested the COWFISH model (USFS 1985) with our data. COWFISH employs Parameter Suitability Indices (PSI) of 5 habitat variables to model the influences of livestock grazing on existing and potential (optimum) trout standing crops and stream width:depth ratios. PSI's are based on the Instream Flow Incremental Methodology Habitat Suitability Index model (Stalnaker 1979, Bovee 1981). The 5 variables include: 1) percent undercut bank, 2) percent vegetative overhang, 3) percent streambank altered, 4) percent embeddedness, and 5) width:depth ratio (Table 2).

Mean-scaled PSI values of these 5 variables determined percent of optimum fish production, the Habitat Suitability Index (HSI) (Table 2).

Existing stream width was multiplied by the PSI for width:depth ratio to determine optimum stream width. Optimum trout carrying capacity (numbers of trout greater than 152 mm [6.0 in] TL per 300 m of stream length) was obtained by multiplying optimum stream width (in feet) by 5.0, the slope of the regression relationship for slopes less than 5% within nongranitic soil types. Only meadow channel types were used for testing purposes, because cattle ostensibly have the most impact to, and the method is supposed to work best in, this habitat type (USFS 1985). Predicted existing standing crops were obtained by multiplying optimum carrying capacity by percent of optimum (HSI) (Table 2).

We evaluated the COWFISH model by regression of observed trout standing crops and predicted existing standing crops. Predicted optimum trout standing crop outputs were compared with a subset of observed values from stream stations with the highest 25% standing crop levels.

Regression Modeling

Multiple linear and logistic regression models were developed in an attempt to obtain the greatest benefits from the data acquisition and model testing aspects of our study. The models were intended to aid in the understanding of the functional relationships between components of the stream environment and fish standing crops, and if validated, to be used as predictive tools for management purposes.

The strategy for building regression models employing habitat variables as predictors and biomass (g/m^2 and g/m^3) estimates of trouts and total fishes as response variables involved 4 phases: 1) determination of the functional form of the variables to be included in the model, 2) reduction of the number of independent variables, 3) model refinement and selection, and 4) model validation. Density measures of fish standing crops were excluded because of the large seasonal variation of this component.

The set of 1,201 habitat transects among 243 fish sampling stations was pooled across stations using transect means, so that a single value for each habitat variable corresponded to each station's fish standing crop value. The distributional assumption of normality was examined by using the Kolmogorov-Smirnov (K-S) one-sample test.

Data used in linear regression modeling included only cases with non-zero values in the response variable (n=223). The decision to use non-zero response data was based on our belief that the absence of fishes in a stream reach may have been caused by historic events unrelated to the condition of the habitat at the time of sampling. In addition, the high proportion of zero observations was likely to dominate the fit of the model, and prediction was of importance in the use of the model. Frequency distributions of the response variables and various transformations were also examined and tested for normality with the K-S test.

Two-dimensional scatterplots of the transformed dependent variables and each independent variable were examined to help determine the functional form of the variables to appear in the model (i.e. linear, quadratic, etc.). Stream channel type (meadow, canyon/headwater, and intermediate) was entered into regression models as a dummy variable.

As a large number of independent variables was available for inclusion into the systematic part of the generalized linear model, methods using "all subsets," Mallow's C_p (total mean squared error), R^2_p (partial coefficient of multiple determination), and MSE_p (mean squared residual error) were considered in variable selection. The "best" subset of independent variables based on these criteria was then examined to see if it made sense statistically and biologically.

Diagnostics including residual plots, probability plots, and influence measures (Cook and Weisberg 1983a, 1983b) were employed to improve the fit of the model. Multicollinearity was investigated through use of the variance inflation factor and correlation matrices. Multicollinearity was minimized in several ways; removal of some highly correlated variables, transformations of variables, and application of ridge estimates. Influential points in the data were determined by the use of the Cook's distance, D_i criterion, in addition to Dffits and Dfbetas. These models were fitted using mainframe SAS with the regression (PROC REG) and generalized linear model (PROC GLM) procedures.

The reliability and robustness of the regression coefficients, the plausibility and usability of the regression function, and the ability to draw biological inferences from the regression analysis were examined by using a hold-out sample. Sixty-seven percent of the available observations were randomly selected for use in the model building process, and the remaining 33% of the data were then used to determine how well the parameter estimates performed on another data set. The steering committee determined that for management purposes, the predicted 95% confidence interval for each observation should bracket 80% of the actual new observations to be validated. Models that utilized the entire data set were also developed and compared to subset models.

RESULTS

Univariate Statistics

There was considerable variability in data for many habitat variables among all transects and fish biomass indices among all stations (Appendix 1). Standard deviations exceeded the size of the mean, often by a substantial margin, for pool width, periphyton width, macrophyte width, most substrate variables, width:depth ratio, shore depth, undercut bank width, discharge, riparian area width, and trout biomass measures. The mean exceeded the size of the median for most variables, reflecting their positively skewed distributions. The K-S test for normality showed that only mean water depth, gravel width, bank soil stability, bank angle, riparian canopy density, and station elevation did not differ significantly from a normal distribution.

Distributions of the dependent variables were shown to be nonnormal based on application of the K-S tests. Both square root (sqrt) and log transformations produced normality for the non-zero dependent variable data, and regression trials were performed with both transformations.

A simple method of comparing fluctuations of habitat variable means with increasing sample size (Elliott 1971) was used to determine the adequacy of the number of sampling units (transects) in the GAWS sampling design. Figure 3 illustrates the behavior of the mean of selected habitat variables from 3 stream reaches with a randomly chosen subset of increasing sample size. For the most part, fluctuation of the mean stabilized after a sample size of approximately 20 transects was attained, but in some instances a sample size of 30 was inadequate.

Intra-reach Comparisons. In order to evaluate the potential bias of early surveys that utilized a single station to summarize reach conditions, the Kruskall-Wallis (K-W) test for comparisons of means was used to test for differences among GAWS habitat variable station mean ranks within reaches. All 23 selected independent variables examined showed some significant differences among stations within a given reach, ranging from 10% to 64% of the 39 1989-1990 stream reaches evaluated ($P < 0.05$). Channel width, stream width, cobble width, and most rated bank variables had the greatest proportion of intra-reach differences; bank measurements, boulder width, other substrate width, and pool width had the fewest. These results indicated that the probability of misrepresenting existing habitat conditions with a single station per reach was high.

Equivalence among trout standing crop estimates within a reach was evaluated by visual inspection of 95% confidence intervals calculated from the Zippin (1958) method. A subset of reaches for this analysis is presented in Figure 4. Most reaches exhibited apparent differences (nonoverlap) among intra-reach population estimates. It is also apparent that many differences occurred between stations at the extremes of the reaches and the more centralized station locations. Non-descending patterns of fish captures with successive electrofishing passes contributed to the occasional appearance of extremely wide error bars (Fig. 4). These findings demonstrate the necessity of employing multiple stations per reach in order to estimate fish populations without bias.

Comparisons between the systematic transect survey design and the clustered transect design were accomplished by testing habitat variable mean ranks of the 2 data sets within each reach. Only 57 of the 897 (6.4%) combinations among 23 selected variables and 39 reaches were significant according to the K-W test ($P < 0.05$), and no single variable was consistently disparate. Therefore, the 2 survey designs yield similar data.

We evaluated the utility of the Rosgen (1985) channel type classification system by examining the distribution of Rosgen channel types to determine their degree of homogeneity within our reach designations. Forty-one of the 68 reaches (60.3%) with multiple stations were comprised of identical major channel types (i.e. all meadow, intermediate, or headwater/canyon). The remainder displayed a mixture of channel types, which was typically between the headwater/canyon and intermediate designations (most meadow reaches were homogeneous). Reaches exhibiting more than 1 channel type often displayed changes near the beginning or terminus of the reach; the distributions of channel types among centrally-located stations were more homogeneous.

Inter-reach Comparisons. Since the majority of reaches were homogeneous for channel types, we evaluated the reach stratification system by comparing mean ranks of GAWS habitat variables among channel types within the same stream. K-W tests of 16 selected habitat variables (riparian

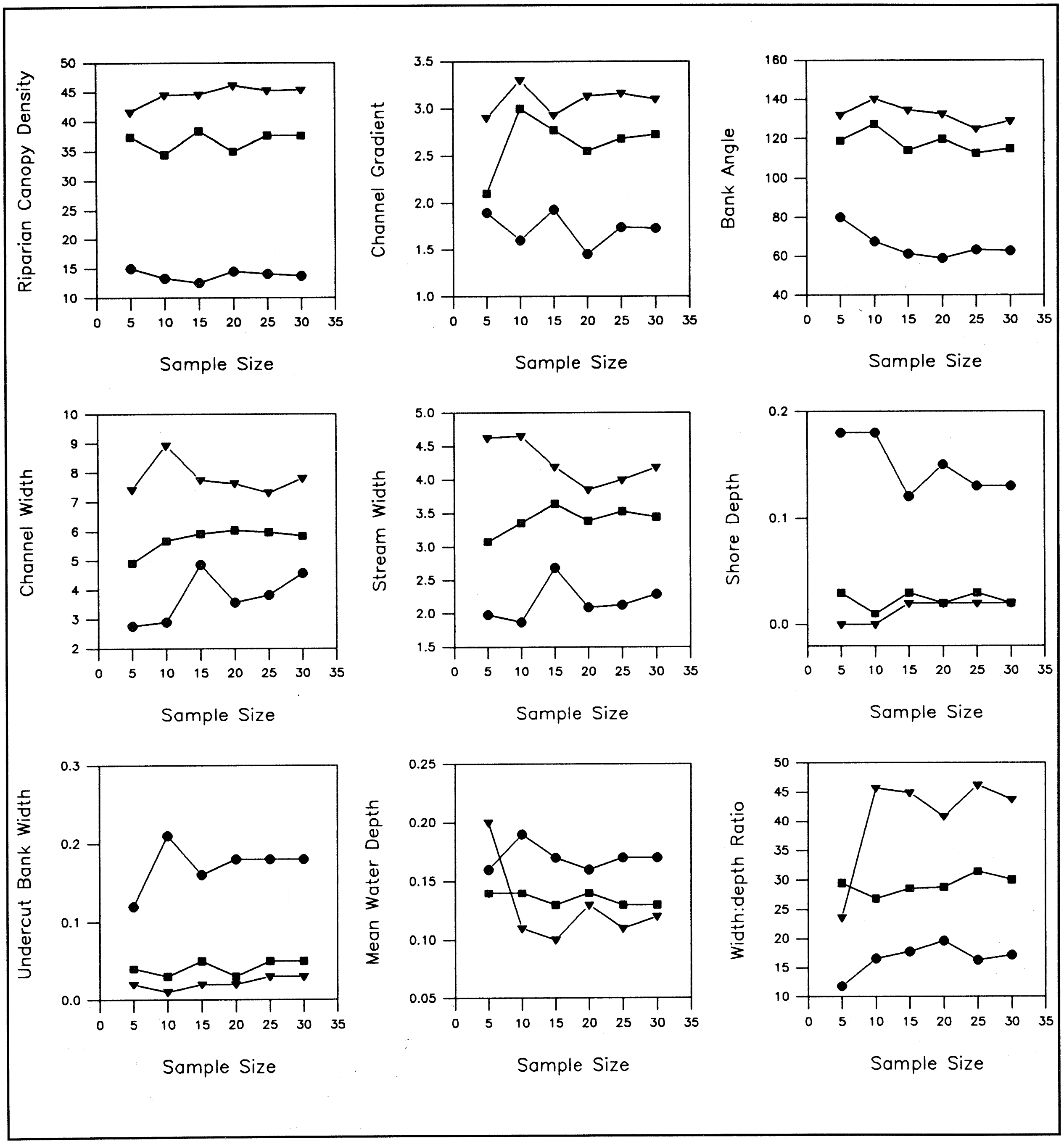


Figure 3. Fluctuations of the mean with sample size of selected habitat variables from Ord Creek reach 1 (circles), Bear Wallow Creek reach 1 (triangles), and West Fork Black River reach 8 (squares).

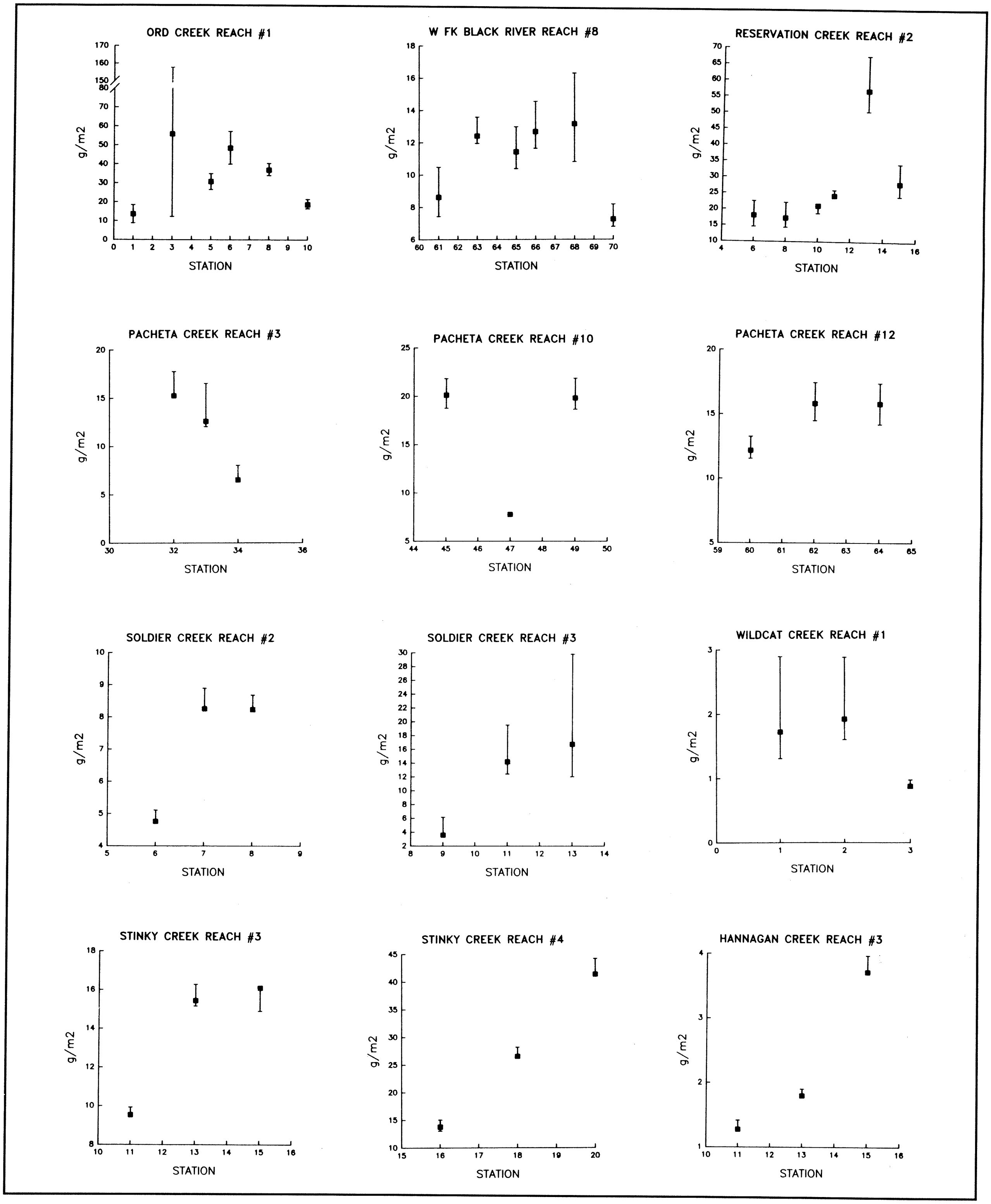


Figure 4. Distributions of trout standing crops among stations within selected stream reaches. Squares represent the mean, and vertical lines 95% confidence intervals of the means from the Zippin (1958) maximum likelihood method.

canopy density, channel gradient, channel width, stream width, bank soil stability, bank vegetative cover, bank ungulate damage, bank angle, undercut bank width, mean water depth, gravel width, cobble width, width:depth ratio, valley bottom width, riparian area width) within 19 streams that exhibited heterogeneity of channel types determined that cobble width was the only measure that was different among channel types in more than one-half of the streams examined (74%; $P<0.05$). Bank soil stability displayed the fewest number of differences (1 of 19). The remaining variables displayed inter-channel type differences in 11-47% (2-9 of 19) of the streams examined. These statistical outcomes imply that the Rosgen classification system as we practiced it does not always define reaches that display significant differences among single habitat measurements.

Trout biomass/m^2 and trout biomass/m^3 were evaluated in a similar manner, with the former measure exhibiting differences among channel types in 4 of 19 streams (21%), and the latter in 2 of 19 streams (11%), as determined by the K-W test ($P<0.05$). These results also question the utility of Rosgen channel types as a basis for stream stratification, if fish populations are assumed to vary according to differences in habitat.

However, when log-transformed non-zero fish standing crops were compared among channel types with ANOVA, they were significantly different. The SNK multiple range test revealed that all were different from each other ($P<0.05$). Meadow channel types displayed the greatest variation in standing crops and also exhibited the highest biomasses. The distributions of fish standing crops by channel type are shown in Figure 5. These results suggest that meadow reaches have the greatest potential for fish production.

Inter-stream Comparisons. Nearly all GAWS habitat variables displayed significant differences among streams and among channel types across streams, indicating the expected heterogeneity within the study area. The single nonsignificant variable, according to the K-W test, was pool width in the latter evaluation ($P>0.05$).

Tests of the 16 selected GAWS habitat variables (above) within a channel type designation also indicated there was considerable variation among streams. Within headwater/canyon channel types, there were significant differences for riparian canopy density, bank vegetative cover, bank angle, and mean water depth variables across streams ($n=25$). Within intermediate channel types, there were significant differences for all selected variables except riparian area width ($n=116$). Within meadow channel types, all variables were different with the exception of mean water depth and valley bottom width ($n=64$).

Evaluations of trout biomass in this manner demonstrated similar heterogeneity among streams. Both trout biomass/m^2 and trout biomass/m^3 were significantly different among channel types by stream, and within meadow and intermediate channel types, but did not display differences within headwater/canyon channel types across streams. These results convey only minimal information, since inter-stream differences among habitats and fishes are pervasive.

Habitat Typing

An evaluation of the variation of habitat types among the study streams was performed with 2 composite habitat type categories: the relative area (%) of slow-flowing habitat types (pool and glide), and the relative area (%) of swift-flowing habitat types (low gradient riffle, high gradient riffle, run, and cascade) (Table 3). The expected heterogeneity of these habitat types was confirmed with the K-W test; both were significant both among streams and among channel types across streams ($P<0.05$).

One of the advantages of the habitat typing technique over the transect methodology is its capability to demonstrate habitat utilization patterns of fishes. Correlations between the numbers of total fishes and total trouts with high gradient riffle area, pool area, swift-flowing habitat area (as above), and slow-flowing habitat area (as above) were significant for both standing crop measures ($P<0.05$) (Table 4). Correlations were all negative in these instances. When the same analyses were performed using the relative areas of habitat types, percent high gradient riffle area was negatively correlated and percent low gradient riffle area positively correlated with both total fishes and total trouts. Other significant correlations of total fishes and relative area of habitat types were with the composite habitat types of slow- (positive) and swift-flowing (negative) habitats, while trouts were also correlated with percent glide area (positive), percent run area (positive), and percent pool area

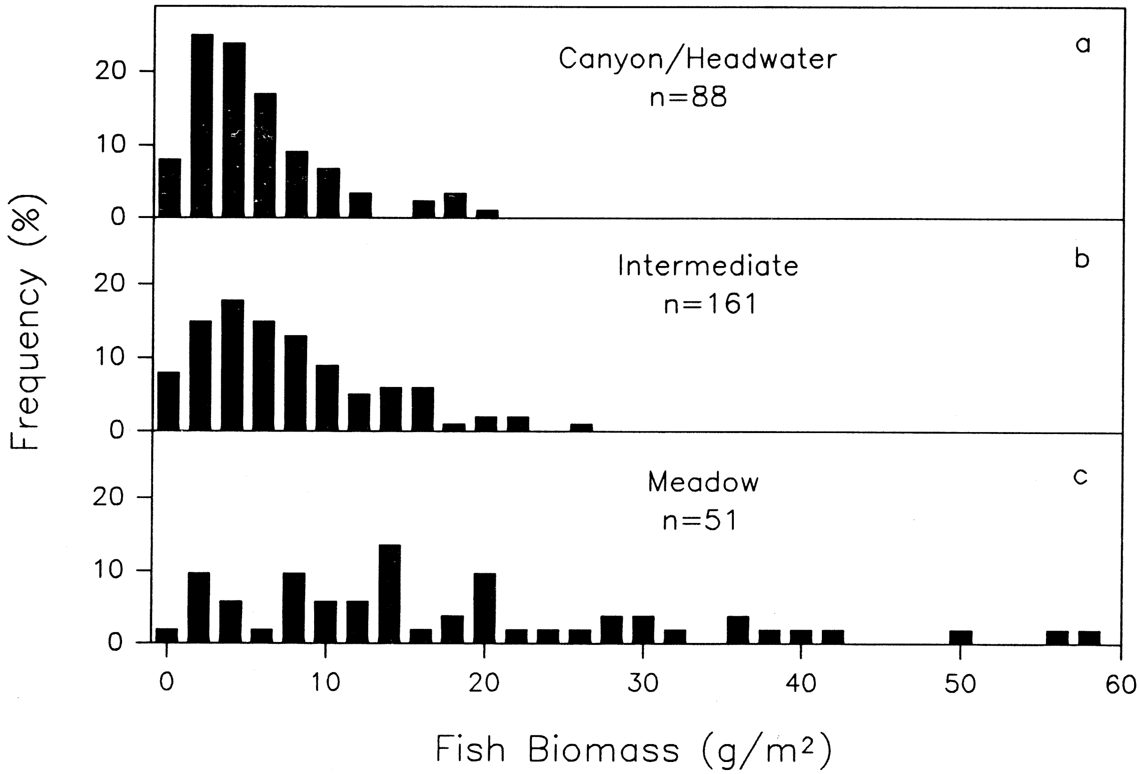


Figure 5. Frequency distributions of fish standing crops (g/m^2) from sampling stations within (a) canyon/headwater channel types, (b) intermediate channel types, and (c) meadow channel types.

Table 4. Correlation matrices (Pearson's r and one-tailed probabilities) for percent habitat type area and absolute habitat type area with total numbers of trout and fish.

	Percent cascade	Percent glide	Percent hi-gradient riffle	Percent lo-gradient riffle	Percent run	Percent pool	Percent swift habitat	Percent slow habitat
Fish	-0.0513	0.0774	-0.2295	0.2260	0.1340	-0.0643	-0.0043	0.0043
	P=0.239	P=0.142	P=0.001	P=0.001	P=0.031	P=0.186	P=0.476	P= 0.476
Trout	-0.0395	0.1248	-0.2843	0.3200	0.1992	-0.1788	0.0602	-0.0602
	P=0.292	P=0.042	P<0.001	P<0.001	P=0.003	P=0.006	P=0.202	P= 0.202

	Absolute cascade	Absolute glide	Absolute hi-gradient riffle	Absolute lo-gradient riffle	Absolute run	Absolute pool	Absolute swift habitat	Absolute slow habitat
Fish	-0.0312	-0.0614	-0.2595	0.0982	0.0780	-0.1458	-0.1967	-0.1454
	P=0.333	P=0.197	P<0.000	P=0.087	P=0.140	P=0.021	P=0.003	P=0.002
Trout	-0.0233	-0.1067	-0.3115	0.1015	0.0673	-0.2809	-0.2457	-0.2724
	P=0.374	P=0.069	P<0.001	P=0.079	P=0.175	P<0.001	P<0.000	P<0.001

(negative). These associations, although relatively weak, suggest an unexpected proclivity of trouts in White Mountain area streams for moderate currents and relatively shallow habitats, as exhibited in low gradient riffles, glides, and runs, while displaying an avoidance of slow-flowing, deep habitats (pools). Relative area estimates of the distributions of habitat types among stream reaches are shown in Appendix 3.

FHRS Models

Habitat Condition Index. HCI assumes that quality trout habitat is associated with high trout standing crops. Thus, we evaluated the HCI by examining its relationship with the log-transformed non-zero trout standing crop estimates trout no./m^2, trout no./m^3, trout biomass/m^2, and trout biomass/m^3, by linear regression. Of the HCI's composite variables, pool measure, streambank soil stability, and streambank vegetation stability had regression coefficients that differed significantly from zero ($P < 0.05$) with all standing crop measures, but coefficients of determination were only between 0.020 and 0.155. Stream bottom was significant only with the log of trout no./m^3 ($R^2 = 0.026$).

With only about half of the composite variables exhibiting nominal correlation with trout standing crops, it was not surprising that HCI displayed only a weak relationship. HCI was significant only with the logs of trout no./m^2 and trout no./m^3, but the low R^2 values of 0.023 and 0.017 rendered the index of little utility as an indicator of trout habitat conditions in the White Mountains area, assuming trout are limited by habitat, and other limitations of the study are accepted.

We separately evaluated the utility of the HCI for management use in meadow reaches by regressing HCI against observed trout standing crops on the subset of surveyed meadow reaches ($n = 51$ stations). The HCI explained 41% of the variation in trout biomass--a considerable improvement, but still well below management and research standards for predictive use.

Habitat Vulnerability Index. Steering committee members who returned the HVI questionnaire from the Delphi evaluation method ranked lower bank angle coefficient, channel stability coefficient, and indicators of potential sediment production coefficient high in importance for rating stream habitat vulnerability, while valley bottom width coefficient and valley side slope coefficient were ranked low. There was no general agreement among rankings of stream gradient coefficient.

Respondents who attended the field evaluation of the HVI agreed that the directions of impact (e.g., low stream gradients more vulnerable to impacts than high gradients) established for these variables were appropriate in most instances, with only a few situational inconsistencies. There was consensus that channel stability coefficient was, in part, constructed independent to habitat needs of fishes, and some sub-components seemed to be contrary to what was considered good salmonid habitat. It was concluded that channel stability coefficient was more a hydrological and geomorphological tool than one indicative of impacts to fishes. The components of this variable were also the most difficult to decipher and rate by field crews (A. Telles, U.S. Forest Service, personal communication).

The major conclusion regarding the suitability of the HVI for its intended purpose, was that most land use activities, by degrading stream habitats, reduce the vulnerability of streams to further impact by the process of becoming degraded. For example, as an undercut bank is eroded and its angle increases, the susceptibility to further erosion is lessened. Therefore, undisturbed streams are highly vulnerable to impacts from land use activities, and restoration of degraded streams must be directed toward making them more vulnerable. A complete summary of the field evaluation of the HVI is found in Appendix 4.

Also evaluated in a Delphi context was the FHRS definition of Potential Spawning Area (USFS 1990), the proportion of stream area comprised of gravel between 3-76 mm in diameter. In reference to Apache trout, it was recommended that the upper range of sediment particle sizes in the definition be restricted to 32 mm (1.25 in) in diameter, based on information of Harper (1976). It was concluded that not enough information was known for a precise definition of this potentially limiting factor, and that any definition could not necessarily be used to predict which areas would be used for spawning.

Potential Rearing Area (USFS 1990), the proportion of stream area with current velocities less than 0.3 m/sec, was concluded by field evaluators to be seldom a limiting factor in

Arizona streams, and thus its definition and utility would not be considered by the group. Potential Overwintering Area (definition not found in USFS 1990) was considered as potentially severely limiting to Arizona trout populations, but insufficient information was available to define it, except that the presence of pools and their depths should be considered.

COWFISH. Testing of the COWFISH model was performed on 45 clustered transect stations classified as meadow channel types by the Rosgen (1985) method. COWFISH component variables, their Parameter Suitability Indexes (PSI), mean PSI, Habitat Suitability Index (HSI), and the existing (predicted) trout density variable were regressed against the observed trout no./300 m and observed trout no./m^2 (both nonsignificant according to the K-S test of normality), and log-transformed estimates of trout no./m^2, trout no./m^3, trout biomass/m^2, and trout biomass/m^3.

Significant regression coefficients were observed among all combinations at $P<0.05$, with the exceptions of: percent streambank altered by ungulate trampling and percent streambank altered by ungulate trampling PSI with observed trout no./300 m; percent embeddedness with the 4 log-transformed trout standing crop measures; percent embeddedness PSI with the logs of trout no./m^2 and trout no./m^3; width:depth ratio with observed trout no./300 m, log trout no./m^2, log trout no./m^3, and log trout biomass/m^3; and width:depth ratio PSI with observed trout no./300 m. Highest significant R^2 values were 0.466 for percent undercut bank with observed trout no./m^2, 0.442 for percent undercut bank PSI with log trout biomass/m^2, 0.365 for percent vegetative overhang with observed trout no./m^2, 0.355 for percent vegetative overhang PSI with log trout no./m^2, 0.213 for percent streambank altered by ungulate trampling with log trout biomass/m^2, 0.253 for percent of streambank altered by ungulate trampling PSI with log trout biomass/m^2, 0.148 for percent embeddedness with observed trout no./300 m, 0.176 for percent embeddedness PSI with observed trout no./m^2, 0.264 for width:depth ratio with observed trout no./m^2, 0.318 for width:depth ratio PSI with observed trout no./m^2, 0.616 for mean PSI with observed trout no./m^2, and 0.556 for HSI with observed trout no./m^2. It is apparent that PSI relationships can be improved for some variables (undercut banks, overhanging vegetation), as evidenced by a reduction of R^2 values for PSI's relative to untransformed variables. The HSI relationship also can be improved considerably, or replaced with mean PSI.

The relationship between existing (predicted) trout no./300 m and observed trout no./300 m is the most objective test of the utility of the COWFISH model. Although this regression was significant ($P<0.01$), only 19.9% of the variation in observed trout no./300 m was explained by existing (predicted) trout no./300 m. The best fit between existing (predicted) trout no./300 m and observed trout standing crops was for observed trout no./m^2 ($R^2=0.306$). The regression equation for this relationship ($n=45$) was:

$$\text{observed trout no./m}^2 = 5.2664 + 5.1700(\text{existing [predicted] trout no./300 m})$$

Regressions of optimum (predicted) trout no./300 m were made with the standing crop measures listed above from stations with the highest 25% of standing crops. According to COWFISH, the best relationship of optimum (predicted) trout no./300 m should be with observed trout no./300 m from these streams. When the top 25% of observed trout no./300 m values were selected from the data set, the coefficient of determination for this regression was 0.326 ($P<0.05$). However, the regression that explained the greatest amount of variation in observed trout no./300 m was when the highest 25% of observed trout no./m^2 was selected. In this case, R^2 between observed trout no./m^2 and optimum (predicted) trout no./300 m was 0.609, a considerable improvement. The regression equation for this relationship ($n=12$) was:

$$\text{observed trout no./m}^2 = 5.1432 + 0.1329(\text{optimum [predicted] trout no./300 m})$$

This was the best fit of any of the trial regressions, and we conclude that the moderate R^2 of this significant equation renders the COWFISH model worthy of additional investigation for use in meadow reaches of Arizona trout streams.

Regression Models

Of the 8 multiple regression models developed for the trout biomass data (2 transformations of the 2 dependent variables using both a random sample of 2/3 subset [$n=127$] and all observations [$n=170$]), the subset model for the square root of trout biomass/m^2 exhibited the highest coefficient of multiple determination (adjusted for degrees of freedom) in combination with a low MSE (Table 5). This model was able to explain 60% of the variation in the square root of the areal estimate of trout biomass. Scrutiny of the model coefficients indicated that the dependent variables exhibited a positive relationship with bank ungulate damage (a variable rated higher with decreasing damage to banks), which explained the greatest amount of variation in trout biomass/m^2. A negative relationship with channel width ranked second, which can also be related to poor bank condition. Another bank condition indicator, a negative relationship with the variable bank angle, ranked fourth. Two variables associated with riparian conditions: riparian canopy density and riparian area width, and the variable gravel width, an instream component, also were high in importance.

A 2-dimensional plot of the predicted Y's *vs.* the standardized residuals does not suggest any nonlinearity of the regression function (Fig. 6a). A plot of predicted *vs.* observed Y's in Figure 6b illustrates the level of agreement between the 2 variables.

The "best" model for the total fish community in the White Mountain area streams was for the log transformation of the fish biomass/m^3 2/3 subset data (Table 6). This model also explained nearly 60% of the variation in standing biomass, in this case a volumetric expression instead of an a real one. Bank ungulate damage was again a variable that contributed most to explaining the variance in Y, but mean depth made a significant impact, though not a variable exhibited in the trout biomass model. Lower ranked variables were those that occurred in the trout model, along with the novel entries of maximum depth, pool measure (an HCI variable), and macrophyte width. The plot in Figure 7a suggests a random distribution of the residuals from the regression function, indicating linearity. A plot of actual *vs.* predicted standing crops in Figure 7b illustrates their degree of association.

Although there were significant correlations among several variables in the final models (Appendix 5), variance inflation factors of both models were considerably less than 10, indicating that multicollinearity did not appear to strongly influence the least squares estimates (Neter et al. 1990). Neter et al. (1990) also argue that multicollinearity should not usually be a problem when the purpose of a regression analysis is to make inferences on the response function or predictions of new observations, provided the inferences or predictions are made within the range of observations.

Validation of these models was performed by testing the relationship of the observed values of the subset of stream stations that were not used in development of the models with the predicted 95% confidence intervals for those observations. For the trout model, 81.4% of the 43 new observations fell within the predicted confidence intervals, and 90.7% of the 43 were within the predicted range for the total fish model (Fig. 8). Average deviation of the predicted values from the observed was 41.5% for the trout model and 21.4% for the total fish model. Since the subset models had higher R^2 values than those using the complete data set, there was no utility in reporting other models that could not be cross-validated with new data.

For purposes of discussion, logistic regression models for the probability of fish or trout presence at a station were developed for the 4 dependent biomass variables. All models contained bank ungulate damage as the most important variable for predicting the presence/absence of trouts and fishes. In addition, the trout biomass/m^2 and trout biomass/m^3 models selected discharge, riparian area width, and either channel gradient or (channel gradient)^2 in decreasing order of contribution, whereas the fish biomass/m^2 and fish biomass/m^3 models had only the channel gradient variable contributing to the function.

In an attempt to further aid in the management of sensitive meadow stream reaches, we developed a separate multiple regression trout-habitat model using the subset of surveyed meadow reaches. This model explained 85% of the variation in trout biomass (Appendix 6), but since we did not validate the meadow model with streams that were not used in the model development, we do not discuss it further.

Table 5. Multiple linear regression statistics for the model sqrt(trout biomass/m^2).

DEPENDENT VARIABLE:
Sqrt(trout biomass/m^2)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	12	183.1105	15.2592	16.741	0.001
Error	114	103.9122	0.9115		
C Total	126	287.0227			

Root MSE	0.9547	R-square	0.6380
Dep Mean	2.7154	Adj R-sq	0.5999
C.V.	35.1600		

Parameter Estimates

Variable	Parameter Estimate	Standard Error	Prob > |T|
Intercept	2.0393	0.9768	0.0391
Bank ungulate damage	0.7529	0.1698	0.0001
Channel width	-0.1335	0.0364	0.0004
Gravel width	1.7636	0.5298	0.0012
Bank angle	-0.0136	0.0042	0.0017
Riparian canopy density	-0.0147	0.0058	0.0123
Riparian area width	0.0080	0.0035	0.0228
Discharge	0.1232	0.0600	0.0424
Pool width	0.8601	0.4780	0.0746
Channel gradient	-0.0486	0.0429	0.2591
Meadow channel type	-0.2834	0.2802	0.3139
Canyon/headwater channel type	0.3097	0.4504	0.4931
Intermediate channel type	-0.1024	0.3176	0.7477

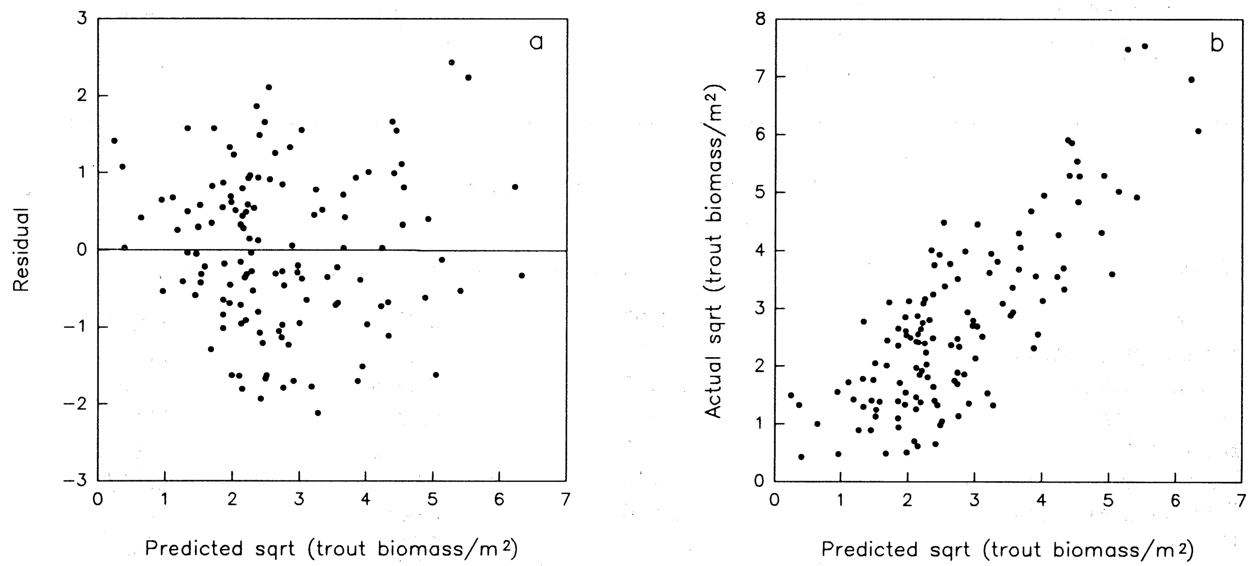


Figure 6. Plots of predicted trout standing crops with standardized residuals (a) and predicted *vs.* observed trout standing crops (b) from the multiple linear regression for square root of trout biomass/m^2 (Table 5).

Table 6. Multiple linear regression statistics for the model $\log_e$(fish biomass/m^3).

DEPENDENT VARIABLE:
$\log_e$(fish biomass/m^3)

Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	16	112.9917	7.0620	12.176	0.001
Error	110	63.8014	0.5800		
C Total	126	176.7931			

Root MSE	0.7616	R-square	0.6391
Dep Mean	4.1144	Adj R-square	0.5866
C.V.	18.5104		

Parameter Estimates

Variable	Parameter Estimate	Standard Error	Prob > |T|
Intercept	3.0665	0.8534	0.0005
Bank ungulate damage	0.9756	0.1412	0.0001
Mean water depth	-17.3395	3.4985	0.0001
Channel width	-0.1049	0.0306	0.0008
Gravel width	1.1517	0.4312	0.0087
Riparian canopy density	-0.0122	0.0048	0.0129
Riparian area width	0.0070	0.0028	0.0135
Discharge	0.1149	0.0538	0.0348
Bank angle	-0.0074	0.0036	0.0418
Maximum water depth	4.1778	2.0488	0.0438
Pool width	1.2133	0.6128	0.0502
Pool measure	-0.0069	0.0040	0.0847
Macrophyte width	0.5228	0.3187	0.1038
Channel gradient	-0.0497	0.0349	0.1575
Canyon/headwater channel type	0.2142	0.3836	0.5777
Intermediate channel type	0.0913	0.2725	0.7383
Meadow channel type	0.0654	0.2352	0.7816

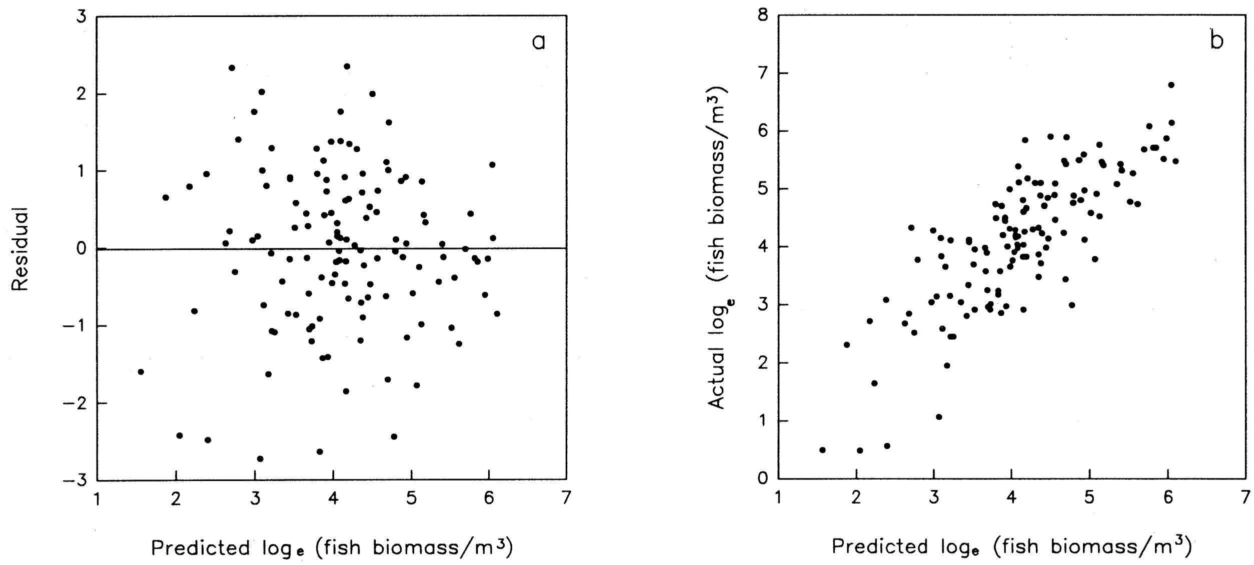


Figure 7. Plots of predicted fish standing crops with standardized residuals (a) and predicted *vs.* observed fish standing crops (b) from the multiple linear regression for natural log of fish biomass/m^3 (Table 6).

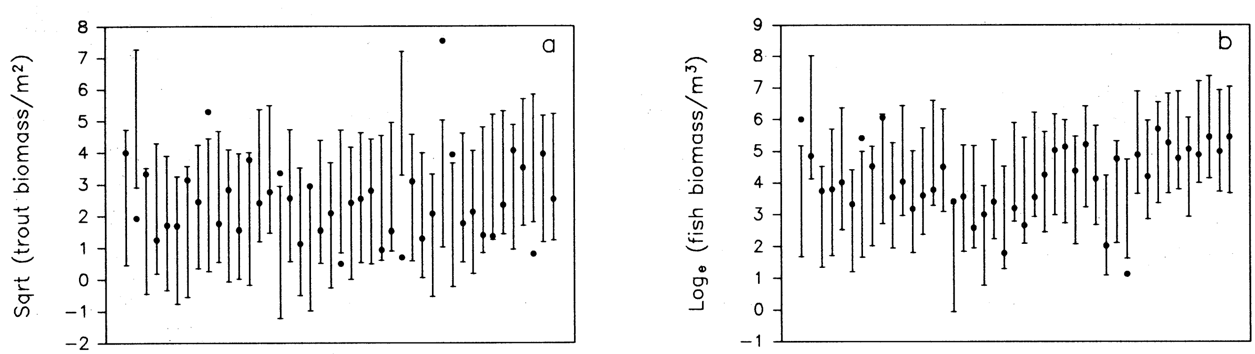
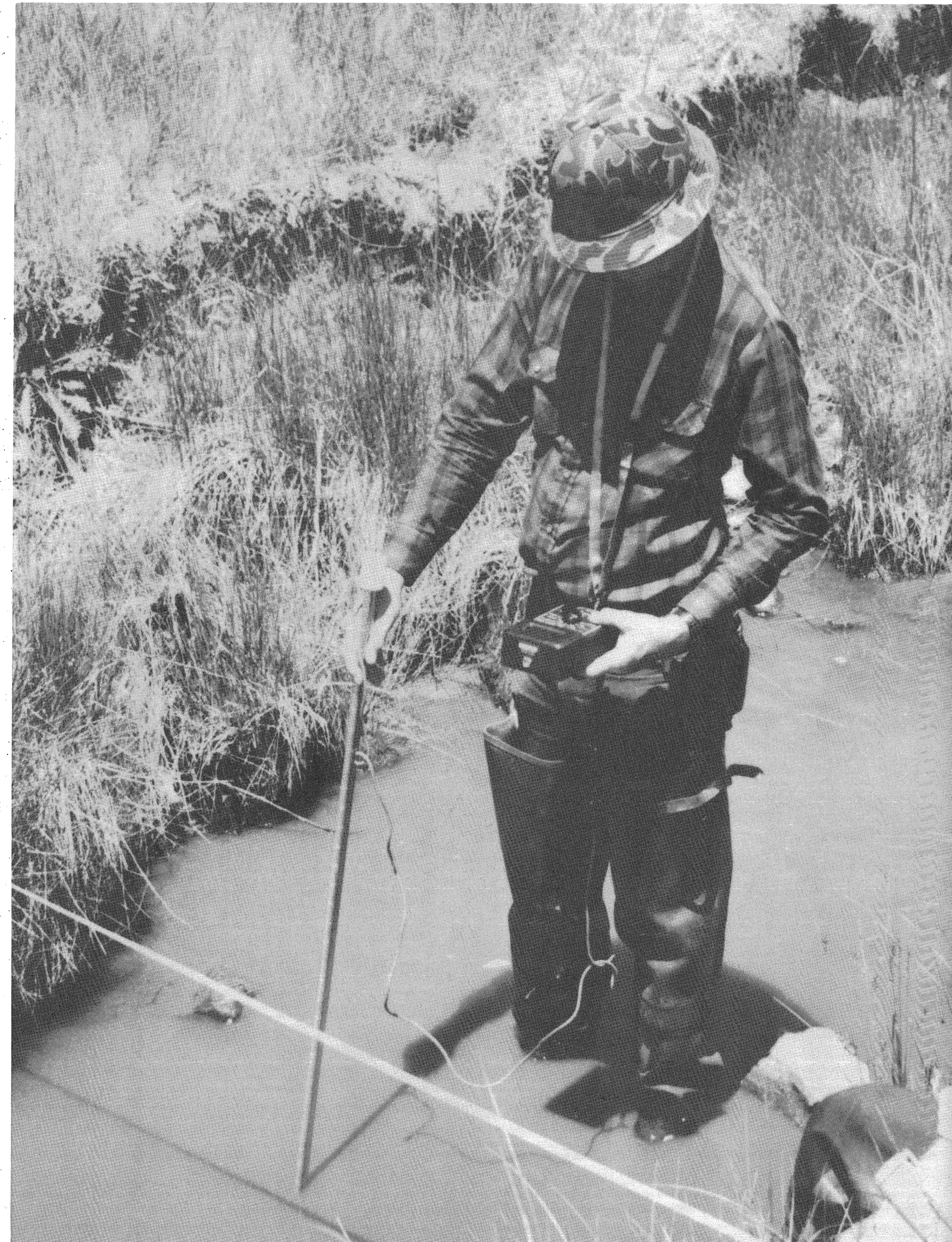


Figure 8. Ninety-five percent confidence intervals (vertical lines) of predicted means and observed values (circles) used in validation of the models (a) square root (trout biomass/m^2) and (b) $\log_e$ (fish biomass/m^3).



DISCUSSION

GAWS Sampling Design

Evaluations of the FHRS clustered transect survey design demonstrate that the level of variation in both habitat and fish populations within a stream, even when stratified by reach types, dictates intensive surveys. Single sampling stations will not describe reach conditions without considerable bias. The equivalence of clustered transect means and means from systematic transects within a reach, however, indicates that perhaps the number of surveyed transects could be reduced without any serious loss of data quality. However, such a practice may confer other sampling problems regarding fishes. Is a single transect capable of providing a summary of habitat information to predict the fish population at that site? The intra-station variance of habitat variables suggests that it is not, and would not be adequate for modeling purposes.

One of the purposes of FHRS models and others, however, is to predict fish standing crops from habitat information, and thereby obtain similar information on fish populations with reduced sampling effort. If such models are capable of adequately predicting standing crops (i.e. they are tested and validated), the equivalence of habitat variable means between clustered and systematic transects within a reach implies that systematic transect sampling, as practiced with our 1989-1990 surveys, would provide the necessary data for management purposes, with a considerable reduction of sampling effort.

Empirically, reach classification is an attractive tool for the integration of fisheries' values into land use planning, and for research purposes, the statistical management of data along a continuum of stream conditions. Classification systems have received a fair degree of attention in the recent literature (reviewed by Bailey et al. 1978, Platts 1980, Lotspeich and Platts 1982, and Frissell et al. 1986), yet most reviewers accept that additional research is necessary before a fully integrated system can be developed. Results presented here demonstrate that refinement of both the Rosgen (1985) channel classification system and our subjective "on-the-ground" reach classification is needed.

In order to stratify the study streams to a degree of homogeneity of habitats and fish communities within reaches, it may be necessary to define "transition" reaches between those that we established. The fluctuation of station means for both habitat variables and fish populations suggest that areas near the upper and lower reach boundaries are often dissimilar to the central portions of the reach. This finding was not unexpected, considering some of the difficulties we had on the ground identifying reach boundaries. The distribution of Rosgen (1985) channel types within our reaches support this conclusion. In most cases, such transition reaches would be relatively short (<500 m), but would significantly increase the amount of sampling effort required to quantify stream conditions. It remains to be determined if such further stratification would significantly improve the statistical homogeneity of within-reach measurements.

Results of the habitat typing procedures we implemented in our 1989-1990 surveys were unexpected in that they failed to demonstrate the patterns of trout habitat use typical of other studies. The negative correlation between trout numbers with absolute and relative pool area certainly ran counter to expectations from the literature (Lewis 1969, Rinne 1982, Rinne and Medina 1988), and significant positive correlations between trout numbers and relative areas of low gradient riffles and runs have not been observed elsewhere with any degree of frequency.

These observations may result from insufficient cover availability in pool habitats, or that our surveys did not account for sizes of fishes electrofished from each habitat type. Juvenile or fry trouts do not always exhibit the proclivity for pools that their larger conspecifics do (Raleigh 1982, Raleigh et al. 1986). Another potential difficulty with our method of quantifying fish use of habitat types was that in certain habitats with undercut banks, we could not always be sure that the site of fish capture was the same as the site of habitat use. Fishes stunned, but not seen, in initial electrofishing passes could have drifted downstream to be collected at a different site during subsequent passes. We are confident, however, that we did not chase any significant numbers of trout out of their normally-occupied habitat type; they would seek the nearest available cover within its occupied habitat. The same could not be said for other species, especially suckers, that would move substantial distances from the initial point of locations prior to capture.

We struggled with identifying the best technique to quantify fish locations within habitat types prior to initiation of the 1989-1990 surveys. Better-watered streams than those typical of our study area are often utilized by researchers for direct observations of fishes via snorkel or SCUBA devices with success (Northcote and Wilke 1963, Schill and Griffith 1984, Hankin and Reeves 1988), but mean depths that were often less than 0.1 m in our streams precluded use of this technique. Other studies have utilized direct visual observations of habitat use from shore (Bachman 1984). Both of these techniques can suffer from difficulty in identifying fish species, and the latter can be time consuming, because it takes several minutes before fish return to normal activities following disturbance.

We recommend that the habitat typing method be further evaluated in Arizona trout streams using the streambank observation technique on a small subset of streams to validate our findings. We emphatically do not recommend that the transect-based survey technique be abandoned in favor of the habitat typing technique, as has been done in other Forest Service regions, without further evaluation. The 2 methodologies deliver different types of data, and it must be determined what the objectives of the survey are prior to choosing one or the other. The GAWS transect design is well suited to site habitat monitoring for evaluation of management practices, while the typing design is more apt for inventorying fish macro-habitat use and stream habitat deficiencies. We have demonstrated that the 2 techniques can be utilized simultaneously.

What variables should be monitored in future surveys, assuming costs of human resources must be contained? If regression models are to be applied for predictions of trout standing crops, those variables listed in Tables 5-6 should be included. Trout standing crops are not, however, the only resource values important in managing stream/riparian ecosystems. Managers must decide which other habitat components are useful indicators of desirable stream conditions, whether they be for fish and wildlife, recreation, or other values. Platts (1983) provided a useful guide for development of stream habitat evaluation systems that should be consulted prior to the undertaking of new survey methodologies.

As will be discussed next, perhaps the most serious shortcoming of any study of fish populations is failure to account for year-to-year fluctuations of fish standing crops that may occur independent of changes in habitat. A long-term monitoring program can easily be accommodated by, and indeed is an intention of, the FHRS design. We recognize that land management decisions may be made without the benefit of such extended data, but believe it is essential that the legal mandates of federal monitoring programs be carried out to evaluate the consequences of those decisions, and as the basis for future decision-making.

Several types of monitoring programs can be utilized to gather these necessary data, and others. A rotational schedule for monitoring of streams (no more often than every 5 years) could provide long-term data to be used for monitoring responses of fish populations to changes in land management practices, as well as assess habitat-independent changes, with proper controls. Alternatively, a subset of representative or special concern streams monitored annually for at least 5 years would supply the necessary information to assess habitat-independent fish responses quickly, and allow a more complete evaluation of results presented here. Since both types of data are in demand, we recommend initiating the latter program for 5 years and then switching to the former as the best use of resources. It is obvious that any monitoring program must be funded adequately and committed for the long term to be worthwhile.

FHRS Models

The Habitat Condition Index is one of the foundations of the Fish Habitat Relationship System. It purports to model, on a 1:1 basis, the relationship between trouts and their habitats, and it is the most universal in its applicability (i.e. it is not limited to certain habitat or reach types). We found the index to perform poorly for White Mountain area trout streams based on regressions of HCI and its component variables with trout standing crops.

It can be argued that, despite its shortcomings, the HCI model does summarize components of the habitat that are useful for purposes of describing existing stream conditions. Of that we have no doubt, but in terms of describing conditions related to the production of trouts, it serves little purpose. Although many of the components of the HCI characterize bank features that our regression models found in general were important in describing variation of trout biomass, the specific bank features utilized or the manner in which they were structured apparently missed or masked the true relationships. Based on our findings, there seems to be little utility for the HCI in Arizona.

Steering committee members who evaluated the Habitat Vulnerability Index agreed that this FHRS model may be useful for hydrologists, but was not useful regarding trout biology and habitat use. Guidelines for its application to land management, if they have been developed, were not available to the authors. We thus hesitate to critique the model further. If such guidelines are clear that low vulnerability ratings of variables, such as bank angle, indicate that the stream is already in a state of degradation and must be restored to a more vulnerable state, then the model is a valuable management tool. If guidelines for its use do not exist, we believe the HVI is potentially dangerous in that it could be used to justify additional land uses within an already overused riparian system.

The COWFISH model, although developed in Montana, holds promise as a useful land management tool within meadow reaches of trout streams in east-central Arizona. Shepard (1989) evaluated aspects of the model in streams of Montana and found that it was able to reasonably predict numbers of catchable cutthroat trout (*O. clarki*), rainbow trout, and their hybrids, but not brook trout. Contor and Platts (1991) applied it to streams in the Great Basin and could find no significant correlations between predicted and actual trout numbers.

Although the coefficients of determination between COWFISH predicted existing and observed numbers of trout were not impressive, the ability of the model to predict optimum numbers of trout was. This suggests that the model could be modified to perform better in Arizona conditions, since the existing trout prediction is based on the prediction of optimum trout. Additional research to develop better PSI curves from Arizona streams would undoubtedly be worthwhile. Without these and other modifications to COWFISH, we do not recommend its use in Arizona unless outputs are adjusted from our regressions for the predicted existing and optimum trout numbers equations. The intent of the model to demonstrate the effect of cattle damage to fishery resources is seriously biased, with a slope of 5.14 for the relationship between observed and predicted existing trout density.

Regression Model Assumptions

The utility of most trout-habitat models is dependent on their ability to predict trout standing crops. A major assumption is that fish populations are limited by physical habitat conditions. Factors such as predation, disease, interspecific competition, or fishing mortality are assumed to play a minor role in influencing standing crops. Effects of fishing mortality in this study were minimized by employing only lightly-fished, unstocked streams in generation and analysis of models. Sample sizes were not large enough to permit stratification by species assemblage to address potential interspecific competition. Influences of predation and disease also could not be controlled.

Another assumption of these models is that fish populations closely track changes in physical habitat. However, considerable short-term fluctuations of stream fish standing crops occur independent of changes in physical habitat (Hall and Knight 1981; Platts and Nelson 1988). Such population variability has been attributed to changes in climatic conditions such as drought, flood, and winter ice, which influence mortality rates, spawning success, and recruitment.

Habitat-independent population fluctuations may also invalidate an assumption that stream fish populations are at carrying capacity. Carrying capacity, the number of individuals or biomass of a species or species assemblage a given area can support indefinitely, is a concept rather than a measurable response variable (Terrell and Nickum 1984). Thus, standing crop point-in-time estimates should not be expected to necessarily coincide with carrying capacity.

Fluctuations of fish populations independent of changes in habitat may confound both the relationships of habitat variables and fish populations used in construction of models, and the interpretation of model outputs relating changes in habitat to changes in fish populations. If habitat-independent population fluctuations are not incorporated into model development, biases can result from over- or underestimating responses of fishes to changes in habitat. Alternatively, potential responses of fishes to habitats may be masked, thereby lowering predictive capabilities of the models.

The design of this study indirectly accounted for a portion of temporal habitat-independent population fluctuation. Population approximations used in model testing and validation, although single point-in-time estimates, spanned 5 years. Since study streams were in relative geographic proximity, climatic events probably affected all streams similarly, provided land management histories were similar (Platts and Nelson 1988). This feature of our study design was, however, a less desirable alternative to multi-year population estimates. Since we did not completely control these effects, we cannot estimate their impact on our findings.

A mechanism to aid interpretation of model outputs, with this limitation in mind, is to compare the relative position of a stream fish standing crop value against a regional biomass frequency distribution curve (Platts and McHenry 1988). In this manner, inferences can be made regarding the relative value a stream fishery exhibits in comparison to others in the same ecoregion. This process will facilitate evaluation of model credibility and help identify productive streams worthy of protection or those degraded and suitable for enhancement.

The models further assume that input variables are measured without error. The precision of most variables we measured was determined by Platts (1981) and Platts et al. (1983). Highly precise measurements (half-width of the confidence interval generally <5% of the size of the mean) were those that could be precisely defined and measured with an instrument, while variables judged visually had lower precision of measurement. Measurement bias is difficult to estimate objectively. Our research did not consider measurement error models.

Finally, it is known that the fit of regression models does not assure that useful predictions can be made from them (Neter et al. 1990). This uncertainty is due both to the habitat-independent fluctuations of fish populations discussed above, and to the existence of conditions that do not necessarily imply cause and effect relationships. The only true test of the relationships between habitat and fish populations is experimentation, i.e. habitat variables are manipulated and responses of the fish community measured. The phenomenon is especially true when attempting to make predictions beyond the range of values measured and used in model construction (Neter et al. 1990).

Regression Models

Fausch et al. (1988) noted that most relatively precise models ($R^2 > 0.75$) that attempted to predict standing crops of stream fishes from habitat variables were based on samples of 20 sites or less collected over relatively short periods (often a single season of 1 year), or over small geographic areas (often a single stream or watershed), or both, and thus lacked generality. However, fluvial habitat to a large extent is a function of drainage basin geology and geomorphology, and thus the generality of fish-habitat relationships is not expected to extend beyond a geologically homogeneous area (Platts 1979; Lanka et al. 1987; Fausch et al. 1988; Nelson et al. 1992). Marcus et al. (1990) concluded that a series of models should be developed to address specific habitat related problems for specific types of habitats.

Our data regarding the variance of habitat variables and fish populations within the relatively small and homogeneous geographic area of the White Mountains area support the conclusion that model generality and high precision may be mutually exclusive. Our relatively large sample sizes of 117-170 stream stations and a large variety of independent variables produced multiple regression coefficients of determination of approximately 0.60. The inability of the HCI and COWFISH models to accurately fulfill their purported predictive capability when applied to Arizona streams is testimony that model generality is likely not possible.

One of the most reviewed and applied (Annear and Conder 1984, Bowlby and Roff 1986, Conder and Annear 1986, Scarnecchia and Bergersen 1987) trout habitat models in the literature is the Habitat Quality Index (HQI) developed by Binns and Eisermann (1979) from streams in Wyoming. It has been praised for the testing and validation procedures that were performed during its development and criticized for the complex relationships and transformations among the independent variables (Fausch et al. 1988, Marcus et al. 1990). The multiple regression HQI model presumably received attention because of its reported R^2 value of 0.97. In fact, this value is actually for the regression of predicted *vs.* actual standing crops, which has no functional relationship. Binns and Eisermann (1979) never reported the model coefficient of determination.

It is highly likely that the real R^2 value is considerably below 0.97.

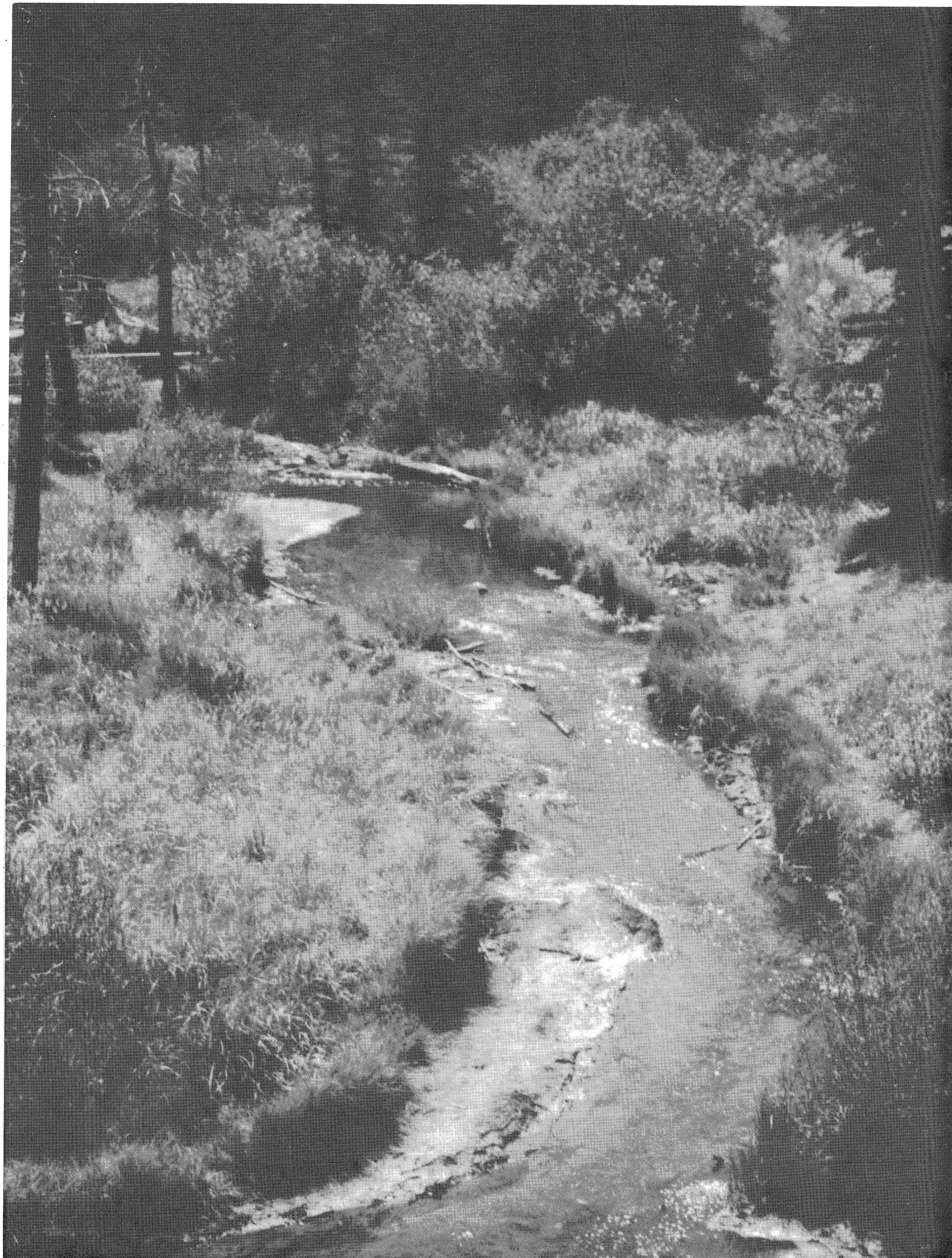
Although our models are capable of explaining only a moderate degree of the variation in trout standing crops in east-central Arizona streams, they were successfully validated within pre-determined predictive levels using stations that were not incorporated in the original model constructions. We still advise caution, however, when basing management decisions on our model outputs. It is likely that at least 10-20% of predicted standing crop values will not be within acceptable distances of actual biomass values, and average differences between predicted and actual values will exceed 20%.

The most significant feature of our regression models is that all consistently showed that damage to streambanks from ungulate trampling and related effects explained the greatest variation in trout standing crops. The high correlations of the bank related variables in the COWFISH model with standing crop corroborated this finding.

A majority of the ungulate damage to streambanks is undoubtedly caused by the domestic cow. Although we cannot unequivocally assure that our models explain a cause-and-effect relationship between cattle use and trout standing crops, the literature abounds with treatises that document the debilitating effects of livestock use on bank morphology and trout populations (see reviews by Kauffman and Krueger 1984, Szaro 1989, Chaney et al. 1990, Marcus et al. 1990, Armour et al. 1991, Platts 1991). The avenues of impact include (Platts and Raleigh 1984): 1) increased stream temperature due to loss of overhanging vegetation that is less suitable for the biology of trouts; 2) increased sedimentation from bank and upland erosion that trap and suffocate eggs and fry; 3) increased channel width due to hoof-induced bank sloughing and consequent erosion that reduces trout cover, decreases winter stream temperatures, and increases susceptibility to formation of anchor ice; 4) stream channel trenching or braiding that degrades instream habitats and increases the stream's susceptibility to catastrophic floods; and 5) plant community alteration and/or vegetation loss that reduces bank cohesiveness, cover attributes, and terrestrial food inputs.

Highest standing crops of trouts in our study were in meadow reaches of streams that received no cattle grazing pressure (upper reaches of Ord, Pacheta, and Reservation creeks). Mean trout biomasses in these reaches (n=17 stations) were 29.6 g/m^2 (SE=3.32) and 242.6 g/m^3 (SE=28.22), levels that approach the highest reported for nonanadromous salmonid streams in North America (Platts and McHenry 1988; Kozel and Hubert 1989a, 1989b; Kozel et al. 1989). In comparison, mean trout biomass in cattle-grazed meadow reaches (n=31 stations) were 11.5 g/m^2 (SE=1.69) and 119.1 g/m^3 (SE=24.28). The Kruskall-Wallis nonparametric test for mean comparisons indicated that the difference in mean rank of trout standing crops in meadow reaches grazed and ungrazed by cattle was highly significant ($P<0.001$). Access to meadow reaches by other ungulates (e.g. elk) was not restricted in any manner.

Only limited experimental research has been conducted regionally on impacts of cattle grazing on stream and riparian habitats and fish populations (Rinne 1985, 1988a, 1988b, 1990; Szaro et al. 1985; Weltz and Wood 1986; Warren and Anderson 1987; Rinne and Medina 1988), and to our knowledge none has been performed in the White Mountains area. We recommend the initiation of long-term controlled field experiments to document local cause-and-effect relationships among these parameters. Our findings, in combination with other published research, however, are convincing to us that better cattle management in many meadow riparian zones in the White Mountains area is necessary for improvement of trout habitats. These habitats are the most vulnerable to impacts from cattle grazing, yet have the most potential for high levels of trout production if managed properly.



MANAGEMENT OPTIONS

1. Limit ungulate grazing on riparian areas of White Mountain area streams, especially in meadow reaches. Meadow stream reaches are those most susceptible to damage from intensive grazing, and at the same time are the reach types with the greatest potential to support high levels of trout biomass. Trout standing crops in reaches of meadows ungrazed by cattle are significantly higher than in grazed meadows. Precise management recommendations should be developed cooperatively between land managers and aquatic biologists, but may include riparian fencing, increased use of rest rotation pastures, and other innovative techniques.

2. Survey 3 or more selected priority streams or stream reaches for fish populations once per year for 5 consecutive years. In order to evaluate the extent of fluctuations of fish populations that occur independent of changes in habitat, selected streams should not be subject to management changes during the 5-year survey period. Surveys should employ the 1989-1990 modified GAWS fish survey methodology at established station locations, and should be conducted during the same time period each year. Survey data will provide population fluctuation information necessary for evaluation of trout-habitat models, and the range of potential responses of fish populations expected from changes in habitat management prescriptions.

3. Initiate a long-term monitoring program of fish populations and their stream/riparian habitats on priority streams. Selected streams should be surveyed at least once every 5 years. Data should be evaluated periodically to determine trends in the condition of area streams, and to determine effectiveness of changes in management prescriptions to responses of fish populations and habitats.

4. Eliminate use of the Habitat Condition Index for evaluating stream habitat potential for trout biomass, at least on non-meadow reaches. Because the HCI is capable of explaining only 2-41% of the variation in trout biomass, its intended utility as a management tool for assessment of trout habitats is poor. Continued use of the HCI for this purpose will result in mismanagement, since management decisions arising from its application will often be wrong. Our validated trout model performed better, and can be used in place of the HCI if a trout habitat rating system in the White Mountains area is needed. A spreadsheet of the model for use by managers is available from the senior author upon request. If a more specific rating system for meadow reaches is desired, the model presented in Appendix 6 is also available in spreadsheet form, but we advise caution in its application since it has not been validated.

   Since trout biomass data are available from most streams in the White Mountains area, the simplest method of identifying stream quality is to compare standing crop values against a regional frequency distribution curve, as shown in Figure 5. This process can identify streams or stream reaches with high trout value worthy of protection, or identify streams with low value that may be suitable for restoration. Suggested stream reach rating criteria based on Figure 5 are: <10 g/m^2 = poor, 10-20 g/m^2 = fair, 20-30 g/m^2 = good, and >30 g/m^2 = excellent. Our models and other literature have identified variables important to trout production, and therefore, restoration techniques for degraded streams should be directed toward improving conditions of those variables. We are convinced that the most rapid improvement of these variables will be achieved by limiting cattle grazing in riparian areas.

5. Adopt and streamline the 1989-1990 modified GAWS survey methodology to reduce human resource expenses, eliminate unnecessary data collection, and increase statistical precision. To allow statistical evaluation of intra- and inter-reach variance of fishes and habitats, sample all stream reaches with a minimum of 3 GAWS stations. Eliminate the use of minor stations and "systematic" transects that were employed experimentally in our study. A careful evaluation of the utility of GAWS variables to fish and habitat management may allow streamlining of the method and savings in survey time. For example, the variables bank soil stability and bank vegetation

stability are rated identically (Table 2), and one or the other should be deleted from use. Because of the difficulty we experienced with measuring the components and interpreting the intent of the Habitat Vulnerability Index, elimination of its component variables (especially the channel stability coefficient) from survey procedures is recommended. Other variables may be also be unnecessary, or of little benefit, for evaluation of stream conditions.

6. Consider the addition of channel cross section sampling, as described by Ray and Megahan (1978) and Platts et al. (1987), for use in long-term stream monitoring. The utility of this measurement is paramount to evaluating effects of changes in land management practices to responses of stream channel morphologies. Its application to monitoring the progress of restoration prescriptions on degraded meadow stream reaches is especially appropriate.

7. Initiate controlled research to document cause-and-effect relationships between ungulate grazing and stream/riparian habitat. Specific research questions should be carefully structured, and a detailed study plan with testable hypotheses developed in advance of such study. Such research will further define trout-habitat relationships, and should help identify best management prescriptions for restoration of degraded streams.

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Appendix 1. Means (upper), standard deviations (middle), and sample sizes (lower) of GAWS habitat variables, summarized by stream reach. See Table 1 for stream designations and Table 2 for variable definitions.

Stream	Reach	Discharge	Channel gradient	Channel width	Stream width	Mean water depth	Max. water depth	Riffle width	Pool width	Periphyton width	Macrophyte width	Boulder width	Cobble width	Gravel width	Sand/silt width	Other substrate width
1	1	4.044	1.73	4.58	2.29	0.17	0.23	0.91	0.09	0.02	0.10	0.01	0.06	0.67	0.26	0.00
		2.801	0.80	4.67	1.23	0.05	0.05	0.10	0.10	0.03	0.07	0.02	0.07	0.12	0.07	0.00
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
1	2	0.599	4.97	3.11	1.67	0.08	0.13	0.77	0.23	0.19	0.03	0.06	0.22	0.46	0.24	0.02
		0.293	1.66	0.89	0.52	0.03	0.03	0.21	0.21	0.18	0.02	0.06	0.09	0.22	0.12	0.02
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2	1	4.898	3.10	7.81	4.18	0.12	0.24	0.72	0.28	0.05	0.00	0.20	0.50	0.13	0.04	0.13
		2.224	1.42	1.65	1.06	0.02	0.04	0.10	0.10	0.05	0.01	0.14	0.19	0.08	0.04	0.14
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2	2	0.366	6.04	5.44	1.90	0.08	0.15	0.49	0.51	0.05	0.01	0.22	0.46	0.22	0.07	0.03
		0.198	1.45	0.59	0.28	0.02	0.04	0.27	0.27	0.03	0.01	0.12	0.12	0.06	0.07	0.06
		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
2	3	2.453	5.34	6.70	3.97	0.14	0.30	0.84	0.16	.04	0.04	0.40	0.41	0.13	0.03	0.03
		0.281	0.42	1.13	0.57	0.01	0.03	0.02	0.02	0.02	0.06	0.16	0.15	0.05	0.03	0.03
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2	4	1.280	5.13	7.30	3.49	0.14	0.27	0.75	0.25	0.02	0.05	0.14	0.39	0.35	0.08	0.03
		0.296	0.79	2.17	1.04	0.03	0.10	0.20	0.20	0.01	0.03	0.09	0.17	0.19	0.06	0.03
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
2	5	0.894	4.63	4.31	2.27	0.10	0.17	0.79	0.21	0.01	0.07	0.11	0.35	0.42	0.10	0.02
		0.124	1.21	0.60	0.65	0.01	0.03	0.11	0.11	0.02	0.08	0.09	0.10	0.10	0.09	0.03
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	1	1.566	2.43	9.93	4.23	0.12	0.22	0.78	0.22	0.01	0.03	0.30	0.40	0.15	0.14	0.01
		0.108	1.18	2.88	0.66	0.03	0.05	0.12	0.12	0.01	0.00	0.15	0.17	0.04	0.08	0.02
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	2	0.695	1.17	5.89	2.63	0.15	0.24	0.93	0.07	0.00	0.11	0.07	0.17	0.46	0.30	0.00
		0.720	0.32	1.10	0.38	0.02	0.02	0.07	0.07	0.00	0.07	0.06	0.15	0.15	0.18	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	3	0.375	4.33	7.48	3.78	0.16	0.26	0.80	0.20	0.01	0.02	0.32	0.18	0.37	0.09	0.04
		0.120	1.55	2.67	1.49	0.02	0.07	0.06	0.06	0.01	0.00	0.29	0.24	0.32	0.06	0.05
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	4	0.349	1.70	6.23	2.48	0.11	0.17	0.76	0.24	0.00	0.09	0.00	0.20	0.54	0.25	0.00
		0.083	0.53	4.50	0.31	0.03	0.06	0.12	0.12	0.00	0.05	0.00	0.22	0.15	0.23	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	5	0.334	2.47	4.47	2.62	0.06	0.11	0.90	0.10	0.03	0.02	0.07	0.30	0.57	0.06	0.01
		0.092	0.35	0.07	0.11	0.01	0.03	0.18	0.18	0.05	0.04	0.09	0.14	0.22	0.07	0.01
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	6	0.381	4.40	5.70	3.15	0.09	0.16	0.86	0.14	0.07	0.01	0.22	0.38	0.28	0.10	0.03
		0.077	1.13	1.97	0.59	0.02	0.03	0.07	0.07	0.02	0.02	0.13	0.15	0.10	0.07	0.04
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
3	7	0.375	1.27	2.31	1.75	0.16	0.23	0.71	0.29	0.08	0.12	0.05	0.12	0.44	0.39	0.00
		0.337	0.14	0.46	0.33	0.07	0.09	0.15	0.15	0.10	0.07	0.04	0.10	0.08	0.03	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Appendix 1. (continued)

Stream	Reach	Discharge	Channel gradient	Channel width	Stream width	Mean water depth	Max. water depth	Riffle width	Pool width	Periphyton width	Macrophyte width	Boulder width	Cobble width	Gravel width	Sand/silt width	Other substrate width
3	8	0.490	3.80	3.41	2.21	0.12	0.19	0.84	0.16	0.14	0.19	0.18	0.63	0.07	0.13	0.00
		0.062	0.62	0.95	0.48	0.05	0.05	0.21	0.21	0.14	0.05	0.08	0.17	0.04	0.07	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	9	0.259	1.30	1.47	1.25	0.15	0.19	0.93	0.07	0.04	0.18	0.02	0.00	0.48	0.50	0.00
		0.240	0.52	0.22	0.01	0.04	0.06	0.12	0.12	0.06	0.16	0.03	0.00	0.20	0.19	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	10	0.516	2.10	2.88	1.67	0.07	0.12	0.90	0.10	0.09	0.15	0.01	0.05	0.58	0.35	0.01
		0.085	0.60	0.21	0.23	0.02	0.02	0.17	0.17	0.09	0.15	0.01	0.08	0.11	0.04	0.01
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	11	0.274	2.62	2.53	1.38	0.08	0.13	0.92	0.08	0.05	0.17	0.01	0.13	0.59	0.28	0.00
		0.133	0.63	1.69	0.46	0.02	0.02	0.20	0.20	0.02	0.08	0.02	0.11	0.18	0.11	0.00
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
3	12	0.475	2.83	2.51	1.73	0.06	0.11	1.00	0.00	0.06	0.16	0.00	0.16	0.77	0.06	0.01
		0.004	0.86	0.59	0.43	0.01	0.01	0.00	0.00	0.07	0.04	0.00	0.06	0.08	0.02	0.02
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3	13	0.298	7.87	3.16	1.80	0.05	0.10	1.00	0.00	0.25	0.06	0.08	0.11	0.73	0.04	0.04
		0.0	1.37	1.05	0.68	0.01	0.01	0.01	0.01	0.12	0.03	0.05	0.05	0.06	0.03	0.05
		1	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4	1	0.144	5.03	6.15	2.29	0.11	0.23	0.53	0.47	0.02	0.01	0.21	0.39	0.14	0.03	0.22
		0.077	2.48	1.53	0.41	0.07	0.11	0.34	0.34	0.03	0.02	0.08	0.27	0.06	0.03	0.32
		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
5	1	0.569	1.23	2.38	1.73	0.12	0.17	0.53	0.47	0.07	0.11	0.05	0.04	0.38	0.52	0.01
		0.248	0.67	1.05	0.27	0.06	0.05	0.31	0.31	0.08	0.06	0.06	0.02	0.03	0.03	0.03
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
5	2	0.743	1.12	1.37	1.19	0.14	0.18	0.64	0.36	0.02	0.17	0.01	0.01	0.58	0.40	0.00
		0.245	0.34	0.38	0.20	0.07	0.07	0.35	0.35	0.02	0.20	0.03	0.02	0.25	0.27	0.00
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
5	3	0.381	1.15	2.22	1.54	0.09	0.12	0.90	0.10	0.04	0.04	0.00	0.00	0.70	0.29	0.02
		0.004	0.35	0.99	0.11	0.02	0.01	0.14	0.14	0.01	0.02	0.00	0.00	0.02	0.00	0.02
		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
5	4	0.179	6.15	3.81	1.94	0.08	0.14	0.61	0.42	0.12	0.01	0.12	0.19	0.37	0.32	0.03
		0.075	2.03	1.60	0.53	0.02	0.03	0.04	0.08	0.09	0.02	0.13	0.09	0.16	0.14	0.05
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
5	5	0.062	12.57	5.03	1.61	0.07	0.11	0.57	0.43	0.07	0.02	0.09	0.14	0.23	0.37	0.16
		0.008	7.23	0.19	0.16	0.04	0.02	0.15	0.15	0.09	0.03	0.08	0.10	0.14	0.16	0.14
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
6	1	1.364	16.13	2.82	2.48	0.13	0.22	0.76	0.24	0.09	0.07	0.39	0.22	0.22	0.12	0.06
		0.258	4.57	0.64	0.78	0.01	0.00	0.21	0.21	0.09	0.03	0.31	0.05	0.20	0.14	0.11
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
6	2	1.300	8.13	3.05	1.91	0.13	0.19	0.89	0.11	0.02	0.11	0.27	0.33	0.11	0.27	0.01
		0.152	1.51	0.32	0.27	0.01	0.02	0.10	0.10	0.03	0.09	0.16	0.07	0.04	0.17	0.02
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Appendix 1. (continued)

Stream	Reach	Discharge	Channel gradient	Channel width	Stream width	Mean water depth	Max. water depth	Riffle width	Pool width	Periphyton width	Macrophyte width	Boulder width	Cobble width	Gravel width	Sand/silt width	Other substrate width
6	3	1.556	4.52	2.47	1.21	0.13	0.24	0.80	0.20	0.04	0.15	0.17	0.12	0.23	0.47	0.00
		0.363	2.16	0.08	0.31	0.02	0.03	0.20	0.20	0.06	0.13	0.19	0.10	0.20	0.09	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
7	1	0.352	2.87	7.14	2.38	0.13	0.19	0.68	0.32	0.00	0.00	0.13	0.55	0.29	0.03	0.00
		0.090	1.59	0.55	0.37	0.12	0.13	0.26	0.26	0.00	0.00	0.03	0.06	0.09	0.04	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
7	2	0.216	4.67	5.21	1.68	0.09	0.14	0.67	0.20	0.01	0.01	0.26	0.31	0.38	0.05	0.00
		0.134	1.19	1.66	0.34	0.05	0.07	0.17	0.24	0.02	0.00	0.18	0.13	0.05	0.03	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
7	3	0.104	2.45	4.40	1.01	0.04	0.08	0.81	0.19	0.00	0.09	0.00	0.16	0.41	0.43	0.00
		0.024	2.33	0.96	0.35	0.01	0.02	0.26	0.26	0.00	0.03	0.00	0.00	0.17	0.17	0.00
		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
8	1	---	5.75	12.84	3.85	0.13	---	0.77	0.23	0.08	0.00	0.15	0.66	0.16	0.01	0.03
		---	0.35	1.81	0.66	0.01	---	0.04	0.04	0.11	0.00	0.10	0.18	0.22	0.01	0.05
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2
8	3	---	3.11	9.00	3.92	0.10	---	0.82	0.17	0.00	0.02	0.26	0.50	0.22	0.01	0.00
		---	1.08	2.81	0.85	0.02	---	0.20	0.19	0.00	0.02	0.18	0.25	0.18	0.02	0.00
		0	8	8	8	8	0	8	8	8	8	8	8	8	8	8
8	4	---	3.20	3.99	1.52	0.06	---	0.84	0.16	0.00	0.15	0.03	0.11	0.70	0.17	0.00
		---	0.85	2.11	0.37	0.01	---	0.22	0.22	0.00	0.22	0.04	0.07	0.08	0.12	0.00
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2
9	1	---	3.75	6.58	2.31	0.09	---	0.60	0.40	0.00	0.00	0.09	0.50	0.38	0.03	0.00
		---	0.35	1.52	1.01	0.04	---	0.08	0.08	0.00	0.00	0.04	0.14	0.12	0.01	0.00
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2
9	2	---	4.00	4.96	1.43	0.08	---	0.23	0.78	0.00	0.11	0.13	0.25	0.52	0.11	0.00
		---	2.83	0.40	0.77	0.06	---	0.04	0.04	0.00	0.15	0.09	0.19	0.13	0.15	0.00
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2
9	3	---	1.20	7.58	1.22	0.05	---	0.16	0.84	0.02	0.51	0.13	0.14	0.19	0.54	0.00
		---	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0	1	1	1	1	0	1	1	1	1	1	1	1	1	1
10	1	---	8.03	4.89	2.12	0.05	---	0.51	0.49	0.00	0.02	0.32	0.28	0.30	0.10	0.00
		---	1.03	0.16	0.79	0.03	---	0.44	0.44	0.00	0.03	0.29	0.03	0.12	0.15	0.00
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2
10	2	---	3.30	4.19	1.41	0.07	---	0.60	0.40	0.00	0.03	0.15	0.12	0.57	0.16	0.00
		---	0.82	1.36	0.23	0.03	---	0.21	0.21	0.00	0.04	0.13	0.04	0.19	0.06	0.00
		0	3	3	3	3	0	3	3	3	3	3	3	3	3	3
10	3	---	2.75	3.76	1.07	0.05	---	0.36	0.64	0.00	0.18	0.06	0.13	0.63	0.18	0.00
		---	1.20	0.96	0.55	0.03	---	0.34	0.34	0.00	0.26	0.04	0.11	0.26	0.18	0.00
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2
11	1	2.297	4.43	14.90	4.47	0.14	0.33	0.72	0.28	0.00	0.00	0.51	0.25	0.16	0.02	0.07
		0.732	1.96	3.49	1.03	0.03	0.14	0.08	0.08	0.00	0.00	0.26	0.25	0.05	0.01	0.12
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Appendix 1. (continued)

Stream	Reach	Discharge	Channel gradient	Channel width	Stream width	Mean water depth	Max. water depth	Riffle width	Pool width	Periphyton width	Macrophyte width	Boulder width	Cobble width	Gravel width	Sand/silt width	Other substrate width
11	2	3.668	2.30	10.92	6.38	0.16	0.30	0.66	0.34	0.00	0.08	0.34	0.08	0.23	0.35	0.00
		1.929	0.14	4.13	3.31	0.01	0.00	0.16	0.16	0.00	0.05	0.27	0.07	0.07	0.14	0.00
		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
11	3	1.423	2.07	4.37	2.42	0.12	0.26	0.80	0.20	0.00	0.01	0.01	0.01	0.64	0.33	0.00
		0.614	1.16	1.68	0.99	0.02	0.08	0.14	0.14	0.00	0.01	0.02	0.02	0.14	0.16	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
12	1	3.132	4.90	9.10	2.84	0.13	0.24	0.77	0.23	0.00	0.10	0.34	0.17	0.29	0.20	0.00
		1.797	2.98	0.50	0.27	0.04	0.06	0.09	0.09	0.00	0.10	0.16	0.04	0.16	0.03	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
12	2	1.738	1.10	8.85	2.15	0.10	0.17	0.87	0.13	0.03	0.24	0.22	0.04	0.43	0.31	0.00
		0.928	0.26	2.33	0.18	0.01	0.02	0.12	0.12	0.05	0.10	0.19	0.05	0.19	0.11	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
13	1	2.199	1.90	9.42	3.91	0.11	0.22	0.59	0.41	0.00	0.07	0.37	0.28	0.03	0.33	0.00
		1.959	0.85	4.47	0.04	0.02	0.06	0.18	0.18	0.00	0.03	0.28	0.27	0.01	0.00	0.00
		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
13	2	1.129	1.00	6.40	1.94	0.09	0.18	0.78	0.22	0.00	0.09	0.03	0.10	0.50	0.37	0.00
		0.784	0.28	2.09	0.20	0.04	0.05	0.31	0.31	0.00	0.13	0.01	0.04	0.35	0.40	0.00
		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
13	3	0.912	6.70	7.26	2.02	0.08	0.14	0.87	0.13	0.00	0.02	0.10	0.17	0.57	0.15	0.00
		0.000	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1	1	1	1	1	1	1	1	1	1	1	1	1	1	1
14	1	---	1.77	5.31	1.45	0.04	0.08	0.67	0.33	0.04	0.11	0.05	0.38	0.49	0.09	0.00
		---	0.29	0.38	0.33	0.02	0.03	0.29	0.29	0.03	0.10	0.04	0.11	0.17	0.04	0.00
		0	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14	2	---	3.25	5.09	1.64	0.04	0.08	0.50	0.50	0.02	0.01	0.08	0.33	0.49	0.10	0.00
		---	0.78	1.20	0.31	0.02	0.03	0.03	0.03	0.02	0.01	0.00	0.00	0.09	0.09	0.00
		0	2	2	2	2	2	2	2	2	2	2	2	2	2	2
14	3	---	3.00	5.59	1.84	0.05	0.11	0.46	0.54	0.01	0.00	0.14	0.33	0.47	0.06	0.00
		---	0.20	0.38	0.21	0.02	0.02	0.34	0.34	0.02	0.01	0.04	0.15	0.16	0.07	0.00
		0	3	3	3	3	3	3	3	3	3	3	3	3	3	3
14	4	---	2.90	4.42	1.26	0.03	0.07	0.52	0.48	0.00	0.04	0.05	0.33	0.45	0.17	0.00
		---	0.64	0.53	0.22	0.01	0.01	0.20	0.20	0.01	0.08	0.03	0.19	0.09	0.26	0.00
		0	5	5	5	5	5	5	5	5	5	5	5	5	5	5
15	7	4.142	0.97	6.30	3.35	0.14	0.23	0.90	0.10	0.01	0.11	0.02	0.21	0.56	0.21	0.00
		0.831	0.45	1.64	0.89	0.02	0.03	0.12	0.12	0.02	0.08	0.04	0.15	0.13	0.09	0.00
		4	4	4	4	4	4	4	4	4	4	4	4	4	4	4
15	8	3.463	2.72	5.85	3.45	0.13	0.25	0.84	0.16	0.07	0.05	0.06	0.19	0.51	0.18	0.06
		0.280	0.69	1.15	0.43	0.02	0.02	0.12	0.12	0.10	0.03	0.03	0.13	0.20	0.09	0.13
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
16	1	0.424	4.10	6.71	2.03	0.08	0.14	0.77	0.23	0.00	0.03	0.33	0.58	0.09	0.00	0.00
		0.237	1.32	0.68	0.62	0.02	0.03	0.10	0.10	0.00	0.01	0.23	0.18	0.05	0.00	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3

Appendix 1. (continued)

Stream	Reach	Discharge	Channel gradient	Channel width	Stream width	Mean water depth	Max. water depth	Riffle width	Pool width	Periphyton width	Macrophyte width	Boulder width	Cobble width	Gravel width	Sand/silt width	Other substrate width
16	2	0.515	7.40	7.79	2.42	0.09	0.24	0.76	0.24	0.05	0.05	0.52	0.44	0.03	0.01	0.00
		0.152	1.05	1.93	0.27	0.01	0.10	0.05	0.05	0.09	0.08	0.16	0.14	0.06	0.01	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
16	3	0.240	0.80	4.37	1.36	0.10	0.16	0.33	0.67	0.00	0.27	0.11	0.07	0.19	0.63	0.00
		0.182	0.42	1.80	0.11	0.05	0.07	0.47	0.47	0.00	0.01	0.13	0.08	0.11	0.32	0.00
		2	2	2	2	2	2	2	2	2	2	2	2	2	2	2
17	1	0.263	3.57	5.31	1.71	0.07	0.12	0.57	0.43	0.01	0.02	0.28	0.35	0.28	0.10	0.00
		0.033	0.59	1.22	0.33	0.02	0.03	0.27	0.27	0.02	0.02	0.08	0.22	0.30	0.06	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
17	2	0.178	1.60	3.12	1.21	0.10	0.14	0.38	0.62	0.02	0.28	0.07	0.04	0.51	0.38	0.00
		0.097	0.35	1.54	0.37	0.05	0.05	0.37	0.37	0.03	0.19	0.08	0.04	0.25	0.19	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
17	3	0.065	3.73	2.99	1.53	0.05	0.09	0.60	0.40	0.05	0.00	0.30	0.38	0.27	0.04	0.01
		0.022	0.96	0.57	0.31	0.02	0.02	0.00	0.00	0.07	0.00	0.07	0.06	0.14	0.04	0.01
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
17	4	0.033	2.13	1.97	1.23	0.07	0.11	0.28	0.72	0.00	0.20	0.06	0.15	0.17	0.62	0.00
		0.012	0.42	0.29	0.14	0.02	0.02	0.11	0.11	0.00	0.20	0.05	0.15	0.10	0.25	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
18	1	1.748	3.00	8.72	5.10	0.12	0.23	0.87	0.13	0.05	0.12	0.22	0.48	0.15	0.14	0.01
		0.521	0.78	2.01	0.29	0.03	0.07	0.11	0.11	0.08	0.11	0.09	0.07	0.05	0.11	0.03
		5	5	5	5	5	5	5	5	5	5	5	5	5	5	5
18	4	---	2.97	4.04	1.31	0.03	0.07	0.73	0.27	0.01	0.04	0.22	0.32	0.17	0.26	0.03
		---	1.83	1.61	0.17	0.02	0.04	0.12	0.12	0.01	0.06	0.21	0.06	0.27	0.08	0.02
		0	3	3	3	3	3	3	3	3	3	3	3	3	3	3
19	1	---	2.88	4.77	3.14	0.14	---	0.43	0.56	0.00	0.22	0.00	0.04	0.54	0.43	0.00
		---	0.85	1.64	0.45	0.05	---	0.22	0.22	0.01	0.20	0.00	0.04	0.15	0.19	0.00
		0	4	4	4	4	0	4	4	4	4	4	4	4	4	4
19	2	---	8.00	3.83	3.50	0.11	---	0.67	0.33	0.00	0.89	0.00	0.12	0.72	0.16	0.00
		---	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0	1	1	1	1	0	1	1	1	1	1	1	1	1	1
20	2	0.026	2.97	2.39	0.94	0.05	0.09	0.56	0.44	0.00	0.00	0.13	0.19	0.14	0.54	0.00
		0.018	0.81	0.56	0.36	0.02	0.03	0.27	0.27	0.00	0.00	0.10	0.11	0.08	0.20	0.00
		6	6	6	6	6	6	6	6	6	6	6	6	6	6	6
20	3	0.051	6.13	1.63	0.77	0.03	0.06	0.67	0.33	0.00	0.00	0.00	0.14	0.36	0.50	0.00
		0.054	0.47	0.58	0.08	0.02	0.03	0.31	0.31	0.00	0.00	0.00	0.09	0.15	0.24	0.00
		3	3	3	3	3	3	3	3	3	3	3	3	3	3	3
21	2	---	4.83	10.92	3.21	0.22	---	0.93	0.07	0.00	0.06	0.60	0.33	0.07	0.00	0.00
		---	0.24	3.79	1.06	0.06	---	0.09	0.09	0.00	0.02	0.02	0.08	0.10	0.00	0.00
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2
21	3	---	1.50	6.25	4.36	0.16	---	0.94	0.03	0.00	0.29	0.11	0.39	0.24	0.26	0.00
		---	0.71	1.32	2.46	0.00	---	0.02	0.05	0.00	0.02	0.01	0.37	0.03	0.33	0.00
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2

Appendix 1. (continued)

Stream	Reach	Discharge	Channel gradient	Channel width	Stream width	Mean water depth	Max. water depth	Riffle width	Pool width	Periphyton width	Macrophyte width	Boulder width	Cobble width	Gravel width	Sand/silt width	Other substrate width
21	5	---	5.00	2.26	2.20	0.14	---	1.00	0.00	0.04	0.00	0.12	0.55	0.33	0.00	0.00
		---	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0	1	1	1	1	0	1	1	1	1	1	1	1	1	1
21	6	---	5.10	4.10	2.00	0.12	---	0.94	0.06	0.17	0.04	0.41	0.34	0.20	0.04	0.00
		---	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0	1	1	1	1	0	1	1	1	1	1	1	1	1	1
21	7	---	1.00	1.63	1.17	0.21	---	0.40	0.60	0.07	0.14	0.00	0.00	0.75	0.25	0.00
		---	0.00	0.81	0.18	0.03	---	0.00	0.00	0.08	0.10	0.00	0.00	0.35	0.35	0.00
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2
21	8	---	5.00	2.42	1.58	0.06	---	0.77	0.23	0.01	0.07	0.00	0.00	0.91	0.04	0.04
		---	0.00	0.00	0.00	0.00	---	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0	1	1	1	1	0	1	1	1	1	1	1	1	1	1
21	9	---	13.50	1.41	0.98	0.15	---	0.74	0.26	0.26	0.03	0.04	0.06	0.65	0.02	0.23
		---	0.71	0.01	0.11	0.05	---	0.09	0.09	0.16	0.04	0.05	0.08	0.02	0.03	0.08
		0	2	2	2	2	0	2	2	2	2	2	2	2	2	2

Appendix 1. (continued)

Stream	Reach	Shore depth	Undercut bank	Bank vegetation cover	Bank soil stability	Bank vegetation stability	Bank ungulate damage	Bank angle	Riparian canopy density	Station elevation	Valley bottom width	Riparian area width	Width:depth ratio
1	1	0.13	0.18	2.00	3.52	3.58	3.65	62.96	13.77	3028	145	44	15.11
		0.07	0.05	0.00	0.38	0.37	0.42	8.16	8.90	9	87	33	8.87
		6	6	6	6	6	6	6	6	6	6	6	6
1	2	0.03	0.08	2.08	2.67	2.82	3.67	95.13	40.06	3100	18	18	23.78
		0.03	0.05	0.26	0.57	0.46	0.50	22.10	11.36	35	11	11	12.11
		6	6	6	6	6	6	6	6	6	6	6	6
2	1	0.02	0.03	3.20	3.50	3.35	3.45	129.33	45.40	2135	41	24	36.36
		0.01	0.01	0.57	0.23	0.45	0.57	7.77	7.22	89	27	20	11.21
		6	6	6	6	6	6	6	6	6	6	6	6
2	2	0.01	0.05	2.74	2.84	2.96	2.88	126.00	41.48	2353	20	10	25.12
		0.01	0.05	0.59	0.56	0.39	0.20	22.16	3.94	56	10	1	7.29
		5	5	5	5	5	5	5	5	5	5	5	5
2	3	0.01	0.02	2.90	3.06	3.17	2.78	136.33	43.35	2337	27	14	28.61
		0.01	0.01	0.42	0.51	0.35	0.24	7.37	7.46	41	13	4	3.96
		6	6	6	6	6	6	6	6	6	6	6	6
2	4	0.02	0.05	2.40	2.73	2.48	2.73	137.17	45.60	2483	22	17	25.46
		0.02	0.04	0.18	0.52	0.21	0.45	9.87	8.37	58	9	7	1.89
		6	6	6	6	6	6	6	6	6	6	6	6
2	5	0.02	0.04	2.47	2.43	2.53	2.30	124.83	45.82	2579	23	17	24.67
		0.01	0.02	0.21	0.23	0.31	0.26	8.08	6.79	6	6	5	10.21
		3	3	3	3	3	3	3	3	3	3	3	3
3	1	0.03	0.05	3.67	3.53	3.90	3.97	108.42	39.40	2496	25	25	36.52
		0.02	0.04	0.12	0.12	0.10	0.06	29.28	3.61	14	6	6	14.40
		3	3	3	3	3	3	3	3	3	3	3	3
3	2	0.04	0.03	2.80	2.43	2.67	3.53	121.50	21.53	2513	62	37	17.37
		0.02	0.02	0.53	0.15	0.06	0.31	19.22	12.12	2	16	21	4.64
		3	3	3	3	3	3	3	3	3	3	3	3
3	3	0.05	0.07	3.33	3.30	3.43	4.00	102.33	45.27	2523	44	15	23.04
		0.01	0.02	0.12	0.26	0.21	0.00	16.00	1.55	7	19	5	6.89
		3	3	3	3	3	3	3	3	3	3	3	3
3	4	0.03	0.03	2.60	2.60	2.87	3.60	124.00	15.40	2545	126	28	24.96
		0.01	0.01	0.35	0.10	0.38	0.53	0.50	13.04	3	45	8	7.90
		3	3	3	3	3	3	3	3	3	3	3	3
3	5	0.01	0.01	3.63	3.32	3.77	3.77	141.83	57.07	2555	67	44	46.57
		0.02	0.02	0.15	0.39	0.25	0.21	29.75	7.93	5	20	13	10.96
		3	3	3	3	3	3	3	3	3	3	3	3
3	6	0.03	0.07	3.07	3.23	3.32	3.73	118.85	48.90	2625	21	18	37.36
		0.02	0.03	0.33	0.45	0.66	0.32	17.10	5.40	36	5	8	9.97
		6	6	6	6	6	6	6	6	6	6	6	6
3	7	0.08	0.08	2.00	3.17	3.47	3.53	97.21	0.53	2682	33	25	12.35
		0.03	0.03	0.00	0.21	0.42	0.25	12.19	0.76	3	6	3	5.81
		3	3	3	3	3	3	3	3	3	3	3	3

Appendix 1. (continued)

Stream	Reach	Shore depth	Undercut bank	Bank vegetation cover	Bank soil stability	Bank vegetation stability	Bank ungulate damage	Bank angle	Riparian canopy density	Station elevation	Valley bottom width	Riparian area width	Width:depth ratio
3	8	0.06	0.08	2.33	3.83	3.37	3.73	110.17	38.13	2695	14	11	19.96
		0.06	0.06	0.64	0.12	0.47	0.31	22.38	13.15	5	6	1	7.25
		3	3	3	3	3	3	3	3	3	3	3	3
3	9	0.05	0.03	2.00	3.10	3.43	3.50	110.50	0.07	2711	139	16	9.10
		0.04	0.03	0.00	0.10	0.51	0.56	29.14	0.12	1	70	5	2.46
		3	3	3	3	3	3	3	3	3	3	3	3
3	10	0.02	0.03	2.93	2.93	3.17	3.13	126.71	25.00	2716	29	17	23.39
		0.01	0.01	0.81	0.40	0.38	0.42	9.87	15.19	2	3	7	7.54
		3	3	3	3	3	3	3	3	3	3	3	3
3	11	0.05	0.08	2.15	3.32	3.47	3.35	96.42	13.03	2735	39	20	18.09
		0.03	0.05	0.29	0.42	0.38	0.60	28.23	7.29	6	20	3	10.58
		6	6	6	6	6	6	6	6	6	6	6	6
3	12	0.01	0.02	3.00	3.33	3.63	3.40	121.50	35.00	2757	43	23	29.21
		0.01	0.01	0.20	0.21	0.35	0.52	6.38	16.04	7	10	11	10.83
		3	3	3	3	3	3	3	3	3	3	3	3
3	13	0.01	0.05	3.00	3.57	3.60	3.87	110.17	54.47	2791	37	8	36.86
		0.00	0.02	0.70	0.45	0.40	0.23	14.68	1.75	24	53	5	22.02
		3	3	3	3	3	3	3	3	3	3	3	3
4	1	0.00	0.00	3.55	3.38	3.10	3.95	149.25	43.15	2097	13	10	26.52
		0.00	0.00	0.17	0.31	0.27	0.10	6.96	3.44	45	11	6	16.16
		4	4	4	4	4	4	4	4	4	4	4	4
5	1	0.09	0.18	2.27	3.50	3.83	3.93	54.96	30.40	2754	33	11	15.90
		0.05	0.02	0.29	0.46	0.15	0.06	4.71	9.90	4	21	2	7.00
		3	3	3	3	3	3	3	3	3	3	3	3
5	2	0.09	0.13	2.20	3.67	3.82	3.78	70.30	21.40	2772	147	58	9.85
		0.05	0.06	0.31	0.16	0.13	0.28	12.60	12.22	8	80	15	4.41
		6	6	6	6	6	6	6	6	6	6	6	6
5	3	0.05	0.08	2.55	3.65	3.75	3.80	97.25	26.90	2787	91	73	18.35
		0.03	0.05	0.21	0.07	0.21	0.28	30.76	18.24	3	5	30	5.58
		2	2	2	2	2	2	2	2	2	2	2	2
5	4	0.04	0.09	2.63	3.58	3.45	3.78	107.50	54.33	2919	35	16	23.67
		0.02	0.05	0.27	0.41	0.35	0.23	17.40	5.24	95	27	12	5.08
		6	6	6	6	6	6	6	6	6	6	6	6
5	5	0.04	0.04	2.30	3.17	3.10	3.30	119.79	36.27	3112	37	11	27.12
		0.04	0.02	0.30	0.35	0.17	0.30	12.74	13.25	30	51	6	11.68
		3	3	3	3	3	3	3	3	3	3	3	3
6	1	0.07	0.10	3.33	3.57	3.57	3.80	96.94	75.73	2170	25	25	18.66
		0.03	0.06	0.31	0.12	0.25	0.00	14.23	6.72	52	15	15	6.65
		3	3	3	3	3	3	2	3	3	3	3	3
6	2	0.04	0.08	2.37	2.20	2.30	3.83	86.00	68.60	2256	15	15	14.77
		0.02	0.03	0.75	0.53	0.56	0.15	33.37	15.13	6	0	0	1.52
		3	3	3	3	3	3	3	3	3	3	3	3

Appendix 1. (continued)

Stream	Reach	Shore depth	Undercut bank	Bank vegetation cover	Bank soil stability	Bank vegetation stability	Bank ungulate damage	Bank angle	Riparian canopy density	Station elevation	Valley bottom width	Riparian area width	Width:depth ratio
6	3	0.01	0.03	2.07	1.70	1.63	3.80	118.17	73.07	2288	15	15	9.60
		0.03	0.06	0.76	0.75	0.65	0.17	9.25	1.29	14	5	5	1.65
		3	3	3	3	3	3	3	3	3	3	3	3
7	1	0.07	0.05	3.50	3.20	3.03	3.83	137.67	31.47	2162	48	11	25.64
		0.09	0.06	0.26	0.10	0.15	0.21	17.32	6.85	76	13	2	14.77
		3	3	3	3	3	3	3	3	3	3	3	3
7	2	0.03	0.03	2.53	2.97	2.77	3.60	120.63	45.60	2369	24	11	22.66
		0.03	0.04	0.68	0.25	0.32	0.35	18.54	8.86	76	18	3	10.94
		3	3	3	3	3	3	3	3	3	3	3	3
7	3	0.00	0.01	1.95	2.05	2.20	2.90	139.10	16.80	2494	27	10	24.16
		0.00	0.00	0.35	0.21	0.42	0.99	4.81	12.16	32	3	7	2.08
		2	2	2	2	2	2	2	2	2	2	2	2
8	1	0.01	0.03	3.00	2.45	2.55	2.45	152.15	49.23	2113	35	20	29.81
		0.01	0.04	0.28	0.49	0.07	0.49	15.34	2.79	24	7	7	3.77
		2	2	2	2	2	2	2	2	2	2	2	2
8	3	0.02	0.00	2.70	2.14	2.17	1.98	154.42	40.84	2429	33	16	42.38
		0.04	0.00	0.67	0.73	0.72	0.66	7.56	16.47	97	8	3	8.28
		8	8	8	8	8	8	8	8	8	8	8	8
8	4	0.02	0.06	2.15	2.20	2.30	2.20	140.75	33.20	2630	25	13	24.46
		0.03	0.06	0.21	0.14	0.42	0.85	15.91	7.64	27	1	0	9.32
		2	2	2	2	2	2	2	2	2	2	2	2
9	1	0.02	0.04	1.00	1.56	1.71	2.88	120.00	5.20	2513	46	10	24.62
		0.01	0.06	0.00	0.09	0.12	0.18	0.0	7.35	43	1	0	1.21
		2	2	2	2	2	2	1	2	2	2	2	2
9	2	0.03	0.00	1.20	2.33	2.26	2.79	156.67	6.90	2593	18	8	19.32
		0.04	0.00	0.28	0.60	0.51	0.83	0.0	1.27	36	11	4	4.05
		2	2	2	2	2	2	1	2	2	2	2	2
9	3	0.01	0.00	2.00	2.10	2.50	2.20	158.33	1.50	2625	47	11	22.88
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0.00
		1	1	1	1	1	1	1	1	1	1	1	1
10	1	0.04	0.01	2.42	2.74	2.33	2.86	165.00	58.10	2544	16	9	54.74
		0.04	0.01	0.25	0.19	0.11	0.37	0.00	8.34	15	4	3	45.28
		2	2	2	2	2	2	2	2	2	2	2	2
10	2	0.03	0.04	2.29	2.11	2.08	2.03	146.19	33.32	2622	28	18	22.59
		0.01	0.06	0.26	0.10	0.16	0.25	19.54	14.36	29	7	6	14.02
		3	3	3	3	3	3	3	3	3	3	3	3
10	3	0.01	0.02	2.35	2.05	1.95	2.00	154.69	34.50	2719	21	11	23.05
		0.01	0.01	0.07	0.49	0.21	0.14	18.12	8.63	18	2	4	3.24
		2	2	2	2	2	2	2	2	2	2	2	2
11	1	0.07	0.04	3.63	3.27	3.30	3.77	115.93	34.93	2195	24	16	33.94
		0.05	0.01	0.32	0.50	0.40	0.32	15.17	2.37	94	8	4	11.85
		3	3	3	3	3	3	3	3	3	3	3	3

Appendix 1. (continued)

Stream	Reach	Shore depth	Undercut bank	Bank vegetation cover	Bank soil stability	Bank vegetation stability	Bank ungulate damage	Bank angle	Riparian canopy density	Station elevation	Valley bottom width	Riparian area width	Width:depth ratio
11	2	0.08	0.02	3.40	2.40	2.60	3.15	142.60	38.80	2305	21	17	40.01
		0.03	0.02	0.28	0.28	0.57	0.49	22.24	4.24	15	1	7	19.08
		2	2	2	2	2	2	2	2	2	2	2	2
11	3	0.01	0.04	3.40	2.20	2.47	2.90	118.67	35.20	2388	42	9	19.93
		0.01	0.04	0.35	0.44	0.58	0.10	26.70	13.00	79	7	3	7.78
		3	3	3	3	3	3	3	3	3	3	3	3
12	1	0.02	0.02	2.20	2.70	2.67	3.10	151.46	25.53	2272	57	7	24.01
		0.01	0.02	0.53	1.01	1.10	0.90	15.86	14.30	68	52	2	9.18
		3	3	3	3	3	3	3	3	3	3	3	3
12	2	0.01	0.01	1.60	1.57	1.60	2.10	153.58	10.00	2336	69	7	21.37
		0.01	0.01	0.26	0.31	0.30	1.15	14.88	6.81	77	25	2	1.77
		3	3	3	3	3	3	3	3	3	3	3	3
13	1	0.02	0.03	3.80	2.85	3.20	3.25	126.29	42.00	2315	62	18	35.44
		0.01	0.01	0.28	0.64	0.42	0.78	0.06	11.88	13	62	4	7.42
		2	2	2	2	2	2	2	2	2	2	2	2
13	2	0.00	0.02	2.85	1.80	2.20	2.06	138.00	16.60	2365	45	15	24.56
		0.00	0.00	1.34	0.57	0.85	1.50	0.71	19.80	46	7	3	9.80
		2	2	2	2	2	2	2	2	2	2	2	2
13	3	0.01	0.02	3.80	2.90	3.20	3.80	135.63	43.60	2469	20	10	26.81
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0.00
		1	1	1	1	1	1	1	1	1	1	1	1
14	1	0.00	0.00	1.97	1.93	2.03	2.60	162.00	10.73	2393	108	8	39.85
		0.00	0.00	0.50	0.46	0.21	0.26	2.78	5.80	2	20	2	9.88
		3	3	3	3	3	3	3	3	3	3	3	3
14	2	0.00	0.01	2.45	2.50	2.55	3.10	151.25	45.70	2426	61	8	45.71
		0.00	0.01	0.64	0.14	0.21	0.85	13.08	3.25	13	5	1	19.03
		2	2	2	2	2	2	2	2	2	2	2	2
14	3	0.01	0.02	2.13	2.33	2.13	3.37	152.67	54.40	2454	46	9	37.73
		0.01	0.03	0.57	0.55	0.55	0.55	10.77	5.24	14	7	2	12.62
		3	3	3	3	3	3	3	3	3	3	3	3
14	4	0.00	0.02	2.44	2.52	2.64	3.12	148.06	42.88	2538	36	10	39.30
		0.00	0.03	0.35	0.33	0.30	0.41	10.10	10.12	54	14	6	13.75
		5	5	5	5	5	5	5	5	5	5	5	5
15	7	0.04	0.04	2.28	1.85	1.95	2.23	125.50	4.95	2697	78	27	23.72
		0.03	0.02	0.39	0.34	0.37	0.52	11.07	4.54	11	32	8	5.13
		4	4	4	4	4	4	4	4	4	4	4	4
15	8	0.02	0.05	3.17	2.73	2.83	3.28	115.12	37.60	2738	26	17	27.11
		0.01	0.04	0.42	0.42	0.52	0.37	20.47	11.47	15	12	8	5.35
		6	6	6	6	6	6	6	6	6	6	6	6
16	1	0.02	0.03	2.93	2.97	3.03	3.67	134.33	41.47	2461	38	12	25.88
		0.00	0.04	0.61	0.58	0.31	0.31	10.37	4.06	58	17	3	6.57
		3	3	3	3	3	3	3	3	3	3	3	3

Appendix 1. (continued)

Stream	Reach	Shore depth	Undercut bank	Bank vegetation cover	Bank soil stability	Bank vegetation stability	Bank ungulate damage	Bank angle	Riparian canopy density	Station elevation	Valley bottom width	Riparian area width	Width:depth ratio
16	2	0.03	0.00	2.50	3.23	3.10	3.35	136.44	39.73	2576	18	12	28.78
		0.01	0.00	0.61	0.49	0.36	0.83	13.17	3.67	50	7	2	7.87
		3	3	3	3	3	3	3	3	3	3	3	3
16	3	0.02	0.04	1.70	1.90	1.90	1.69	138.23	0.70	2679	104	6	16.06
		0.01	0.05	0.42	0.99	0.99	0.44	13.99	0.99	20	16	1	7.37
		2	2	2	2	2	2	2	2	2	2	2	2
17	1	0.01	0.04	3.33	3.50	3.83	3.83	117.11	66.40	2616	16	16	27.91
		0.01	0.03	0.31	0.36	0.12	0.06	23.78	11.97	14	2	2	12.77
		3	3	3	3	3	3	3	3	3	3	3	3
17	2	0.06	0.09	2.20	2.80	3.07	3.07	101.50	8.73	2638	38	30	14.46
		0.02	0.03	0.36	0.60	0.61	0.59	20.84	8.33	4	24	11	6.18
		3	3	3	3	3	3	3	3	3	3	3	3
17	3	0.02	0.04	2.40	3.00	3.20	3.53	119.00	63.13	2686	20	20	30.83
		0.01	0.02	0.40	0.44	0.30	0.29	14.40	22.63	12	7	7	12.11
		3	3	3	3	3	3	3	3	3	3	3	3
17	4	0.04	0.05	2.10	2.40	2.73	2.40	108.17	19.67	2720	46	46	17.76
		0.03	0.04	0.10	0.10	0.23	0.78	15.83	21.49	7	24	24	6.29
		3	3	3	3	3	3	3	3	3	3	3	3
18	1	0.02	0.03	3.96	3.20	3.38	3.56	139.75	43.28	2214	146	89	46.74
		0.02	0.03	0.09	0.20	0.29	0.43	17.07	9.97	43	36	86	15.69
		5	5	5	5	5	5	5	5	5	5	5	5
18	4	0.00	0.02	2.93	3.13	2.97	3.50	135.17	42.60	2427	28	7	49.28
		0.00	0.02	0.59	0.25	0.31	0.56	12.50	7.02	21	1	3	24.16
		3	3	3	3	3	3	3	3	3	3	3	3
19	1	0.05	0.03	3.24	2.19	2.27	2.29	89.63	34.17	2423	46	10	24.40
		0.01	0.01	0.65	0.35	0.19	0.41	11.57	21.84	34	11	5	12.21
		4	4	4	4	4	4	4	3	4	4	4	4
19	2	0.04	0.08	2.17	2.83	2.50	3.00	37.50	21.67	2549	30	3	31.82
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0.00
		1	1	1	1	1	1	1	1	1	1	1	1
20	2	0.01	0.07	3.25	2.08	2.40	3.50	124.11	94.13	2558	23	23	21.71
		0.01	0.10	0.89	0.48	0.55	0.45	20.46	3.23	30	11	11	8.72
		6	6	6	6	6	6	6	6	6	6	6	6
20	3	0.01	0.06	3.67	2.63	2.93	3.43	93.00	93.33	2684	25	15	26.51
		0.01	0.02	0.12	0.78	0.68	0.57	18.30	3.56	10	5	7	10.05
		3	3	3	3	3	3	3	3	3	3	3	3
21	2	0.11	0.11	3.17	3.87	3.87	4.00	87.50	52.50	2682	38	30	15.98
		0.02	0.08	0.24	0.05	0.05	0.00	35.36	12.02	44	16	12	9.46
		2	2	2	2	2	2	2	2	2	2	2	2
21	3	0.00	0.00	2.00	3.05	3.20	3.05	155.25	0.00	2805	45	20	27.33
		0.00	0.00	0.00	1.06	0.85	1.06	23.69	0.00	43	21	7	15.78
		2	2	2	2	2	2	2	2	2	2	2	2

Appendix 1. (continued)

Stream	Reach	Shore depth	Undercut bank	Bank vegetation cover	Bank soil stability	Bank vegetation stability	Bank ungulate damage	Bank angle	Riparian canopy density	Station elevation	Valley bottom width	Riparian area width	Width:depth ratio
21	5	0.14	0.10	3.30	4.00	4.00	4.00	75.00	75.40	2859	80	25	16.20
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0.00
		1	1	1	1	1	1	1	1	1	1	1	1
21	6	0.09	0.10	2.90	2.60	2.80	2.70	79.17	60.80	2883	106	19	16.85
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0.00
		1	1	1	1	1	1	1	1	1	1	1	1
21	7	0.14	0.08	2.30	3.40	3.35	3.35	84.56	16.00	2906	110	38	5.69
		0.07	0.09	0.42	0.85	0.92	0.92	47.99	22.63	21	57	4	1.69
		2	2	2	2	2	2	2	2	2	2	2	2
21	8	0.04	0.09	3.00	3.70	3.90	3.80	107.50	77.60	2957	100	15	25.97
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0	0.00
		1	1	1	1	1	1	1	1	1	1	1	1
21	9	0.06	0.06	3.00	4.00	4.00	4.00	88.81	83.00	3017	12	5	7.00
		0.03	0.02	0.00	0.00	0.00	0.00	4.51	0.28	21	2	1	3.00
		2	2	2	2	2	2	2	2	2	2	2	2

Appendix 2. Means (upper), standard deviations (middle), and sample sizes (lower) of standing crop estimates from multiple pass depletion electrofishing. See Table 1 for stream designations.

Stream	Reach	Fish no./m²	Fish biomass/m²	Fish no./m³	Fish biomass/m³	Trout no./m²	Trout biomass/m²	Trout no./m³	Trout biomass/m³
1	1	1.62	34.02	10.55	215.86	1.62	34.02	10.55	215.86
		0.52	16.50	5.05	129.07	0.52	16.50	5.05	129.07
		6	6	6	6	6	6	6	6
1	2	0.25	5.98	3.29	70.06	0.25	5.98	3.29	70.06
		0.12	5.64	2.02	50.26	0.12	5.64	2.02	50.26
		6	6	6	6	6	6	6	6
2	1	0.50	6.69	4.39	59.43	0.24	5.77	2.07	51.28
		0.25	1.98	2.65	21.45	0.16	2.98	1.38	26.13
		6	6	6	6	6	6	6	6
2	2	0.05	0.40	0.73	6.01	0.05	0.40	0.73	6.01
		0.08	0.56	1.13	8.58	0.08	0.56	1.13	8.58
		5	5	5	5	5	5	5	5
2	3	0.09	2.51	0.66	17.90	0.09	2.51	0.66	17.90
		0.03	0.64	0.18	3.48	0.03	0.64	0.18	3.48
		6	6	6	6	6	6	6	6
2	4	0.04	0.99	0.27	6.86	0.04	0.99	0.27	6.86
		0.02	0.66	0.12	3.82	0.02	0.66	0.12	3.82
		6	6	6	6	6	6	6	6
2	5	0.03	0.50	0.30	5.08	0.03	0.50	0.30	5.08
		0.03	0.68	0.32	6.45	0.03	0.68	0.32	6.45
		3	3	3	3	3	3	3	3
3	1	0.60	5.16	4.85	40.37	0.27	3.71	2.18	29.33
		0.19	2.39	0.88	8.26	0.08	1.54	0.02	5.21
		3	3	3	3	3	3	3	3
3	2	0.58	7.32	3.73	46.32	0.31	6.73	1.93	42.53
		0.25	3.06	1.39	15.85	0.16	2.98	0.89	15.73
		3	3	3	3	3	3	3	3
3	3	0.27	4.57	1.69	28.59	0.19	4.05	1.21	25.35
		0.10	2.28	0.71	15.38	0.12	2.27	0.80	15.25
		3	3	3	3	3	3	3	3
3	4	0.42	11.49	4.38	121.83	0.36	11.26	3.80	119.66
		0.13	6.34	2.06	80.36	0.14	6.36	2.11	80.11
		3	3	3	3	3	3	3	3
3	5	0.58	7.95	10.40	136.71	0.57	7.93	10.35	136.22
		0.13	1.64	3.87	8.42	0.14	1.68	3.86	8.87
		3	3	3	3	3	3	3	3
3	6	0.61	7.70	7.67	91.78	0.61	7.65	7.64	91.31
		0.33	4.61	5.78	55.91	0.33	4.56	5.79	55.66
		6	6	6	6	6	6	6	6
3	7	0.41	12.02	3.11	92.21	0.36	11.45	2.71	88.07
		0.20	4.78	2.55	75.91	0.18	4.47	2.29	72.62
		3	3	3	3	3	3	3	3
3	8	0.37	11.66	3.34	104.23	0.28	11.24	2.61	100.54
		0.02	6.45	1.10	60.40	0.03	6.46	1.01	60.38
		3	3	3	3	3	3	3	3

Appendix 2. (continued)

Stream	Reach	Fish no./m^2	Fish biomass/m^2	Fish no./m^3	Fish biomass/m^3	Trout no./m^2	Trout biomass/m^2	Trout no./m^3	Trout biomass/m^3
3	9	0.76	12.64	5.83	92.07	0.71	12.21	5.58	89.83
		0.32	1.05	3.72	28.28	0.37	1.30	4.03	31.57
		3	3	3	3	3	3	3	3
3	10	0.86	15.90	11.11	207.51	0.86	15.90	11.11	207.51
		0.40	7.04	3.38	66.95	0.40	7.04	3.38	66.95
		3	3	3	3	3	3	3	3
3	11	1.47	24.57	16.81	281.93	1.47	24.52	16.77	281.41
		0.61	9.81	3.94	64.51	0.61	9.74	3.92	64.18
		6	6	6	6	6	6	6	6
3	12	1.24	14.58	20.52	242.29	1.24	14.58	20.52	242.29
		0.08	2.10	2.98	52.50	0.08	2.10	2.98	52.50
		3	3	3	3	3	3	3	3
3	13	0.66	5.29	11.98	92.70	0.66	5.29	11.98	92.70
		0.26	3.18	1.66	42.44	0.26	3.18	1.66	42.44
		3	3	3	3	3	3	3	3
4	1	1.50	8.27	16.54	82.51	0.15	3.90	1.48	32.60
		1.59	3.30	16.42	32.73	0.08	3.94	0.64	20.16
		4	4	4	4	4	4	4	4
5	1	0.59	11.32	5.61	100.17	0.59	11.32	5.61	100.17
		0.10	1.55	2.81	27.15	0.10	1.55	2.81	27.15
		3	3	3	3	3	3	3	3
5	2	0.95	27.58	7.78	230.19	0.95	27.58	7.78	230.19
		0.18	14.88	2.78	140.31	0.18	14.88	2.78	140.31
		6	6	6	6	6	6	6	6
5	3	1.21	23.58	14.62	275.47	1.21	23.58	14.62	275.47
		0.20	2.31	5.76	37.62	0.20	2.31	5.76	37.62
		2	2	2	2	2	2	2	2
5	4	0.56	9.32	7.36	122.37	0.56	9.32	7.36	122.37
		0.39	6.77	5.38	95.69	0.39	6.77	5.38	95.69
		6	6	6	6	6	6	6	6
5	5	0.07	1.17	1.41	22.83	0.07	1.17	1.41	22.83
		0.09	1.50	2.04	34.55	0.09	1.50	2.04	34.55
		3	3	3	3	3	3	3	3
6	1	0.20	7.02	1.45	52.60	0.20	7.02	1.45	52.60
		0.07	1.25	0.45	10.88	0.07	1.25	0.45	10.88
		3	3	3	3	3	3	3	3
6	2	0.26	7.08	2.06	55.33	0.26	7.08	2.06	55.33
		0.07	2.01	0.63	17.92	0.07	2.01	0.63	17.92
		3	3	3	3	3	3	3	3
6	3	0.37	11.50	3.09	98.93	0.37	11.50	3.09	98.93
		0.18	6.98	1.70	66.35	0.18	6.98	1.70	66.35
		3	3	3	3	3	3	3	3
7	1	0.18	3.03	2.51	43.45	0.18	3.03	2.51	43.45
		0.12	2.25	2.09	36.28	0.12	2.25	2.09	36.28
		3	3	3	3	3	3	3	3

Appendix 2. (continued)

Stream	Reach	Fish no./m²	Fish biomass/m²	Fish no./m³	Fish biomass/m³	Trout no./m²	Trout biomass/m²	Trout no./m³	Trout biomass/m³
7	2	0.27	4.16	3.07	48.94	0.27	4.16	3.07	48.94
		0.15	2.12	1.31	18.67	0.15	2.12	1.31	18.67
		3	3	3	3	3	3	3	3
7	3	0.11	2.42	3.04	67.82	0.11	2.42	3.04	67.82
		0.09	2.08	2.93	68.51	0.09	2.08	2.93	68.51
		2	2	2	2	2	2	2	2
8	2	0.18	1.91	1.42	14.92	0.03	0.85	0.25	6.82
		0.01	0.38	0.04	3.67	0.04	1.19	0.31	9.58
		2	2	2	2	2	2	2	2
8	3	0.78	5.54	8.85	62.23	0.12	2.90	1.44	31.27
		0.48	2.44	6.56	34.20	0.04	1.13	0.70	11.76
		8	8	8	8	8	8	8	8
8	4	0.21	3.96	3.47	61.20	0.17	3.69	2.79	56.44
		0.11	1.21	2.19	9.98	0.05	1.59	1.23	16.71
		2	2	2	2	2	2	2	2
9	1	0.79	4.69	8.79	52.42	0.16	1.91	1.91	21.24
		0.19	0.97	1.43	10.10	0.01	0.44	0.84	3.56
		2	2	2	2	2	2	2	2
9	2	0.31	2.30	2.84	20.34	0.11	1.09	0.94	9.47
		0.40	3.07	2.95	23.98	0.14	1.48	1.06	11.79
		2	2	2	2	2	2	2	2
9	3	0.01	0.24	0.20	4.54	0.01	0.22	0.10	4.13
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1	1	1	1	1	1	1	1
10	1	0.98	6.73	18.73	133.85	0.19	2.68	3.87	55.66
		0.68	3.85	3.65	5.45	0.09	1.15	0.27	6.90
		2	2	2	2	2	2	2	2
10	2	1.44	8.72	17.48	120.45	0.26	4.42	4.14	71.87
		1.01	3.59	9.30	24.73	0.10	1.34	2.81	49.78
		3	3	3	3	3	3	3	3
10	3	0.06	2.00	1.47	60.13	0.06	2.00	1.47	60.13
		0.02	1.06	0.46	59.91	0.02	1.06	0.46	59.91
		2	2	2	2	2	2	2	2
11	1	0.47	4.45	3.14	35.16	0.09	3.61	0.69	29.43
		0.47	1.86	2.80	20.23	0.06	2.41	0.50	23.50
		3	3	3	3	3	3	3	3
11	2	0.14	4.22	0.91	26.70	0.08	3.68	0.52	23.23
		0.07	0.47	0.47	1.70	0.01	1.05	0.09	5.53
		2	2	2	2	2	2	2	2
11	3	0.20	4.89	1.69	38.60	0.13	4.41	1.08	34.51
		0.02	2.68	0.09	18.78	0.08	2.71	0.51	19.00
		3	3	3	3	3	3	3	3
12	1	0.07	1.51	0.60	13.41	0.07	1.51	0.60	13.41
		0.03	0.55	0.36	7.88	0.03	0.55	0.36	7.88
		3	3	3	3	3	3	3	3

Appendix 2. (continued)

Stream	Reach	Fish no./m²	Fish biomass/m²	Fish no./m³	Fish biomass/m³	Trout no./m²	Trout biomass/m²	Trout no./m³	Trout biomass/m³
12	2	0.01	0.47	0.12	4.98	0.01	0.47	0.12	4.98
		0.02	0.67	0.18	7.26	0.02	0.67	0.18	7.26
		3	3	3	3	3	3	3	3
13	1	0.18	3.60	1.45	30.27	0.04	3.06	0.36	26.00
		0.16	2.57	1.13	16.79	0.00	1.94	0.05	12.05
		2	2	2	2	2	2	2	2
13	2	2.68	7.02	27.11	106.67	0.38	6.41	6.20	101.20
		2.41	4.85	14.15	107.81	0.41	5.63	7.73	114.02
		2	2	2	2	2	2	2	2
13	3	0.19	3.57	2.56	47.38	0.19	3.57	2.56	47.38
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1	1	1	1	1	1	1	1
14	1	0.57	0.67	20.65	24.24	0.00	0.00	0.00	0.00
		0.98	1.15	35.77	41.99	0.00	0.00	0.00	0.00
		3	3	3	3	3	3	3	3
14	2	0.03	0.23	0.97	8.27	0.03	0.23	0.97	8.27
		0.02	0.17	1.11	9.06	0.02	0.17	1.11	9.06
		2	2	2	2	2	2	2	2
14	3	0.19	2.26	3.82	46.09	0.19	2.26	3.82	46.09
		0.09	1.28	1.95	30.40	0.09	1.28	1.95	30.40
		3	3	3	3	3	3	3	3
14	4	0.13	1.60	3.80	48.58	0.13	1.60	3.80	48.58
		0.10	1.35	3.08	43.54	0.10	1.35	3.08	43.54
		5	5	5	5	5	5	5	5
15	7	0.45	9.34	3.21	67.29	0.25	8.15	1.82	59.13
		0.05	5.79	0.57	39.50	0.18	7.02	1.33	47.78
		4	4	4	4	4	4	4	4
15	8	0.36	10.93	2.84	85.56	0.36	10.93	2.84	85.56
		0.06	2.42	0.57	21.10	0.06	2.42	0.57	21.10
		6	6	6	6	6	6	6	6
16	1	0.07	2.77	0.98	41.18	0.05	2.63	0.79	39.52
		0.06	3.07	0.99	52.08	0.06	3.06	0.96	51.99
		3	3	3	3	3	3	3	3
16	2	0.06	2.69	0.73	31.52	0.03	2.49	0.35	28.78
		0.02	0.82	0.42	9.80	0.02	0.86	0.15	8.08
		3	3	3	3	3	3	3	3
16	3	3.58	8.53	40.62	95.70	0.00	0.00	0.00	0.00
		0.80	2.29	13.25	27.18	0.00	0.00	0.00	0.00
		2	2	2	2	2	2	2	2
17	1	0.35	9.77	5.37	151.68	0.26	9.24	3.96	143.57
		0.27	5.37	4.03	81.62	0.14	4.59	2.08	70.15
		3	3	3	3	3	3	3	3
17	2	2.35	29.02	40.15	429.02	0.59	22.83	8.31	307.56
		1.63	9.85	48.79	405.01	0.20	6.20	7.16	228.79
		3	3	3	3	3	3	3	3

Appendix 2. (continued)

Stream	Reach	Fish no./m^2	Fish biomass/m^2	Fish no./m^3	Fish biomass/m^3	Trout no./m^2	Trout biomass/m^2	Trout no./m^3	Trout biomass/m^3
17	3	0.62	13.69	12.87	280.68	0.62	13.69	12.87	280.68
		0.20	3.61	6.58	129.92	0.20	3.61	6.58	129.92
		3	3	3	3	3	3	3	3
17	4	0.74	27.22	11.07	354.97	0.74	27.22	11.07	354.97
		0.36	13.80	7.44	108.02	0.36	13.80	7.44	108.02
		3	3	3	3	3	3	3	3
18	1	0.43	8.43	4.16	69.24	0.20	5.20	1.80	41.51
		0.11	4.97	2.58	29.99	0.07	3.00	0.65	14.39
		5	5	5	5	5	5	5	5
18	4	0.02	0.82	0.60	27.33	0.02	0.82	0.60	27.33
		0.03	1.43	1.03	47.33	0.03	1.43	1.03	47.33
		3	3	3	3	3	3	3	3
19	1	0.00	0.33	0.03	1.84	0.00	0.33	0.03	1.84
		0.01	0.38	0.04	2.14	0.01	0.38	0.04	2.14
		4	4	4	4	4	4	4	4
19	2	0.00	0.10	0.03	0.92	0.00	0.10	0.03	0.92
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.0
		1	1	1	1	1	1	1	1
20	2	0.57	4.95	10.21	85.01	0.57	4.95	10.21	85.01
		0.61	6.78	7.55	86.39	0.61	6.78	7.55	86.39
		6	6	6	6	6	6	6	6
20	3	0.14	1.99	4.61	69.23	0.14	1.99	4.61	69.23
		0.04	1.34	2.43	66.15	0.04	1.34	2.43	66.15
		3	3	3	3	3	3	3	3
21	2	0.06	3.74	0.30	18.37	0.06	3.74	0.30	18.37
		0.02	0.89	0.16	9.41	0.02	0.89	0.16	9.41
		2	2	2	2	2	2	2	2
21	3	0.07	3.47	0.41	21.63	0.05	2.91	0.29	18.05
		0.00	0.98	0.02	5.77	0.03	1.78	0.18	10.84
		2	2	2	2	2	2	2	2
21	5	0.18	4.68	1.36	34.45	0.17	3.74	1.23	27.53
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1	1	1	1	1	1	1	1
21	6	0.29	4.75	2.46	40.01	0.28	4.50	2.38	37.93
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1	1	1	1	1	1	1	1
21	7	0.76	12.09	3.75	58.62	0.76	12.09	3.75	58.62
		0.28	1.31	1.87	14.63	0.28	1.31	1.87	14.63
		2	2	2	2	2	2	2	2
21	8	0.36	5.11	5.87	83.97	0.36	5.11	5.87	83.97
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1	1	1	1	1	1	1	1
21	9	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		2	2	2	2	2	2	2	2

Appendix 3. Means (upper), standard deviations (middle), and sample sizes (lower) of percent areas of habitat types among stream reaches.

Stream	Reach	% cascade area	% glide area	% high gradient riffle area	% low gradient riffle area	% run area	% pool area	% slow-velocity habitat area	% swift velocity habitat area
1	1	0.00	0.22	0.09	0.38	0.14	0.16	0.38	0.62
		0.00	0.19	0.21	0.22	0.20	0.06	0.18	0.18
		6	6	6	6	6	6	6	6
1	2	0.00	0.06	0.70	0.10	0.00	0.14	0.20	0.80
		0.00	0.04	0.28	0.18	0.00	0.11	0.11	0.11
		6	6	6	6	6	6	6	6
2	1	0.02	0.13	0.27	0.14	0.04	0.41	0.54	0.46
		0.03	0.07	0.17	0.08	0.05	0.09	0.09	0.09
		6	6	6	6	6	6	6	6
2	2	0.00	0.22	0.36	0.12	0.00	0.30	0.52	0.48
		0.01	0.13	0.22	0.09	0.00	0.18	0.18	0.18
		5	5	5	5	5	5	5	5
2	3	0.00	0.06	0.46	0.09	0.14	0.25	0.31	0.69
		0.01	0.07	0.18	0.12	0.07	0.13	0.17	0.17
		6	6	6	6	6	6	6	6
2	4	0.00	0.06	0.62	0.10	0.09	0.12	0.19	0.81
		0.01	0.08	0.13	0.09	0.12	0.11	0.14	0.14
		6	6	6	6	6	6	6	6
2	5	0.01	0.17	0.52	0.04	0.00	0.25	0.43	0.57
		0.02	0.11	0.24	0.07	0.00	0.11	0.18	0.18
		3	3	3	3	3	3	3	3
3	1	0.00	0.16	0.70	0.02	0.00	0.12	0.28	0.72
		0.00	0.15	0.25	0.02	0.00	0.10	0.23	0.23
		3	3	3	3	3	3	3	3
3	2	0.00	0.40	0.02	0.50	0.00	0.08	0.48	0.52
		0.00	0.15	0.03	0.32	0.00	0.14	0.28	0.28
		3	3	3	3	3	3	3	3
3	3	0.00	0.15	0.47	0.21	0.00	0.17	0.32	0.68
		0.00	0.24	0.41	0.13	0.00	0.15	0.36	0.36
		3	3	3	3	3	3	3	3
3	4	0.00	0.25	0.04	0.36	0.02	0.32	0.58	0.42
		0.00	0.04	0.07	0.06	0.03	0.14	0.11	0.11
		3	3	3	3	3	3	3	3
3	5	0.00	0.19	0.20	0.54	0.00	0.07	0.26	0.74
		0.00	0.08	0.34	0.42	0.00	0.07	0.11	0.11
		3	3	3	3	3	3	3	3
3	6	0.00	0.12	0.40	0.25	0.00	0.23	0.34	0.66
		0.00	0.15	0.16	0.13	0.00	0.15	0.18	0.18
		6	6	6	6	6	6	6	6
3	7	0.00	0.17	0.03	0.34	0.00	0.46	0.63	0.37
		0.00	0.10	0.05	0.29	0.00	0.30	0.27	0.27
		3	3	3	3	3	3	3	3
3	8	0.01	0.37	0.00	0.34	0.07	0.21	0.58	0.42
		0.02	0.26	0.00	0.20	0.07	0.13	0.25	0.25
		3	3	3	3	3	3	3	3

Appendix 3. (continued)

Stream	Reach	% cascade area	% glide area	% high gradient riffle area	% low gradient riffle area	% run area	% pool area	% slow-velocity habitat area	% swift velocity habitat area
3	9	0.00	0.78	0.00	0.12	0.04	0.06	0.84	0.16
		0.00	0.08	0.00	0.11	0.05	0.07	0.14	0.14
		3	3	3	3	3	3	3	3
3	10	0.00	0.41	0.00	0.45	0.01	0.14	0.54	0.46
		0.00	0.07	0.00	0.14	0.02	0.09	0.15	0.15
		3	3	3	3	3	3	3	3
3	11	0.00	0.27	0.00	0.59	0.07	0.07	0.34	0.66
		0.00	0.20	0.00	0.22	0.13	0.06	0.20	0.20
		6	6	6	6	6	6	6	6
3	12	0.00	0.06	0.00	0.81	0.00	0.13	0.19	0.81
		0.00	0.03	0.00	0.18	0.00	0.14	0.18	0.18
		2	2	2	2	2	2	2	2
3	13	0.02	0.10	0.59	0.20	0.00	0.10	0.20	0.80
		0.03	0.15	0.37	0.21	0.00	0.06	0.19	0.19
		4	4	4	4	4	4	4	4
4	1	0.01	0.02	0.09	0.29	0.00	0.59	0.62	0.38
		0.03	0.02	0.14	0.17	0.00	0.24	0.22	0.22
		4	4	4	4	4	4	4	4
5	1	0.00	0.03	0.00	0.40	0.03	0.53	0.57	0.43
		0.00	0.03	0.00	0.13	0.04	0.12	0.10	0.10
		3	3	3	3	3	3	3	3
5	2	0.00	0.12	0.00	0.33	0.19	0.36	0.48	0.52
		0.00	0.06	0.00	0.20	0.25	0.18	0.22	0.22
		7	7	7	7	7	7	7	7
5	3	0.00	0.15	0.01	0.44	0.23	0.16	0.32	0.68
		0.00	0.12	0.01	0.33	0.03	0.23	0.35	0.35
		2	2	2	2	2	2	2	2
5	4	0.13	0.04	0.11	0.37	0.03	0.32	0.36	0.64
		0.16	0.04	0.26	0.18	0.04	0.15	0.14	0.14
		6	6	6	6	6	6	6	6
5	5	0.17	0.10	0.12	0.34	0.00	0.27	0.37	0.63
		0.17	0.09	0.11	0.21	0.00	0.03	0.09	0.09
		3	3	3	3	3	3	3	3
7	1	0.00	0.35	0.38	0.14	0.01	0.12	0.47	0.53
		0.00	0.14	0.10	0.05	0.01	0.06	0.10	0.10
		3	3	3	3	3	3	3	3
7	2	0.00	0.18	0.39	0.10	0.00	0.33	0.51	0.49
		0.01	0.07	0.05	0.03	0.00	0.10	0.03	0.03
		3	3	3	3	3	3	3	3
7	3	0.00	0.32	0.31	0.31	0.00	0.07	0.38	0.62
		0.00	0.17	0.34	0.15	0.00	0.02	0.19	0.19
		2	2	2	2	2	2	2	2
8	1	0.00	0.20	0.59	0.03	0.00	0.18	0.39	0.61
		0.00	0.09	0.02	0.04	0.00	0.14	0.06	0.06
		2	2	2	2	2	2	2	2

Appendix 3. (continued)

Stream	Reach	% cascade area	% glide area	% high gradient riffle area	% low gradient riffle area	% run area	% pool area	% slow-velocity habitat area	% swift velocity habitat area
8	3	0.03	0.20	0.55	0.07	0.01	0.14	0.34	0.66
		0.07	0.15	0.14	0.06	0.02	0.08	0.13	0.13
		8	8	8	8	8	8	8	8
8	4	0.00	0.22	0.28	0.29	0.00	0.21	0.43	0.57
		0.00	0.05	0.22	0.11	0.00	0.16	0.11	0.11
		2	2	2	2	2	2	2	2
10	1	0.01	0.02	0.80	0.01	0.00	0.15	0.18	0.82
		0.00	0.03	0.16	0.02	0.00	0.11	0.14	0.14
		2	2	2	2	2	2	2	2
10	2	0.00	0.15	0.61	0.10	0.02	0.11	0.27	0.73
		0.00	0.03	0.05	0.02	0.01	0.02	0.04	0.04
		3	3	3	3	3	3	3	3
10	3	0.00	0.07	0.32	0.42	0.00	0.20	0.27	0.73
		0.00	0.03	0.24	0.34	0.00	0.13	0.10	0.10
		2	2	2	2	2	2	2	2
11	1	0.00	0.05	0.48	0.08	0.01	0.37	0.42	0.58
		0.00	0.03	0.14	0.11	0.02	0.07	0.08	0.08
		3	3	3	3	3	3	3	3
11	2	0.00	0.04	0.26	0.04	0.00	0.66	0.70	0.30
		0.00	0.02	0.30	0.06	0.00	0.25	0.24	0.24
		2	2	2	2	2	2	2	2
11	3	0.00	0.09	0.09	0.33	0.00	0.49	0.58	0.42
		0.00	0.03	0.16	0.12	0.00	0.07	0.05	0.05
		3	3	3	3	3	3	3	3
12	1	0.01	0.08	0.56	0.08	0.06	0.21	0.29	0.71
		0.01	0.08	0.14	0.14	0.05	0.10	0.04	0.04
		3	3	3	3	3	3	3	3
12	2	0.00	0.17	0.00	0.46	0.00	0.38	0.54	0.46
		0.00	0.03	0.00	0.31	0.00	0.32	0.31	0.31
		3	3	3	3	3	3	3	3
13	1	0.00	0.26	0.33	0.34	0.01	0.06	0.32	0.68
		0.00	0.11	0.12	0.04	0.02	0.01	0.09	0.09
		2	2	2	2	2	2	2	2
13	2	0.00	0.39	0.06	0.48	0.00	0.07	0.46	0.54
		0.00	0.28	0.09	0.35	0.00	0.01	0.27	0.27
		2	2	2	2	2	2	2	2
13	3	0.00	0.13	0.30	0.46	0.00	0.11	0.23	0.77
		0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
		1	1	1	1	1	1	1	1
14	1	0.00	0.09	0.10	0.52	0.04	0.25	0.34	0.66
		0.00	0.06	0.17	0.23	0.07	0.14	0.17	0.17
		3	3	3	3	3	3	3	3
14	2	0.00	0.17	0.00	0.57	0.00	0.27	0.43	0.57
		0.00	0.23	0.00	0.06	0.00	0.18	0.06	0.06
		2	2	2	2	2	2	2	2

Appendix 3. (continued)

Stream	Reach	% cascade area	% glide area	% high gradient riffle area	% low gradient riffle area	% run area	% pool area	% slow-velocity habitat area	% swift velocity habitat area
14	3	0.00 0.00 3	0.10 0.11 3	0.00 0.00 3	0.52 0.14 3	0.00 0.00 3	0.38 0.15 3	0.48 0.14 3	0.52 0.14 3
14	4	0.00 0.00 5	0.08 0.10 5	0.07 0.10 5	0.43 0.13 5	0.00 0.00 5	0.42 0.14 5	0.50 0.09 5	0.50 0.09 5
15	7	0.00 0.00 4	0.16 0.17 4	0.00 0.00 4	0.60 0.12 4	0.05 0.06 4	0.20 0.15 4	0.36 0.13 4	0.64 0.13 4
15	8	0.03 0.07 6	0.03 0.04 6	0.08 0.16 6	0.64 0.13 6	0.07 0.12 6	0.14 0.04 6	0.18 0.06 6	0.82 0.06 6
16	1	0.00 0.00 3	0.19 0.07 3	0.29 0.10 3	0.25 0.17 3	0.00 0.00 3	0.26 0.13 3	0.45 0.07 3	0.55 0.07 3
16	2	0.00 0.00 3	0.13 0.11 3	0.28 0.06 3	0.09 0.06 3	0.00 0.00 3	0.50 0.11 3	0.63 0.00 3	0.37 0.00 3
16	3	0.00 0.00 2	0.41 0.17 2	0.00 0.00 2	0.15 0.21 2	0.00 0.00 2	0.44 0.38 2	0.85 0.21 2	0.15 0.21 2
18	1	0.03 0.05 6	0.23 0.25 6	0.15 0.09 6	0.34 0.18 6	0.09 0.11 6	0.17 0.12 6	0.40 0.19 6	0.60 0.19 6
18	4	0.00 0.00 3	0.14 0.05 3	0.09 0.10 3	0.26 0.07 3	0.02 0.04 3	0.49 0.14 3	0.63 0.09 3	0.37 0.09 3

Appendix 4. Minutes of the Habitat Vulnerability Index field evaluation.

Date: October 30, 1990

Attendees: Art Telles, Jerry Stefferud, John Rinne, Jim Novy, Bill Persons, Rob Clarkson

Began discussion at the meadow reach above Phelps Cabin in the Mt. Baldy Wilderness Area on the East Fork of the Little Colorado River, one of the more pristine reaches on the Apache-Sitgreaves National Forest.

Discussed components of the Habitat Vulnerability Index (HVI). Valley bottom component is less susceptible to impact from land uses with increasing width according to GAWS. Depending on cattle density, this direction of vulnerability may be opposite when referring to grazing activities, since cattle tend to concentrate in wide valleys. Fine alluvium in wide valleys also is more susceptible to headward and lateral erosion. The direction of lesser susceptiblity to impact with increasing width is probably appropriate for recreation, timber, and road building activities.

Stream gradient component is more vulnerable to impact with lower gradient according to GAWS, which was generally agreed upon since finer substrate materials in gently-sloped streams are more prone to erosion. This vector would indicate that, according to GAWS, an undisturbed meadow reach would be vulnerable in terms of stream gradient but not in terms of valley bottom width.

Valley side-slope component is least impacted by land uses when gradient is gradual according to GAWS, i.e. sediment and debris would not carry to the stream as readily. This vector also tends to counter the high susceptibility to impact of meadow reaches in terms of stream gradient.

Lower bank component is more vulnerable to impact when angle is lower, i.e. undercut banks (angle less than 90°) are prone to disturbance from land uses. This agreed upon vector indicates that land use activities (especially cattle grazing) reduce the vulnerability of natural meadow stream reaches since bank angles become greater.

Channel stability component vulnerability is reduced with greater stability according to GAWS. The components of the channel stability coefficient, however, appeared to be constructed independent to the habitat needs of fishes and seemed related to hydrological and geomorphological stability only. For example, a stable channel as indicated by a lack of point bars or tightly packed bottom materials is contradictory to what is considered good salmonid habitat. Many of the 15 components of the channel stability coefficient were difficult to decipher by the biologists present, and Telles reported that there was considerable disagreement among members of the field survey crews when rating this variable. This may be a reflection of the fact that a GAWS explanatory manual which is supposed to accompany the habitat survey handbook according to Stefferud was never received (nor known about) by the Apache-Sitgreaves National Forest or AGFD. It was concluded that these channel stability components must be judged following flood events, and that biologists should probably not be the ones to evaluate them.

Indicators of potential sediment production sources component were generally agreed upon to increase susceptibility to impact with increasing numbers. The presence of alder, however, was not considered an indicator of potential soil movement as concluded by GAWS.

Results of the questionnaire previously filled out by the group were presented. Bank angles, bank stability, and the presence of potential sediment sources were ranked high in importance by most, while valley bottom width and side-slope gradient were ranked consistently low. There was no general agreement among rankings of stream gradient.

Moved downstream to the adjacent higher gradient forested reach of the East Fork of the LCR to briefly review the HVI components in a different stream situation. All agreed that this relatively undisturbed stream section would rate fairly high in terms of habitat vulnerability because of narrow valley bottom width, steep side-slope gradients and bank angles, and certain elements of the channel stability component.

Appendix 4. (continued)

The major conclusion reached by the group regarding the HVI was that most land use activities, by degrading stream habitats, reduce the vulnerability of streams to further impact by the process of becoming degraded. Undisturbed streams are highly vulnerable to impacts from land use activities, and thus restoration of degraded streams must be directed toward making them more vulnerable. This conclusion raised skepticism of the utility of the HVI to a land manager if a low vulnerability rating was used as justification for further land use activities. In addition, some components of the index were unrelated to the resource (fishes), and thus further confounded its utility except as a tool for hydrologists and geomorphologists.

Drove to the headwaters of Coyote Creek (LCR drainage) and discussed the situation of headward erosion occurring there. It was noted that the HVI does not include susceptibility to impact from this avenue. The unusual nature of this reach--- deep downcutting of the stream with otherwise good bank formation within the constricted channel---made it difficult to apply and understand the functionality of the HVI.

Appendix 5. Correlation matrix of variables used in multiple regression analyses. Upper value is the Pearson correlation coefficient, middle value the one-tailed probability, and the lower value the number of observations. Sr denotes square root transformation, Ln denotes natural log transformation. See Table 2 for variable definitions.

	Pool Measure	Mean Water Depth	Maximum Water Depth	Macro-phyte Width	Embed-dedness	Discharge	Channel Gradient	Channel Width	Pool Width
Pool Measure	1.00000 0.0 219	-0.09801 0.1483 219	0.03247 0.6626 183	-0.01418 0.8347 219	-0.10870 0.1095 218	-0.03413 0.6577 171	0.06780 0.3179 219	0.04044 0.5516 219	0.62152 0.0001 219
Mean Water Depth	-0.09801 0.1483 219	1.00000 0.0 219	0.82510 0.0001 183	-0.06128 0.3668 219	0.08420 0.2156 218	0.45506 0.0001 171	-0.09923 0.1433 219	0.21664 0.0013 219	-0.07467 0.2712 219
Maximum Water Depth	0.03247 0.6626 183	0.82510 0.0001 183	1.00000 0.0 183	0.09156 0.2177 183	0.09741 0.1908 182	0.51724 0.0001 171	0.03500 0.6381 183	0.48423 0.0001 183	-0.02579 0.7290 183
Macrophyte Width	-0.01418 0.8347 219	-0.06128 0.3668 219	0.09156 0.2177 183	1.00000 0.0 219	-0.00989 0.8846 218	0.01634 0.8320 171	-0.07647 0.2598 219	-0.01443 0.8318 219	0.16750 0.0131 219
Embed-dedness	-0.10870 0.1095 218	0.08420 0.2156 218	0.09741 0.1908 182	-0.00989 0.8846 218	1.00000 0.0 218	0.14615 0.0572 170	0.04246 0.5329 218	0.16125 0.0172 218	-0.21356 0.0015 218
Discharge	-0.03413 0.6577 171	0.45506 0.0001 171	0.51724 0.0001 171	0.01634 0.8320 171	0.14615 0.0572 170	1.00000 0.0 171	-0.11873 0.1219 171	0.39763 0.0001 171	-0.19091 0.0124 171
Channel Gradient	0.06780 0.3179 219	-0.09923 0.1433 219	0.03500 0.6381 183	-0.07647 0.2598 219	0.04246 0.5329 218	-0.11873 0.1219 171	1.00000 0.0 219	0.00676 0.9208 219	-0.00491 0.9424 219
Channel Width	0.04044 0.5516 219	0.21664 0.0013 219	0.48423 0.0001 183	-0.01443 0.08318 219	0.16125 0.0172 218	0.39763 0.0001 171	0.00676 0.9208 219	1.00000 0.0 219	-0.09163 0.1767 219
Pool Width	0.62152 0.0001 219	-0.07467 0.2712 219	-0.02579 0.7290 183	0.16750 0.0131 219	-0.21356 0.0015 218	-0.19091 0.0124 171	-0.00491 0.9424 219	-0.09163 0.1767 219	1.00000 0.0 219
Gravel Width	-0.16039 0.0175 219	-0.06851 0.3129 219	-0.22695 0.0020 183	0.08713 0.1990 219	0.02072 0.7609 218	0.00512 0.9470 171	-0.25632 0.0001 219	-0.35659 0.0001 219	-0.17024 0.0116 219
Riparian Canopy Density	0.09455 0.1642 218	-0.30415 0.0001 218	-0.21044 0.0042 183	-0.14906 0.0278 218	0.04252 0.5333 217	-0.13570 0.0768 171	0.48438 0.0001 218	-0.06223 0.3605 218	0.05745 0.3986 218
Bank Angle	0.10573 0.1213 216	-0.34099 0.0001 216	0.00831 0.9113 182	0.05894 0.3887 216	0.03971 0.5625 215	0.03133 0.6850 170	0.02641 0.6996 216	0.41418 0.0001 216	0.04819 0.4811 216
Riparian Area Width	-0.12118 0.0735 219	0.09318 0.1694 219	-0.00121 0.9870 183	-0.04428 0.5145 219	0.03979 0.5590 218	0.05664 0.4618 171	-0.18263 0.0067 219	0.01426 0.8338 219	-0.08405 0.2154 219
Bank Ungulate Damage	-0.05845 0.3893 219	0.06861 0.3121 219	-0.08456 0.2551 183	-0.13068 0.0535 219	0.19565 0.0037 218	-0.15303 0.0457 171	0.19655 0.0035 219	-0.19053 0.0047 219	-0.12187 0.0719 219
Sr (trout biomass/m^2)	-0.18212 0.0069 219	0.15180 0.0247 219	-0.05972 0.4220 183	-0.08745 0.1973 219	0.00487 0.9430 218	-0.00640 0.9338 171	-0.24436 0.0003 219	-.043903 0.0001 219	-0.09007 0.1842 219
Sr (trout biomass/m^3)	-0.15434 0.0223 219	-0.24399 0.0003 219	-0.38553 0.0001 183	-0.09087 0.1803 219	-0.01165 0.8642 218	-0.21139 0.0055 171	-0.19900 0.0031 219	-0.49950 0.0001 219	-0.07898 0.2444 219

Appendix 5. (continued)

	Pool Measure	Mean Water Depth	Maximum Water Depth	Macro-phyte Width	Embed-dedness	Discharge	Channel Gradient	Channel Width	Pool Width
Sr (trout biomass/m^3)	-0.15434 0.0223 219	-0.24399 0.0003 219	-0.38553 0.0001 183	-0.09087 0.1803 219	-0.01165 0.8642 218	-0.21139 0.0055 171	-0.19900 0.0031 219	-0.49950 0.0001 219	-0.07898 0.2444 219
Sr (fish biomass/m^2)	-0.17348 0.0101 219	0.15694 0.0201 219	-0.02754 0.7113 183	-0.08913 0.1888 219	0.00957 0.8883 218	0.01886 0.8066 171	-0.26619 0.0001 219	-0.39336 0.0001 219	-0.09046 0.1823 219
Sr (fish biomass/m^3)	-0.14060 0.0376 219	-0.25828 0.0001 219	-0.36188 0.0001 183	-0.08758 0.1967 219	-0.00829 0.9031 218	-0.19599 0.0102 171	-0.21114 0.0017 219	-0.45654 0.0001 219	-0.07493 0.2695 219
Valley Bottom Width	-0.12354 0.0680 219	0.21400 0.0014 219	0.04815 0.5174 183	-0.01859 0.7844 219	0.07826 0.2499 218	0.12837 0.0943 171	-0.31501 0.0001 219	-0.03431 0.6136 219	-0.14880 0.0277 219
Ln (trout biomass/m^2)	-0.18625 0.0057 219	0.12736 0.0599 219	-0.03468 0.6412 183	-0.22695 0.0007 219	0.01547 0.8203 218	-0.04230 0.5828 171	-0.17446 0.0097 219	-0.37874 0.0001 219	-0.14738 0.0292 219
Ln (trout biomass/m^3)	-0.14435 0.0327 219	-0.23615 0.0004 219	-0.36953 0.0001 183	-0.18664 0.0056 219	-0.00450 0.9473 218	-0.21492 0.0048 171	-0.14549 0.0314 219	-0.47013 0.0001 219	-0.10711 0.1140 219
Ln (fish biomass/m^2)	-0.18965 0.0049 219	0.15229 0.9242 219	0.01609 0.8289 183	-0.19933 0.0030 219	0.04045 0.5525 218	0.01334 0.8625 171	-0.20613 0.0022 219	-0.31134 0.0001 219	-0.15765 0.0196 219
Ln (fish biomass/m^3)	-0.14536 0.0315 219	-0.25151 0.0002 219	-0.33664 0.0001 183	-0.16268 0.0160 219	0.01887 0.7817 218	-0.17182 0.0246 171	-0.17496 0.0095 219	-0.41687 0.0001 219	-0.11555 0.0880 219
Canyon/ headwater channel type	-0.01469 0.8289 219	-0.09236 0.1732 219	0.00392 0.9580 183	-0.02741 0.6867 219	0.05395 0.4280 218	-0.04314 0.5753 171	0.27619 0.0001 219	0.10616 0.1172 219	-0.01031 0.8794 219
Intermediate channel type	0.14592 0.0309 219	-0.10834 0.1098 219	-0.02278 0.7596 183	-0.10811 0.1106 219	-0.00757 0.9115 218	-0.02028 0.7923 171	0.38976 0.0001 219	0.06391 0.3465 219	0.07880 0.2455 219
Meadow channel type	-0.06898 0.3095 219	-0.02774 0.6831 219	-0.06463 0.3847 183	0.10744 0.1129 219	0.05509 0.4183 218	0.00631 0.9347 171	-0.35554 0.0001 219	-0.00218 0.9744 219	0.01238 0.8554 219

Appendix 5. (continued)

	Gravel Width	Riparian Canopy Density	Bank Angle	Riparian Area Width	Bank Ungulate Damage	Sr (trout biomass/m^2)	Sr (trout biomass/m^3)	Sr (fish biomass/m^2)	Sr (fish biomass/m^3)
Pool Measure	-0.16039 0.0175 219	0.09455 0.1642 218	0.10573 0.1213 216	-0.12118 0.0735 219	-0.05845 0.3893 219	-0.18212 0.0069 219	-0.15434 0.0223 219	-0.17348 0.0101 219	-0.14060 0.0376 219
Mean Water Depth	-0.06851 0.3129 219	-0.30415 0.0001 218	-0.34099 0.0001 216	0.09318 0.1694 219	0.06861 0.3121 219	0.15180 0.0247 219	-0.24399 0.0003 219	0.15694 0.0201 219	-0.25828 0.0001 219
Maximum Water Depth	-0.22695 0.0020 183	-0.21044 0.0042 183	0.00831 0.9113 182	-0.00121 0.9870 183	-0.08456 0.2551 183	-0.05972 0.4220 183	-0.38553 0.0001 183	-0.02754 0.7113 183	-0.36188 0.0001 183
Macro-phyte Depth	0.08713 0.1990 219	-0.14906 0.0278 218	0.05894 0.3887 216	-0.04428 0.5145 219	-0.13068 0.0535 219	-0.08745 0.1973 219	-0.09087 0.1803 219	-0.08913 0.1888 219	-0.08758 0.1967 219
Embed-dedness	0.02072 0.7609 218	0.04252 0.5333 217	0.03971 0.5625 215	0.03979 0.5590 218	0.19565 0.0037 218	0.00487 0.9430 218	-0.01165 0.8642 218	0.00957 0.8883 218	-0.00829 0.9031 218
Discharge	0.00512 0.9470 171	-0.13570 0.0768 171	0.03133 0.6850 170	0.05664 0.4618 171	-0.15303 0.0457 171	-0.00640 0.9338 171	-0.21139 0.0055 171	0.01886 0.8066 171	-0.19599 0.0102 171
Channel Gradient	-0.25632 0.0001 219	0.48438 0.0001 218	0.02641 0.6996 216	-0.18263 0.0067 219	0.19655 0.0035 219	-0.24436 0.0003 219	-0.19900 0.0031 219	-0.26619 0.0001 219	-0.21114 0.0017 219
Channel Width	-0.35659 0.0001 219	-0.06223 0.3605 218	0.41418 0.0001 216	0.01426 0.8338 219	-0.19053 0.0047 219	-0.43903 0.0001 219	-0.49950 0.0001 219	-0.39336 0.0001 219	-0.45654 0.0001 219
Pool Width	-0.17024 0.0116 219	0.05745 0.3986 218	0.04819 0.4811 216	-0.08405 0.2154 219	-0.12187 0.0719 219	-0.09007 0.1842 219	-0.07898 0.2444 219	-0.09046 0.1823 219	-0.07493 0.2695 219
Gravel Width	1.00000 0.0 219	-0.29428 0.0001 218	-0.24346 0.0003 216	0.04823 0.4776 219	-0.05949 0.3809 219	0.32464 0.0001 219	0.34847 0.0001 219	0.30823 0.0001 219	0.33283 0.0001 219
Riparian Canopy Density	-0.29428 0.0001 218	1.00000 0.0 218	0.06278 0.3596 215	-0.08726 0.1993 218	0.27802 0.0001 218	-0.26141 0.0001 218	-0.10082 0.1379 218	-0.28319 0.0001 218	-0.11386 0.0936 218
Bank Angle	-0.24346 0.0003 216	0.06278 0.3596 215	1.00000 0.0 216	-0.11520 0.0912 216	-0.37692 0.0001 216	-0.52361 0.0001 216	-0.36111 0.0001 216	-0.47027 0.0001 216	-0.29574 0.0001 216
Riparian Area Width	0.04823 0.4776 219	-0.08726 0.1993 218	-0.11520 0.0912 216	1.00000 0.0 219	0.07459 0.2717 219	0.28449 0.001 219	0.22927 0.0006 219	0.31744 0.0001 219	0.25455 0.0001 219
Bank Ungulate Damage	-0.05949 0.3809 219	0.27802 0.0001 218	-0.37692 0.0001 216	0.07459 0.2717 219	1.00000 0.0 219	0.29393 0.0001 219	0.26286 0.0001 219	0.25491 0.0001 219	0.21840 0.0011 219

Appendix 5. (continued)

	Gravel Width	Riparian Canopy Density	Bank Angle	Riparian Area Width	Bank Ungulate Damage	Sr (trout biomass/m²)	Sr (trout biomass/m³)	Sr (fish biomass/m²)	Sr (fish biomass/m³)
Sr (trout biomass/m²)	0.32464 0.0001 219	-0.26141 0.0001 218	-0.52361 0.0001 216	0.28449 0.0001 219	0.29393 0.0001 219	1.00000 0.0 219	0.89358 0.0001 219	0.97116 0.0001 219	0.85340 0.0001 219
Sr (trout biomass/m³)	0.34847 0.0001 219	-0.10082 0.1379 218	-0.36111 0.0001 216	0.22927 0.0006 219	0.26286 0.0001 219	0.89358 0.0001 219	1.00000 0.0 219	0.86457 0.0001 219	0.96956 0.0001 219
Sr (fish biomass/m²)	0.30823 0.0001 219	-0.28319 0.0001 218	-0.47027 0.0001 216	0.31744 0.0001 219	0.25491 0.0001 219	0.97116 0.0001 219	0.86457 0.0001 219	1.00000 0.0 219	0.88242 0.0001 219
Sr (fish biomass/m³)	0.33283 0.0001 219	-0.11386 0.0936 218	-0.29574 0.0001 216	0.25455 0.0001 219	0.21840 0.0011 219	0.85340 0.0001 219	0.96956 0.0001 219	0.88242 0.0001 219	1.00000 0.0 219
Valley Bottom Width	0.23314 0.0005 219	-0.31827 0.0001 218	-0.20520 0.0024 216	0.54690 0.0001 219	0.09626 0.1557 219	0.29708 0.0001 219	0.16961 0.0119 219	0.30189 0.0001 219	0.16401 0.0151 219
Ln (trout biomass/m²)	0.22133 0.0010 219	-0.15418 0.0228 218	-0.43159 0.0001 216	0.24738 0.0002 219	0.35284 0.0001 219	0.90442 0.0001 219	0.83059 0.0001 219	0.86690 0.0001 219	0.78431 0.0001 219
Ln (trout biomass/m³)	0.26348 0.0001 219	-0.02829 0.6779 218	-0.30480 0.0001 216	0.19910 0.0031 219	0.32868 0.0001 219	0.82215 0.0001 219	0.90270 0.0001 219	0.77860 0.0001 219	0.85890 0.0001 219
Ln (fish biomass/m³)	0.20331 0.0025 219	-0.18604 0.0059 218	-0.37880 0.0001 216	0.29427 0.0001 219	0.30704 0.0001 219	0.88260 0.0001 219	0.79980 0.0001 219	0.92301 0.0001 219	0.82818 0.0001 219
Ln (fish biomass/m³)	0.25331 0.0002 219	-0.04620 0.4974 218	-0.24343 0.0003 216	0.24341 0.0003 219	0.28359 0.0001 219	0.80236 0.0001 219	0.89117 0.0001 219	0.83617 0.0001 219	0.92218 0.0001 219
Canyon/ headwater channel type	-0.17990 0.0076 219	0.24854 0.0002 218	0.00976 0.8866 216	-0.11582 0.0873 219	0.08370 0.2173 219	-0.15637 0.0206 219	-0.09501 0.1612 219	-0.16816 0.0127 219	-0.09688 0.1530 219
Intermediate channel type	-0.18617 0.0057 219	0.36554 0.0001 218	0.18279 0.0071 216	-0.11725 0.0834 219	0.00172 0.9798 219	-0.30444 0.0001 219	-0.25217 0.0002 219	-0.32434 0.0001 219	-0.27029 0.0001 219
Meadow channel type	0.10958 0.1058 219	-0.23813 0.0004 218	0.06534 0.3392 216	0.08823 0.1934 219	-0.07165 0.2912 219	0.11910 0.0786 219	0.14746 0.0291 219	0.16844 0.0125 219	0.19482 0.0038 219

Appendix 5. (continued)

	Valley Bottom Width	Ln (trout biomass/m^2)	Ln (trout biomass/m^3)	Ln (fish biomass/m^2)	Ln (fish biomass/m^3)	Canyon/ Headwater channel type	Intermediate channel type	Meadow channel type
Pool Measure	-0.12354 0.0680 219	-0.18625 0.0057 219	-0.14435 0.0327 219	-0.18965 0.0049 219	-0.14536 0.035 219	-0.01469 0.8289 219	0.14592 0.0309 219	-0.06898 0.3095 219
Mean Water Depth	0.21400 0.0014 219	0.12736 0.0599 219	-0.23615 0.0004 219	.15229 0.0242 219	-0.25151 0.0002 219	-0.09236 0.1732 219	-0.10834 0.1098 219	-0.02774 0.6831 219
Maximum Water Depth	0.04815 0.5174 183	-0.03468 0.6412 183	-0.36953 0.0001 183	0.01609 0.8289 183	-0.33664 0.0001 183	0.00392 0.9580 183	-0.02278 0.7596 183	-0.06463 0.3847 183
Macro-phyte Depth	-0.01859 0.7844 219	-0.22695 0.0007 219	-0.18664 0.0056 219	-0.19933 0.0030 219	-0.16268 0.0160 219	-0.02741 0.6867 219	-0.10811 0.1106 219	0.10744 0.1129 219
Embed-dedness	0.07826 0.2499 218	0.01547 0.8203 218	-0.00450 0.9473 218	0.04045 0.5525 218	0.01887 0.7817 218	0.05395 0.4280 218	-0.00757 0.9115 218	0.05509 0.4183 218
Discharge	0.12837 0.0943 171	-0.04230 0.5828 171	-0.21492 0.0048 171	0.01334 0.8625 171	-0.17182 0.0246 171	-0.04314 0.5753 171	-0.02028 0.7923 171	0.00631 0.9347 171
Channel Gradient	-0.31501 0.0001 219	-0.17446 0.0097 219	-0.14549 0.0314 219	-0.20613 0.0022 219	-0.17496 0.0095 219	0.27619 0.0001 219	0.38976 0.0001 219	-0.35554 0.0001 219
Channel Width	-0.03431 0.6136 219	-0.37874 0.0001 219	-0.47013 0.0001 219	-0.31134 0.0001 219	-0.41687 0.0001 219	0.10616 0.1172 219	0.06391 0.3465 219	-0.00218 0.9744 219
Pool Width	-0.14880 0.0277 219	-0.14738 0.0292 219	-0.10711 0.1140 219	-0.15765 0.0196 219	-0.11555 0.0880 219	-0.01031 0.8794 219	0.07880 0.2455 219	0.01238 0.8554 219
Gravel Width	0.23314 0.0005 219	0.22133 0.0010 219	0.26348 0.0001 219	0.20331 0.0025 219	0.25331 0.0002 219	-0.17990 0.0076 219	-0.18617 0.0057 219	0.10958 0.1058 219
Riparian Canopy Density	-0.31827 0.0001 218	-0.15418 0.0228 218	-0.02829 0.6779 218	-0.18604 0.0059 218	-0.04620 0.4974 218	0.24854 0.0002 218	0.36554 0.0001 218	-0.23813 0.0004 218
Bank Angle	-0.20520 0.0024 216	-0.43159 0.0001 216	-0.30480 0.0001 216	-0.37880 0.0001 216	-0.24343 0.0003 216	0.00976 0.8866 216	0.18279 0.0071 216	0.06534 0.3392 216
Riparian Area Width	0.54690 0.0001 219	0.24738 0.0002 219	0.19910 0.0031 219	0.29427 0.0001 219	0.24341 0.0003 219	-0.11582 0.0873 219	-0.11725 0.0834 219	0.08823 0.1934 219

Appendix 5. (continued)

	Valley Bottom Width	Ln (trout biomass/m²)	Ln (trout biomass/m³)	Ln (fish biomass/m²)	Ln (fish biomass/m³)	Canyon/ Headwater channel type	Intermediate channel type	Meadow channel type
Bank Ungulate Damage	0.09626 0.1557 219	0.35284 0.0001 219	0.32868 0.0001 219	0.30704 0.0001 219	0.28359 0.0001 219	0.08370 0.2173 219	0.00172 0.9798 219	-0.07165 0.2912 219
Sr (trout biomass/m²)	0.29708 0.0001 219	0.90442 0.0001 219	0.82215 0.0001 219	0.88260 0.0001 219	0.80236 0.0001 219	-0.15637 0.206 219	-0.30444 0.0001 219	0.11910 0.0786 219
Sr (trout biomass/m³)	0.16961 0.0119 219	0.83059 0.0001 219	0.90270 0.0001 219	0.79980 0.0001 219	0.89117 0.0001 219	-0.09501 0.1612 219	-0.25217 0.0002 219	0.14746 0.0291 219
Sr (fish biomass/m²)	0.30189 0.0001 219	0.86690 0.0001 219	0.77860 0.0001 219	0.92301 0.0001 218	0.83617 0.0001 219	-0.16816 0.0127 219	-0.32434 0.0001 219	0.16844 0.0125 219
Sr (fish biomass/m³)	0.16401 0.0151 219	0.78431 0.0001 219	0.85890 0.0001 219	0.82818 0.0001 219	0.92218 0.0001 219	-0.09688 0.1530 219	-0.27029 0.0001 219	0.19482 0.0038 219
Valley Bottom Width	1.00000 0.0 219	0.23072 0.0006 219	0.15057 0.0259 219	0.24427 0.0003 219	0.15791 0.0194 219	-0.10172 0.1334 219	-0.22789 0.0007 219	0.05606 0.4091 219
Ln (trout biomass/m²)	0.23072 0.0006 219	1.00000 0.0 219	0.92607 0.0001 219	0.92300 0.0001 219	0.84983 0.0001 219	-0.12260 0.0702 219	-0.22988 0.0006 219	0.11156 0.0996 219
Ln (trout biomass/m³)	0.15057 0.0259 219	0.92607 0.0001 219	1.00000 0.0 219	0.83025 0.0001 219	0.92055 0.0001 219	-0.07651 0.2596 219	-0.18365 0.0064 219	0.10791 0.1113 219
Ln (fish biomass/m²)	0.24427 0.0003 219	0.92300 0.0001 219	0.83025 0.0001 219	1.00000 0.0 219	0.90938 0.001 219	-0.15251 0.0240 219	-0.26296 0.0001 219	0.18324 0.0065 219
Ln (fish biomass/m³)	0.15791 0.0194 219	0.84983 0.0001 219	0.92055 0.0001 219	0.90938 0.0001 219	1.00000 0.0 219	-0.10312 0.1282 219	-0.21265 0.0015 219	0.17910 0.0079 219
Canyon/ Headwater channel type	-0.10172 0.1334 219	-0.12260 0.0702 219	-0.07651 0.2596 219	-0.15251 0.0240 219	-0.10312 0.1282 219	1.00000 0.0 219	-0.31985 0.0001 219	-0.21285 0.0015 219
Intermediate channel type	-0.22789 0.0007 219	-0.22988 0.0006 219	-0 .18365 0.0064 219	-0.26296 0.0001 219	-0.21265 0.0015 219	-0.31985 0.0001 219	1.00000 0.0 219	-0.58015 0.0001 219
Meadow channel type	0.05606 0.4091 219	0.11156 0.0996 219	0.10791 0.1113 219	0.18324 0.0065 219	0.17910 0.0079 219	-0.21285 0.0015 219	-0.58015 0.0001 219	1.00000 0.0 219

Appendix 6. Multiple linear regression statistics for the model ln(trout g/m^2) based on meadow reaches. Model coefficient of multiple determination (R^2)=0.848.

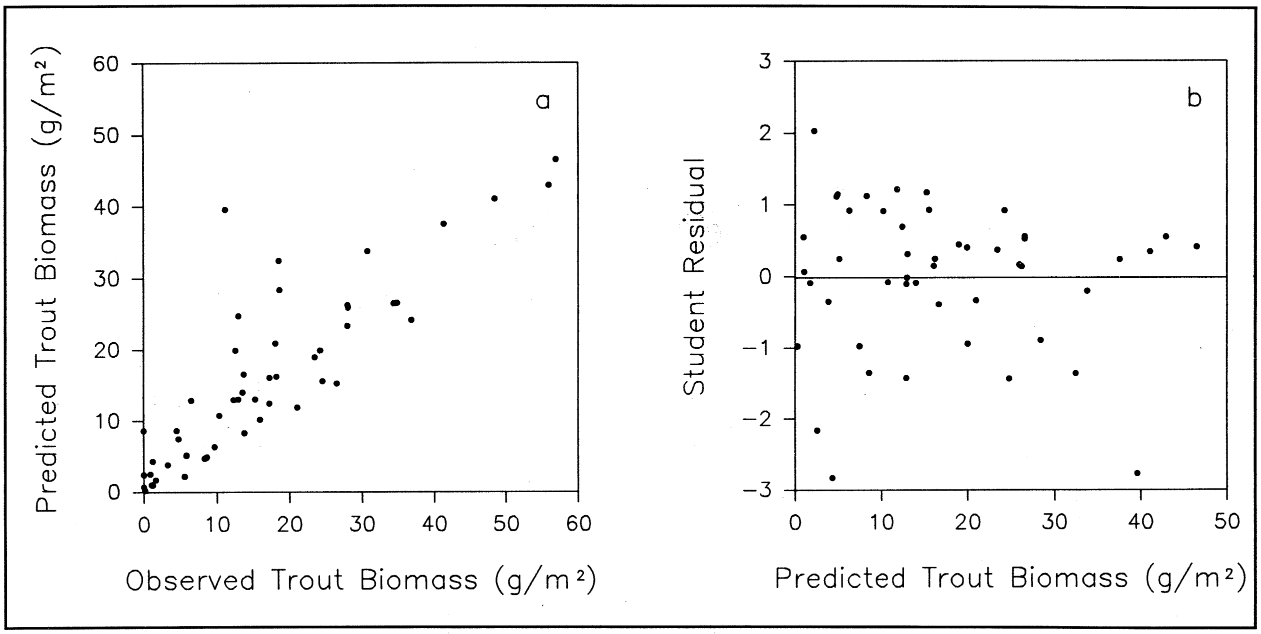
Analysis of Variance

Source	DF	Sum of Squares	Mean Square	F Value	Prob>F
Model	9	56.9717	6.3302	23.552	0.0001
Error	38	10.2136	0.2688		
C Total	47	67.1854			

Root MSE	0.5184	R-square	0.8480
Dep Mean	2.4329	Adj R-sq	0.8120
C.V.	21.3093		

Parameter Estimates

Variable	Parameter Estimate	Standard Error	Prob > |T|
Intercept	-8.4260	1.6639	0.0001
Channel gradient	0.2919	0.1024	0.0070
Boulder width	-1.9376	0.5486	0.0011
Sand/silt width	-1.1610	0.2902	0.0003
Bank vegetation cover	0.3690	0.1366	0.0103
Riparian canopy density	-0.0205	0.0077	0.0110
Station elevation width)	0.0034	0.0006	0.0001
HCI pool structure	0.0040	0.0018	0.0352
HCI streambottom	-0.0192	0.0057	0.0017
HCI average bank vegetation cover	0.0415	0.0094	0.0001



Appendix 6 (continued). Plots of predicted vs. observed trout standing crops (a) and predicted trout standing crops with standardized residuals (b) from the multiple linear regression model for natural log of trout biomass/m^2 from meadow reaches.

NOTES

NOTES

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Key Words: Arizona, FHRS, habitat models, streams, trout populations, ungulate grazing

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