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AN APPLICATION AND ASSESSMENT OF A STEELHEAD HABITAT MODEL

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ABSTRACT

A steelhead habitat assessment model was field tested on three northwest rivers. The test rivers represented an excellent and two poor steelhead producing streams. Resulting test scores failed to represent these differences and actually indicated little difference between the three rivers. Several potential weaknesses in the model were isolated and discussed. The model was developed for resident trout and apparently does not work for anadromous fish. There is also a lack of information regarding factors critical to steelhead survival and productivity, and the dynamic and variable nature of coastal rivers is ignored.

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INTRODUCTION

The Olympia Fisheries Assistance Office contracted with Habitat Preservation at the Portland Regional Office of the U.S. Fish and Wildlife Service to field test a steelhead habitat suitability index (HSI) model (Raleigh and Hickman, 1982). This report presents the results of that application and an evaluation of the model's ability to predict habitat values on Pacific Northwest streams.

Our contract with the Reginal Office directed us to apply the model to both high and low quality steelhead producing streams for which good biological data is available. Good biological data relating to steelhead productivity and habitat preferences is often lacking for northwest streams, particularly for low quality streams. In addition, plants of hatchery smolts may increase catch and escapement estimates and may mask the ability of habitat to produce steelhead. However, there are several rivers which are recognized by biologists as excellent steelhead producers and for which good data are available. There are also several rivers which are recognized as poor steelhead streams. These rivers suffer obvious habitat degradation and support low sport and commercial catches. Two such high quality and two low quality rivers were selected for this application. It was assumed that the HSI model would produce habitat suitability index scores between 0 and 1.0 which would reflect these known differences. A score of 0 represents unsuitable conditions and 1.0 indicates optimum conditions.

Stream Description

The two high quality rivers selected for use in this study were the Kalama and Nisqually rivers. The Kalama is one of the region's premier steelhead rivers. This lower Columbia River tributary is a moderate sized river by Northwest standards (Table 1) and contains excellent steelhead habitat throughout its main stem and tributary streams. The average annual sport catch of winter steelhead in the Kalama from the 1977-78 season through the 1980-81 season was 2,781 fish while the summer-run catch for the same period was 5,224. In 1981-82, Kalama River sport catch of summer- and winter-run steelhead was the second and fourth highest, respectively, of any river in the state although it appears that steelhead from the Cowlitz and Toutle rivers strayed into the Kalama following the eruption of Mount St. Helens in May, 1980. Research conducted by the Washington Department of Game (WDG) has indicated significantly higher smolt production levels in the Kalama than other larger rivers for which comparable data are available.

Although little smolt production data is available for the Nisqually River, good spawning escapement estimates have been compiled by the Nisqually Tribe and WDG. Recent spawner escapements into the Nisqually were the highest recorded counts per mile for any river in the state. The river supports moderate to good steelhead catches each year for sport fishermen and treaty Indian net fisheries. Unfortunately, glacial turbidity during the low flow period reduced visibility so that instream cover and spawning parameters could not be measured and no HSI score could be computed for this stream.

The two low quality streams selected were the North Fork Newaukum and White rivers. Although less data is available for these streams, they are widely recognized as poor steelhead producers. Both rivers suffer moderate to severe habitat degradation. Sport catches are low relative to their size and other comparable rivers. Winter-run catches in the Newaukum River (includes the North and South forks) average 18 fish per year and in the White River they have been about 100 per year. Indian gill net and sport fisheries operate in downstream areas of both rivers although most of their catch is thought to originate from tributaries other than the North Fork Newaukum and White rivers. Neither river supports summer-run steelhead.

The North Fork Newaukum River is a relatively small tributary (Table 1) to the Newaukum River which, in turn, is a tributary to the upper Chehalis River. The Chehalis empties into Grays Harbor on the Washington Coast. WDG compared the number of steelhead smolts migrating out of the Kalama and upper Chehalis rivers and found the production of smolts in the upper Chehalis (including the North Fork Newaukum) was one-twelfth of that in the Kalama. The Washington Department of Fisheries (Phinney and Bucknell, 1975) lists factors which limit salmon production in the North Fork Newaukum as a high rate of municipal diversion, high water temperatures, predatory fish, extensive siltation of spawning beds, and agricultural activity along much of its length. Presumably, these factors also impact steelhead production.

The White River is a major tributary to the Puyallup River which flows into southern Puget Sound. This river system is larger than the Kalama (Table 1) but a high rate of diversion through the portion of the river studied reduces stream flows considerably. There are two dams on this river which have had major impacts on the fishery resource. An interagency committee of federal, state, local, and tribal representatives was recently formed to address problems affecting White River anadromous fish stocks. They compiled a list of 53 problems of which 42 were related to the poor quality of the river's habitat or to developments which have impacted the river.

METHODS

Study segments for each river system were selected using techniques developed by the Cooperative Instream Flow Group (Bovee and Milhous, 1978). It was usually necessary to spend at least one day examining the area of the river to which the model was to be applied. This could best be accomplished by floating the river. The river was divided into segments based upon similar habitat characteristics as suggested by Bovee and Milhous (1978). The entire segment was then subdivided into accessible reaches of equal length and one of these reaches was selected at random. Each randomly selected reach was then further subdivided into cross sections and 10 of these cross sections were randomly selected from the total. Two persons were normally required to collect field measurements along the cross sections. Each study reach required approximately one day of field work. The model did not provide direction on the treatment of tributary streams and they were not included in this analysis.

The main stem Kalama was divided into 4 segments (Figure 1). Segment I begins at the Weyerhaeuser Company logging camp and extends downstream for 3 miles passing through several steep-walled canyons with numerous deep pools, swift rapids, and moderate amounts of spawning gravel (Figure 2). Segment II covers 6 miles and has a lower gradient, although there are numerous broad riffles. The third segment is bounded by steep-sloped walls as it passes through another canyon. It covers 2.7 miles of deep pools and swift rapids (Figure 3) and has limited spawning habitat. The last segment (IV) covers 4.7 miles of the lower river and has a lower gradient and numerous broad riffles which provide excellent spawning habitat for salmon and steelhead (Figure 4).

The North Fork Newaukum was divided into 3 segments for purposes of this study (Figure 5). The upper segment (I) traverses 2.2 miles and begins at a reservoir operated by the cities of Centralia and Chehalis. There is a heavy canopy of trees and shrubs throughout the section (Figure 6). The gradient is fairly high with shallow pools and small rapids. Spawning habitat is limited by the extensive amount of bedrock. Segment II has a much lower gradient, little riparian cover, but more extensive spawning area (Figure 7). However, the quality of the spawning habitat is degraded by high amounts of fine sediments. Land use along the river is primarily agricultural with heavy grazing in many areas. Segment III extends for 2.4 miles and is somewhat similar to segment II except that the gradient is quite low, there are numerous deep pools, and the amount of fine sediments is greater.

The White River was divided into 3 segments (Figure 8). Segment I begins at the Dieringer diversion dam and extends downstream 11.0 miles. Access to this area is very poor which greatly reduced the number of available sample sites. Stream gradient through this section is higher than downstream areas and the river is bordered by a confined valley (Figure 9). Segment II is 4.75 miles in length and begins to broaden with braided channels, riprap banks, and extensive streamside development. Segment III exhibits a lower gradient as well as extensive riprap (Figure 10) and meanders through a broad highly developed valley. Spawning potential in all 3 segments are limited by the large size of the substrate and high percentage of fines.

Some of the data collection techniques presented by Terrell, et al (1982) were utilized in this assessment. However, there remained great latitude in the methods available to collect the data. Rather than present a lengthy narrative describing the techniques used in this application, our methods are presented in tabular form in Appendix A.

The model utilizes 18 variables relating to one or more steelhead life history stages. Six of these variables require information regarding water quality or instream flow. This information was taken from United States Geological Survey (USGS) records. The Kalama River, with three years of daily temperature readings, had the most complete water quality data. Other water quality parameters were taken from bimonthly readings collected in 1977. Daily flow records on the Kalama were compiled in 1974 and 1975.

Only bimonthly water quality data from the 1975 water year was available for the White River. Daily flow records for the White River were recorded by USGS from 1978-80. Water quality and flow data for the North Fork Newaukum was most limited. On this stream, bimonthly flow and water quality readings were only recorded in 1975.

Habitat variables were combined to compute the following five life history component scores: adult, juvenile, fry, embryo, and other (a combination of variables affecting all life stages). Formulas for computing these life history component scores were provided in the HSI model and are reproduced in Appendix B. The embryo component was computed using the three spawning quality variables (V_5, V_7, and V_{16}; no data for V_5, was collected) plus the amount of suitable spawning area available up to 5%. The model assumes that spawning area equal to 5% of the total habitat produces the optimum combination of spawning, rearing, and holding area for nonandromous trout. Washington State steelhead experts did not believe information was available to determine this figure for anadromous trout and, for lack of better information, 5% was used in this analysis.

The model provides two methods of combining the resulting life history components and computing an overall habitat suitability index score. The unequal component value method assumes that the life history components do not exert equal influence on the HSI and critical component scores can be multiplied by values greater than 1.0. However, no guidance is provided for weighting the values. The equal component value method assumes that each component exerts equal influence on the HSI score. Although it is likely that neither the life history components nor the individual variables exert equal influence in determining a stream's productivity, no basis for weighting could be found and the equal component value method was used.

RESULTS

There was surprisingly little variation in the suitability index (SI) scores for the 17 variables measured on the three study streams (Table 2). The water quality variables in particular (V_1, V_2, V_3, and V_{13}) were consistently high with most scores equal to 1.0, or optimum conditions according to the model. The minimum score of 0.6 (V_{2A}) was a reflection of high water temperatures during the spring smoltification period on the Kalama River. However, the apparent higher springtime temperature on the Kalama may actually be a reflection of more complete temperature data for this river where 3 years of daily records are available. The only usable temperature data for the White and North Fork Newaukum rivers were bimonthly readings from 1975.

The minimum flow variable (V_{14}) produced consistently low SI scores ranging from 0.1 to 0.4 for the North Fork Newaukum and Kalama rivers, respectively. While the flow records are limited for each of the three study streams and particularly the North Fork Newaukum, it would appear that the range of values associated with the SI scores for this variable may be inappropriate for northwest streams.

The vegetative index score (V_{11}) for the White River was well below those assigned to the Kalama and North Fork Newaukum rivers. This was expected due to extensive riprap along much of the river. This same riprap did, however, improve the White River's bank stability score (V_{12}) on its two lower river segments. As a result, all three rivers received 1.0 scores for bank stability.

There was some spread in the percent shaded area scores (V_{17}). The North Fork Newaukum was assigned a score of 0.8 while the Kalama and White rivers received scores of 0.4. These scores probably reflect the size of the respective rivers more than the amount of vegetation bordering each.

The White River received unexpectedly high SI scores for instream cover (V_6), bank stability (V_{12}), pool class rating (V_{15}), and percent fines (V_{16}). The high score for winter cover in the form of boulders 10-40 centimeters (V_8) was not surprising due to the large size of substrate in this stream (Figure 9). Similar unexpected high scores for the North Fork Newaukum were winter cover (V_8), bank stability (V_{12}), and percent fines (V_{16}). These scores may be attributable to an inappropriate range of values associated with the SI scores, unrepresentive sample reaches, or high variability in habitat characteristics.

The resulting life history component scores are presented in Table 3. We anticipated that the Kalama River scores would be between 0.8 and 1.0, North Fork Newaukum scores would tend to be below 0.5, and the White River scores would be the lowest. The actual scores did not follow this pattern at all. The lowest score recorded was 0.50 for Kalama River embryo habitat. The White River actually received the highest score (0.86) for juvenile steelhead habitat and a relatively high score of 0.91 for fry habitat. the North Fork Newaukum scores for fry (0.93) and embryo (0.64) were the highest for those categories. The Kalama rated top scores for adult and other (a combination of variables affecting all life stages) habitat requirements.

It is quite surprising to note the low embryo component score of 0.5 assigned to the Kalama River. This component score is defined as the lower of the values for variables two (maximum springtime water temperature), three (minimum dissolved oxygen levels), or a value computed from the quality and quantity of spawning habitat. The model assumes a fixed five percent of the total habitat should be spawning area. In relatively large streams, such as the Kalama and White rivers, there is probably a lower percentage of spawnable area available because of greater depth and velocities found over a greater portion of the stream bed. For these reasons, the quantity of spawning habitat was usually well below 5% on the larger streams resulting in a low score. At the same time, the White River embryo component score of 0.54 is surprisingly high since it is generally thought to contain very poor salmonid spawning habitat.

Steelhead fry habitat suitability scores greater than 0.9 on the North Fork Newaukum and White rivers were also unexpected. This score is computed using variable 8, 10, and 16. The scores assigned to these variables were quite high ranging from 0.7 - 1.0. Again, it would appear that these high scores resulted from an inappropriate range of values associated with the individual SI curves, unrepresentative sample reaches, or high variability in habitat characteristics.

The model combines life history stage component scores to compute an overall HSI for each stream. The resulting HSI scores were totally unexpected with the Kalama, North Fork Newaukum and White rivers scoring 0.78, 0.71, and 0.72, respectively, indicating that all three streams contained relatively good steelhead habitat. These rivers represent extremes in the range of steelhead habitat quality encountered in northwest river systems. Despite obvious differences, these HSI scores imply very little difference in habitat quality. We could only conclude that the model was incapable of assessing these differences.

DISCUSSION

The habitat suitability index (HSI) scores which resulted from a trial application of this model do not apear to adequately represent the steelhead habitat qualities of the streams tested. In addition, it appears that the model tends to minimize differences between streams. This may be due to the number of variables measured, the number of sites measured within a river system, and the variability inherent in northwest streams. The HSI score is computed by a series of arithmetic and geometric averaging techniques which may also contribute toward minimizing differences.

We noted a number of potential weaknesses in reviewing and applying the model. On page 8, the authors assume ". . . the freshwater habitat requirements of adult and juvenile steelhead are essentially the same as other rainbow trout." It is doubtful that adult requirements are the same for anadromous and nonanadromous trout. Besides the obvious difference in size, adult winter steelhead are only present in the natal stream during late winter and spring migration and spawning periods. And yet, many of the variables are described in terms of adult requirements and are measured during the low flow period when adult winter steelhead are not present. For example, variables 4 and 6A are measured during summer low flow and are estimates of the thalweg depth and instream cover for adult steelhead, respectively. If summer steelhead utilize the stream, these are appropriate measurements. Otherwise, they should be measured during the late winter and spring when winter steelhead are present in rivers.

Another important difference between anadromous and nonanadromous trout relates to their juvenile rearing ecology. Anadromous trout in coastal areas inhabit river systems which exhibit rapid fluctuations in flow and contain a diversity of habitat types. Recent studies have indicated that juvenile salmon and steelhead have evolved life history strategies to take advantage of these diverse habitats. Cedarholm and Scarlett (1982) found that juvenile coho and steelhead in the Clearwater River on the Washington coast moved into riverine ponds, marshes, and runoff tributaries during winter freshets. They suggest that juvenile salmonids move into these areas to avoid severe winter floods which disrupt main stem cover sites and result in displacement and mortality. Access to riverine ponds and tributaries may help buffer the impact of severe winter freshets. Seidel (personal communication) examined summer rearing ecology of salmonids in the South Fork Hoh and Queets rivers on the Washington coast and found main stem sloughs, side channels, debris piles and natural river bends to be important rearing areas during the reduced flow periods of summer. These riverine features are probably important factors in determining a river's capacity to produce anadromous trout and should be incorporated into an HSI model.

Another important riverine feature for steelhead is the quality and extent of tributary streams. The model does not give guidance for incorporating tributaries into the HSI score and they were not included in the analysis. However, they are known to provide important spawning areas and are frequently used for rearing in summer and winter. Incorporating them into the HSI analysis could be difficult. Six of the 18 variables used to compute the HSI score are based upon flow and water quality records. These records are rarely available for the many small tributaries accessible to steelhead on major Northwest river systems. Another difficulty may arise in combining scores for tributaries and main stem areas. Because of their smaller size, they will generally have higher percentages of instream cover, suitable spawning area, and shaded surface area. Unless their importance as steelhead habitat is known relative to main stem areas and weighted accordingly, they may have a disporportionate influence on the overall HSI score.

The model probably cannot be applied to all northwest streams. We were unable to apply the model to the Nisqually River because the glacial nature of this stream reduced visibility making it impossible to measure instream cover and spawning habitat. Fortunately, a period of cool weather in the fall caused flows to drop and clear sufficiently to apply this model on the White River, another glacial river. Many of the northwest's major steelhead streams are glacial and are normally highest and most turbid during the spring although many do not clear until the cold winter months. There are often short unpredictable periods of cool weather during the fall when most of these streams are low and clear.

Another limitation in using the model on some streams is the availability of adequate flow and water quality records. Although relatively good flow and temperature data is available for the northwest's larger rivers, particularly those with existing dams, data on the majority of the northwest's steelhead streams is limited or nonexistent. Of the 128 streams in western Washington which had reported steelhead sport catches in 1981-82, only 42% and 28% had flow or water quality data available from USGS in 1979 or 1980, respectively. Water quality records normally consisted of 1-2 readings per month which is probably inadequate to describe the range of values which could be expected on an individual stream or to define limiting factors which may be lethal to steelhead.

While the lack of adequate flow data is a limitation, it appeared that some of the water quality variables had little impact in the HSI scores. The dissolved oxygen (DO) and pH variables (V_3 and V_{13}), in particular, rated scores of 1.0 for all three river systems. While these water quality measures are important and should be considered in evaluating habitat quality, they are not generally a limiting factor in steelhead production in the northwest.

Summer low flow (Variable 14) is a critical factor influencing both juvenile coho salmon and steelhead survival rates (Zillges, 1977 and Hunter, 1973) and should be given greater weight in the model. As presently written, the model combines and averages the low flow score with 8 other variables to compute a composite score which affects all life stages. The low flow variable loses much of its impact through this process and is given equal weight with scores for vegetative index, bank stability, and percent shaded area. The low flow variable would influence adult summer steelhead but has no effect on adult winter fish. It is suggested that this variable be treated as a major component in the fry and juvenile stages but should be considered as a factor in the adult stage only when summer steelhead utilize the system being considered.

Another critical variable in salmonid survival is the amount of fine sediments in a stream. Variable 16, the percent fines in riffle-run and spawning areas, was very difficult to measure by visual observation. The other variable influencing the amount of fine sediments in the stream is the average percent rooted vegetation and stable, rocky ground cover along the streambank (V_{12}). There are several northwest streams in which one or two localized slides impact downstream spawning substrate for many miles. Examples of this situation are found on the North and South Forks of the Stillaguamish, South Fork Nooksack, and Tolt rivers. Unless a randomly selected study reach falls within one of these slide areas, variable 12 would rank unrealistically high.

Some of the other variables, particularly the substrate size and in-stream cover, were also quite difficult to evaluate visually. Coupled with this inherent lack of precision is the fact that many of the suitability index curves have steep ascending and descending legs. For instance, a small error in assessing the average size of the substrate in spawning areas (V_7) will result in a large change in the suitability score. An average substrate size of 0.25 centimeter produces a score of 0.3, an average size of 0.5 centimeter results in a score of 0.6 and an average size of 1.5 centimeters gives a perfect score of 1.0. A difference of 1.25 centimeters in average substrate size multiplies the score over threefold.

Even those variables which required field measurements were sometimes of questionable value. Despite its importance in determining the amount of available spawning habitat, variable 5 (average velocity over spawning areas during embryo development) was not included in our assessment. The period of steelhead embryo development in most northwest streams extends from March - July. During this period, flows are much higher than the low flow period and no reliable means was found to relate them. Likewise, winter cover was only measured within the wetted boundaries of the streambed at the time measurements were recorded even though it is known that flows are higher in the winter covering a much greater area. However, water levels change frequently and rapidly during the winter, rising from near low flows during cold spells to the highest floods of the year, in a few days. Measurement of available spawning habitat was also hindered in that a number of areas on the Nisqually River, which we knew were extensively used for steelhead spawning in the spring of 1982, were completely exposed lying 10-20 feet from the edge of the river during the low flow period when these measurements would be taken.

The final area of weakness in the model was the lack of specific guidance in data collection techniques. Considerable time was spent assessing various techniques. In several instances, methods used on a small stream (North Fork Newaukum) were very difficult to apply on the larger rivers (Kalama, White). In other cases, additional field guidance was needed. Variable 8, for example, is an assessment of winter escape cover for fry and is a measure of the percent of the substrate between 10-40 centimeters in diameter. It became apparent that a matrix of cobble within this size range is required and that individual pieces scattered along a transect would not provide adequate cover. We also noted large areas of the required cobble habitat along dewatered gravel bars but could not determine how much was available to fry at normal winter flows.

RECOMMENDATIONS

It is apparent that this steelhead HSI model was unable to rank the quality of three northwest steelhead streams. A number of steps need to be taken to improve the model's ability to accurately recognize and assess steelhead habitat quality. We concluded that its most apparent weaknesses were differences in habitat requirements of anadromous and nonanadromous trout, lack of information regarding factors most critical in determining steelhead survival and productivity, and the dynamic and variable nature of northwest streams. The following suggestions are offered to improve this model:

A. Significant differences between anadromous and nonanadromous trout need to be recognized and consideration should be given to developing separate models. Bovee provides separate probabilty of use criteria curves for rainbow trout and steelhead in his 1978 compilation of salmonid preference curves. The most significant differences are probably in spawning and adult preferences. In this model it was noted that several variables which need to be assessed at low flows are described in terms of adult trout requirements even though adult winter steelhead are not present in streams during the summer and fall months when low flows occur. The importance of riverine ponds, marshes, runoff streams, side channels, and natural river bends should be recognized as important rearing areas for anadromous trout. Many of the citations referenced in this model are taken from semi-arid regions of the western United States or refer to nonandromous trout which casts some doubt on its applicability to coastal streams and anadromous trout.

B. The range of values for each variable should be reexamined to determine if they are appropriate to coastal rivers and anadromous trout. Variable 14, annual base flow regime during the low flow period, should be adjusted to accommodate the wide fluctuations in stream flow on coastal rivers. An examination of several years of USGS records would provide an expected range of flows. Variable

11, allochthonous input, is probably not limiting in the Northwest. But, if it is used in this model, input in the form of alder leaves should probably be weighted more heavily than the input from shrubs or grasses. Studies conducted by the University of Washington have suggested that alder leaves provide an important contribution to the support of aquatic insects in coastal streams. Variable 6 confines instream cover to depths greater than 15 centimeters (cm). We suspect that fry will occupy shallower depths, if cover is present. Instream cover for juvenile and adult trout is also constrained to velocities less than 15 cm per second. However, Bovee (1978) lists the preferred velocity of adult steelhead at 45 cm per second.

C. The variables which are most critical in determining freshwater survival of steelhead need to be identified. This HSI model probably incorporates too many nonlimiting variables which, when combined with more critical variables, tend to obscure differences between streams. The variable for dissolved oxygen, pH, and allochthonous input are probably not limiting and only serve to raise the HSI scores. Unless unusual conditions exist, it may be more appropriate to ensure that these variables are within an acceptable range and then proceed with the model application without them or give them less weight in HSI calculation. However, it should be recognized that Phillips, et al (1981) studied juvenile rearing ecology in the Skagit system and were unable to correlate juvenile densities to any habitat values except for a negative relationship with bank cover. It would appear that the most critical variables in steelhead productivity have not been isolated and additional basic research is needed. A determination of the most critical variables would allow the model user to weight them accordingly. This could greatly increase the model's ablity to accurately reflect steelhead habitat values.

D. Provide a sampling scheme capable of incorporating the variability which is likely to be encountered on coastal river systems. This could be a particularly difficult requirement considering the dynamic nature of northwest streams. Stream flows ofter change significantly from day to day making it very difficult to collect representative data at a particular point in time. Because of this dynamic nature, we recommend that field measurements be collected at appropriate times unless a reliable technique is available to allow back calculation. Winter cover measurements should be collected at normal winter flows, spawning habitat during late winter or spring, adult holding in winter or summer (depending on use by winter- or summer-runs) and juvenile rearing in late summer. Techniques utilized in the Instream Flow Incremental Methodology (IFIM) should be considered for use in a HEP analysis. If suitable preference curves are available for steelhead, it should be possible to measure a high, intermediate, and low flow on a selected river and use IFIM to predict the amount of spawning, rearing, and winter cover habitat available at any flow within the range normally expected.

E. Additional guidance in the use and application of this model is needed. Appropriate techniques for collecting data would be helpful, particularly reliable methods of assessing gravel size and percent fines. Guidance in selecting sample sites and incorporating tributary streams is also important.

Due to the inability of this model to accurately rank the three streams tested, we reviewed alternate methods of assessing steelhead habitat quality. Potential techniques might be: the use of spawner escapement goals provided by the fishery management agencies, spawning ground surveys, or juvenile abundance indices. However, each of these methods has serious deficiencies and probably do not offer any better assessment than this HSI model. Another technique which may be applicable to habitat assessment is a flow/drainage area index for salmonid smolt production. This technique is being evaluated by the Seattle National Fisheries Research Center as a tool in hatchery out-stocking. Unfortunately, it is not yet available for review. When complete, this index should be assessed as a potential habitat quality index or at least as a major variable within a habitat model.

Recognizing the need for a fishery habitat assessment technique and the shortcomings of existing methodologies, we believe several of the changes we have suggested should be incorporated into Raleigh and Hickman's (1982) model followed by another field evaluation. We believe that the most important changes would be the development of separate anadromous and non-anadromous rainbow trout models. The anadromous model would have to accommodate the special requirements of both winter- and summer-run steelhead. The model should only use variables which limit steelhead productivity and the range of the variables should be appropriate for the region in which they are applied. These variables should also be weighted according to their influence. Selecting and weighting the variables would be difficult. However, this might be accomplished by correlating fish abundance with several variables through multiple regression analysis. The correlation coefficients in this analysis could serve as weighting factors in the HSI models. It may be possible to analyze existing data to determine these values but it is quite likely that new field studies would be required.

The revised model should also provide a data collection scheme capable of accounting for the large variability present in coastal steelhead streams. This might require sampling at each life history stage or this may be accomplished by using the Instream Flow Incremental Methodology. The model should also present techniques for assessing substrate size and a scheme for incorporating tributary streams into the assessment.

Until this model is modified and re-evaluated, we believe it will be necessary to continue relying upon existing catch and escapement data plus the professional judgment of state, federal, and tribal biologists when assessing steelhead habitat.

LITERATURE CITED

Bovee, K. D. 1978. Probability-of-use criteria for the family Salmonidae. Instream Flow Information Paper No. 4, Cooperative Instream Flow Service Group. U.S. Fish and Wildlife Service. p. 80.

Bovee, K. D. and R. Milhous. 1978. Hydraulic simulation in instream flow studies: Theory and techniques. Instream Flow Information Paper No. 5. Cooperative Instream Flow Service Group. U.S. Fish and Wildlife Service. p. 131.

Cedarholm, D. J. and W. J. Scarlett. 1982. Seasonal immigrations of juvenile salmonids into four small tributaries of the Clearwater River, Washington, 1977-1981. In Proceedings of the Salmon and Trout Migratory Behavior Symposium. Edited by E. L. Brannon and E. O. Salo, University of Wasington. p. 98-110.

Hunter, J. W. 1973. A discussion of game fish in the State of Washington as related to water requirements. Wash. State Dept. of Game. p. 8.

Phillips, C., R. Cooper, and T. Quinn. 1981. Skagit River salmonid studies, 1977-1981. Wash. State Game Dept. and U.S. Fish and Wildlife Service. p. 104.

Phinney, L. A. and P. Bucknell. 1975. A catalog of Washington streams and salmon utilization. Volume 2, Coastal region. Washington Dept. of Fisheries.

Raleigh, R. F. and T. Hickman. 1982. Habitat suitability index models: Rainbow trout. Draft report, Western Energy and Land Use Team, U.S. Fish and Wildlife Service. p. 56.

Terrell, J. W., T. E. McMahon, P. D. Inskip, R. F. Raleigh, and K. L. Williamson. 1982. Habitat suitability index models: Appendix A, Guidelines for riverine and lacustrine applications of fish HSI models with the habitat evaluation procedures. Draft report, Western Energy and Land Use Team, U.S. Fish and Wildlife Service. p. 56.

Zillges, G. 1977. Methodology for determining Puget Sound coho escapement goals, escapement estimates, 1977 pre-season run size prediction and in-season run assessment. Wash. Dept. of Fish., Tech. Rpt. No. 28. p. 64.

FIGURES AND TABLES

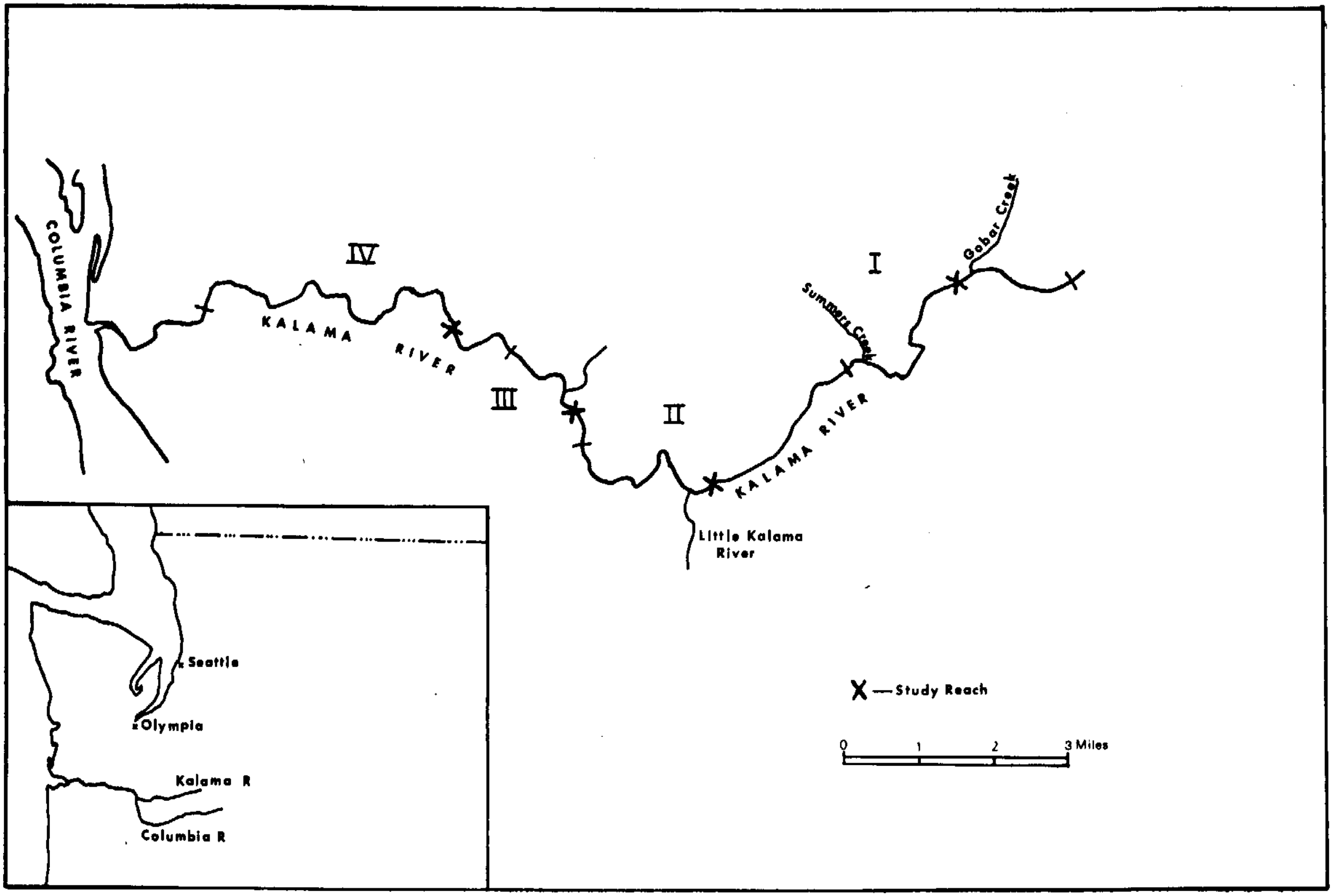

Figure 1. Kalama River showing four representative river segments and study reaches used to test this steelhead habitat model. Boundaries of representative river segments are indicated by (—).

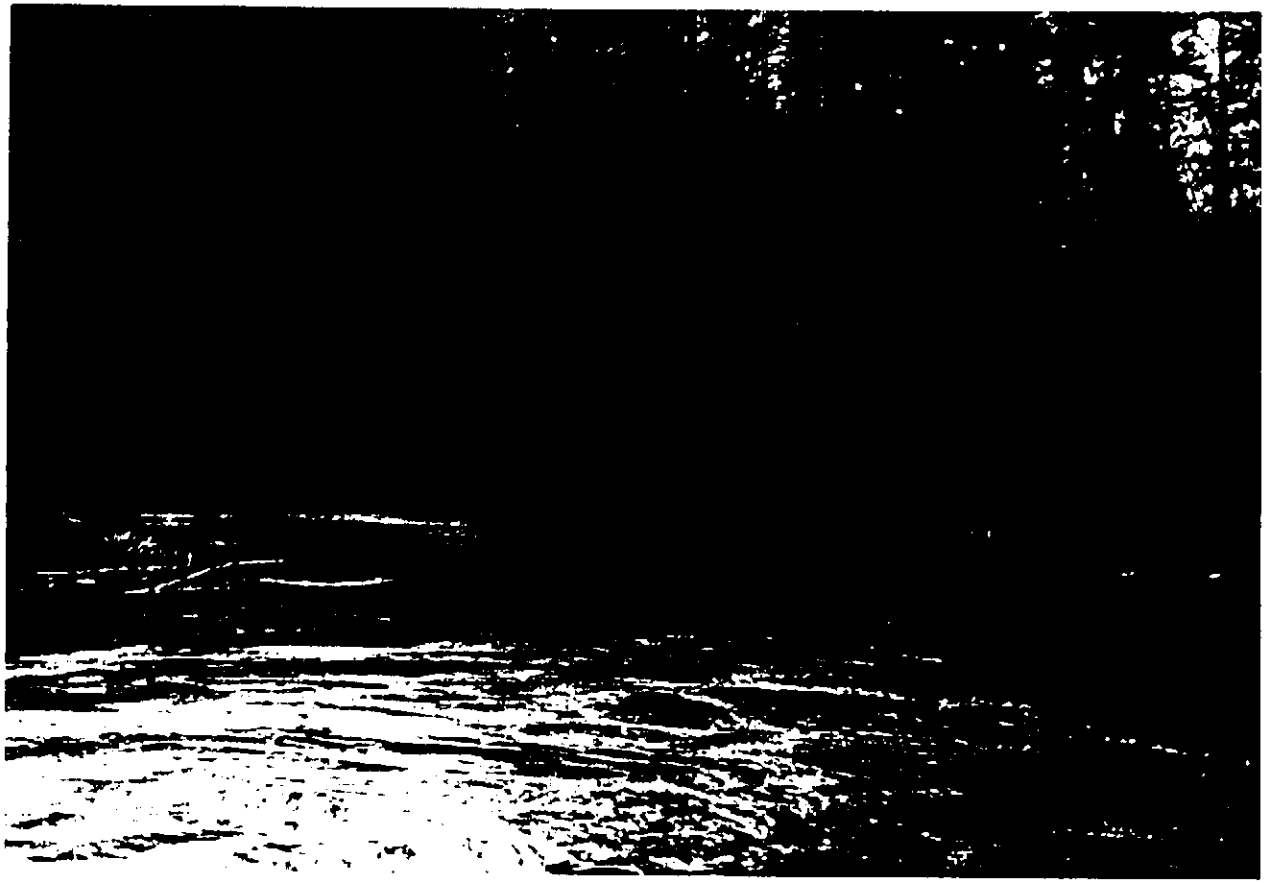

Figure 2. Section of upper Kalama River typical of Segment I. Deep pools, swift rapids, and vertical walls occurred through this section of the river.

Figure 3. Randomly selected study reach in Segment III of the Kalama River. This river segment passed through another steep canyon.

Figure 4. Randomly selected study reach in Segment IV of the Kalama River. Numerous rapids with excellent spawning gravels were common in this segment.

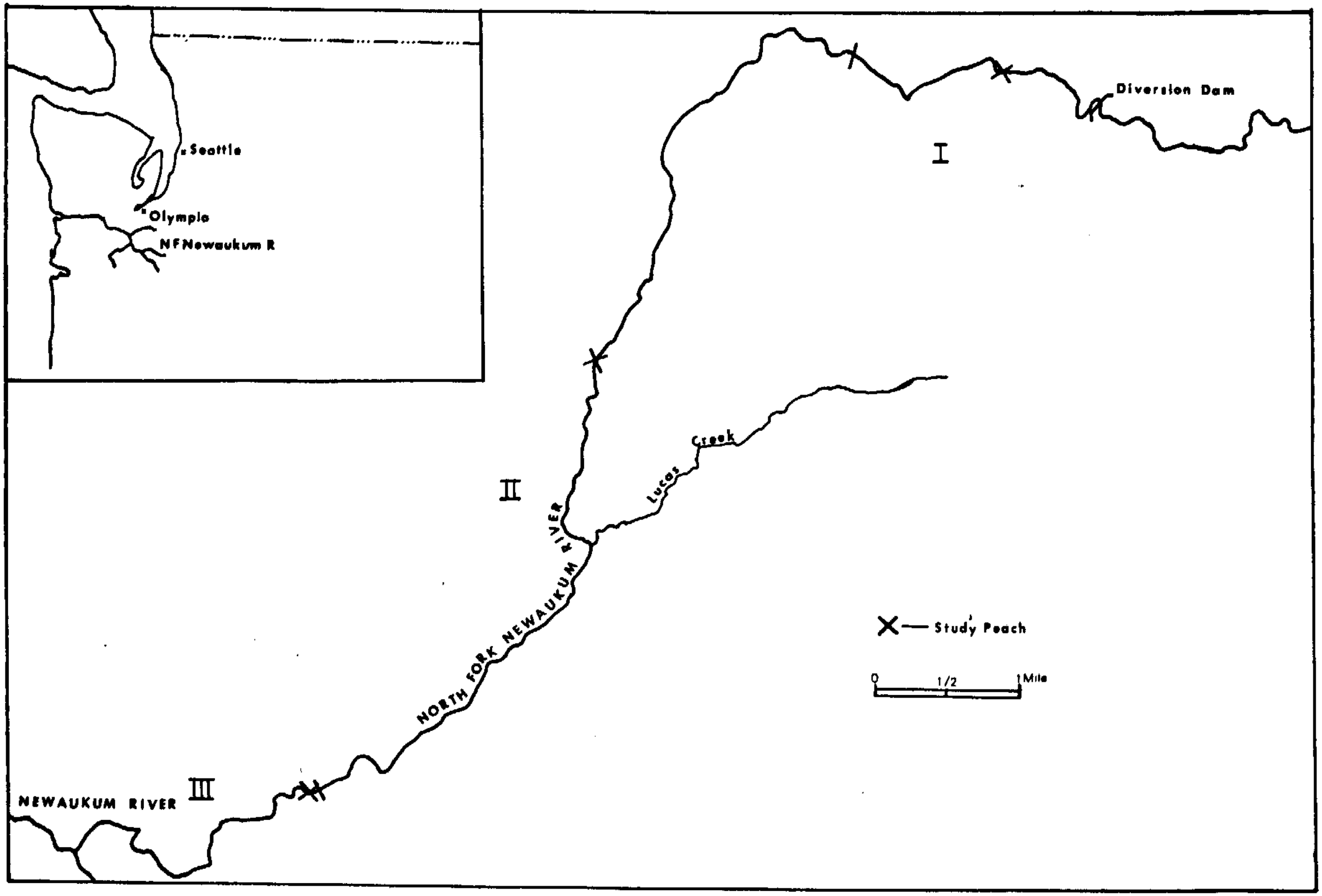

Figure 5. North Fork Newaukum showing three representative river segments and study reaches used to test this steelhead habitat model. Boundaries of representative river segments are indicated by (—).

Figure 6. Randomly selected study reach in Segment I of the North Fork Newaukum River. Heavy canopy and extensive bedrock characterize this segment.

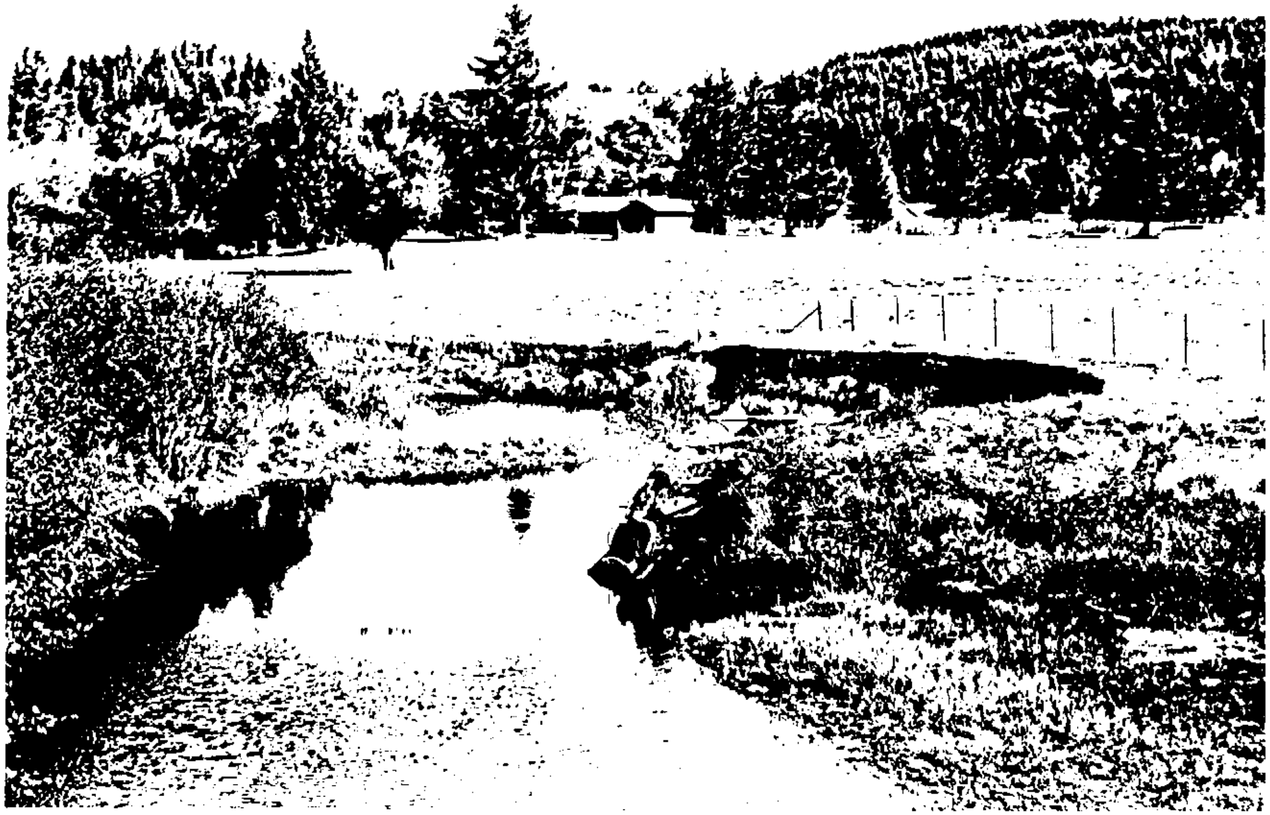

Figure 7. Randomly selected study reach in Segment II of the North Fork Newaukum River. Riparian vegetation was limited in this segment and gradient was low.

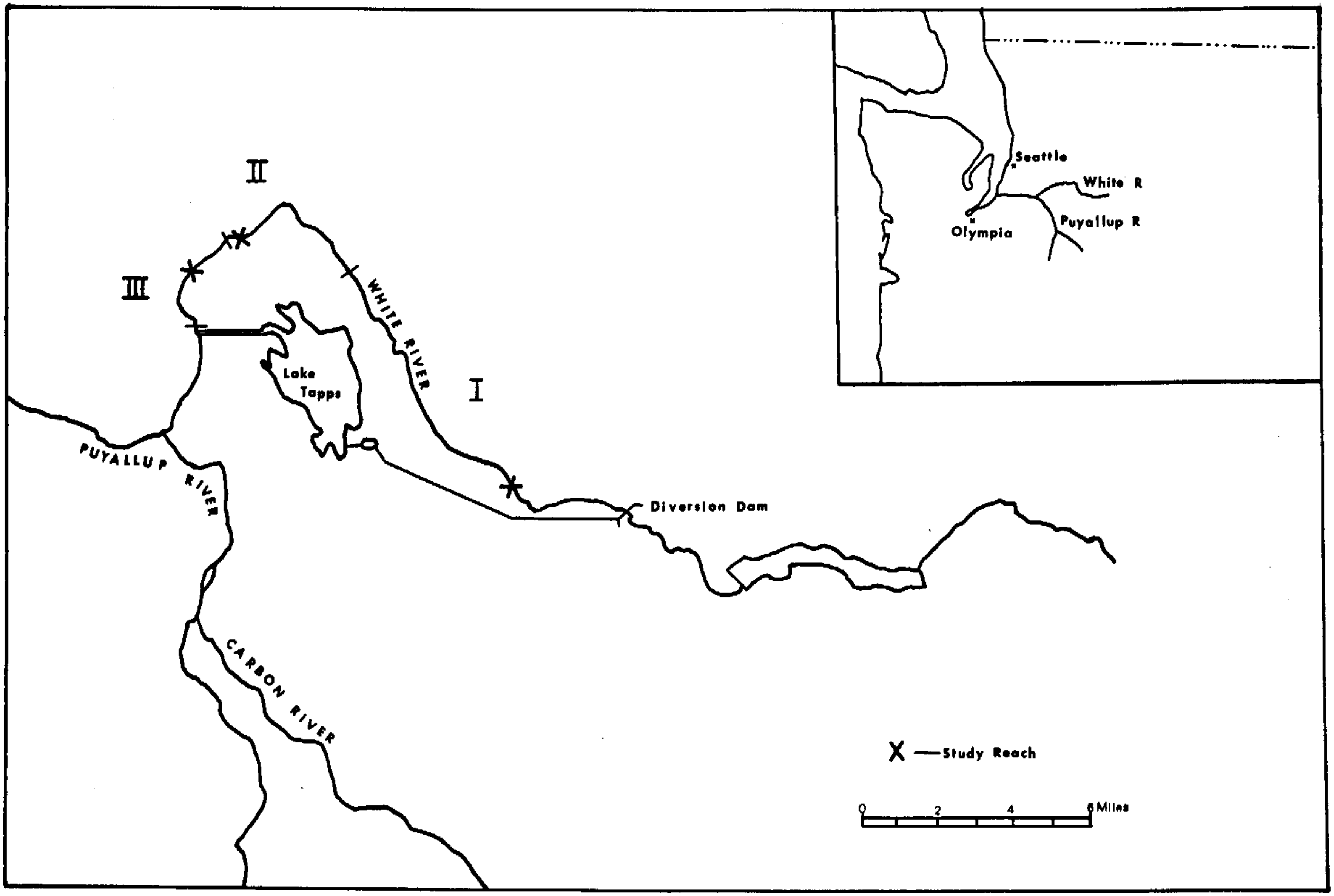

Figure 8. White River showing three representative river segments and study reaches used to test this steelhead habitat model. Boundaries of representative segments are indicated by (—).

Figure 9. Typical section of the White River in Segment I. Access was limited in this area reducing the number of potential study sites. Note the large size of the stream bed substrate.

Figure 10. Randomly selected study reach in Segment III of the White River. Extensive riprap predominated throughout this segment.

Table 1. The three rivers selected for study and the percentage of each river segment included within study reaches.

River	Drainage Area (sq. miles)	Average Annual Flow (cfs)	River Segment	Area of Study Reach (sq. meter)	% of Total Study Segment
Kalama	205	1,500	I	11,774	8.6
			II	12,852	3.8
			III	12,301	11.6
			IV	20,055	7.2
N. F. Newaukum	71	250	I	9,988	8.0
			II	3,332	1.3
			III	3,276	4.2
White	494	1,000 1/	I	15,736	2.2
			II	17,460	4.5
			III	14,420	4.2

1/ High rate of diversion for hydropower above the portion of river evaluated. Return is near river mouth.

Table 2. Steelhead habitat values and suitability index scores for 18 variables collected from three study streams.

Variable	Kalama		N.F. Newaukum		White		Optimum 1/
	Variable Score	Suitability Score	Variable Score	Suitability Score	Variable Score	Suitability Score	Variable Score
1. Maximum water temperature:summer rearing (A), Adult migration (B)	A=18.1°C B=11.0°C	1.0 1.0	A=18.8°C B=10.1°C	0.8 0.9	A=16.4°C B=11.9°C	1.0 1.0	A=12-18°C B=12-14°C
2. Maximum water temperature (spring) smolts (A), embryo (B)	A=13.1°C B=12.0°C	0.6 1.0	A=11.3°C B=12.8°C	0.9 1.0	A=11.8°C B=12.4°C	0.8 1.0	A=7-10°C B=7-12°C
3. Minimum dissolved oxygen	10.9 mg/1	1.0	10.8 mg/1	1.0	11.1 mg/1	1.0	>9 mg/1
4. Thalweg depth	110 cm	1.0	N/A		N/A		>45 cm
5. Velocity over spawning areas	Unavailable		Unavailable		Unavailable		30-60 cm/sec
6. Instream cover: juvenile (J) adult (A)	11%	A=0.7 J=1.0	12%	A=NA J=1.0	8%	A=NA J=0.8	A > 22% J > 14%
7. Substrate size in spawning areas	9.5 cm	1.0	5.3 cm	1.0	7.3 cm	1.0	1.5-10 cm
8. Winter cover	54%	1.0	21%	1.0	47%	1.0	>10%
9. Riffle-run rating	A	1.0	B	0.6	B	0.6	A

Table 2. (Con't)

Variable	Kalama		N.F. Newaukum		White		Optimum 1/ Variable Score
	Variable Score	Suitability Score	Variable Score	Suitability Score	Variable Score	Suitability Score	
10. % pools	28%	0.9	51%	1.0	37%	1.0	40-60%
11. Vegetative index	191	1.0	191	1.0	58	0.4	> 150
12. Bank stability	94%	1.0	93%	1.0	82%	1.0	> 75%
13. pH	6.8	1.0	7.7	1.0	8.2	1.0	6.5 - 8
14. Low flow	19%	0.4	8%	0.1	11%	0.2	> 50%
15. Pool class rating	A	1.0	C	0.3	A	1.0	A
16. % fines in spawning areas	12%	0.9	14%	0.8	15%	0.7	< 10%
17. % shaded area	10%	0.4	36%	0.8	3%	0.4	50-75%
18. Flow during adult migration	147%	1.0	246%	1.0	68%	0.5	> 110%

1/ Variable score rounded to nearest suitability index score.

Table 3. Life history component and HSI scores for three study streams.

	Adult	Juvenile	Fry	Embryo	Other
Kalama	0.98	0.76	0.92	0.50	0.85
N.F. Newaukum	0.79	0.52	0.93	0.64	0.73
White	0.79	0.86	0.91	0.54	0.59

APPENDIX A

Variable	Application
V_1: Average maximum water temperature during adult migration and late summer.	
A - Late summer	Average maximum monthly temperature during the 3 warmest months of the year. Based upon an average of most recent USGS data. Used in computing adult component only where summer-run steelhead are present.
B - Migration period	Average maximum monthly temperature during the 3 warmest months between December and May in streams with winter-run steelhead or between December and July in streams with both winter- and summer-run steelhead. Based on an average of most recent USGS data.
V_2: Average maximum water temperature during embryo development and smoltification.	
A - Smoltification period	Average maximum monthly temperature, March - June. Based on an average of most recent USGS data.
B - Embryo development	Average maximum monthly temperature March - July. Based on an average of most recent USGS data.
V_3: Average minimum dissolved oxygen level during embryo development and low water period.	Average of lowest monthly dissolved oxygen levels, March - September. Based on an average of most recent USGS data.
V_4: Average thalweg depth during low water period.	Average of maximum channel depths from randomly selected cross sections. Used only on streams with summer-run steelhead.

V_5:	Average velocity over spawning areas during embryo development.	No method of collecting reliable data during the low water period; therefore, this variable was not utilized. Should be collected during March - June.
V_6:	Percent instream cover during low water period.	Measured amount of cover (brush, logs, debris, inundated or overhanging vegetation, undercut bank, boulders and depth) along transect which was at depth $\geq$ 15 cm and velocities $<$ 15 cm/sec. Velocities were visually estimated. The sum of these measurements was divided by the total width of all transects to determine percentage.
V_7:	Average size of substrate in spawning areas.	Estimated average substrate size in all areas of the reach containing most suitable substrate up to 5% of total area. Only assessed areas within wetted area of stream and observable by wading.
V_8:	Percent substrate usable as winter and escape cover.	Measured or estimated percent of the substrate along the transect which was 10-40 cm boulders. Only assessed areas within wetted area of stream and observable by wading.
V_9:	Substrate type in riffle-run areas.	Visual estimates along transects which were considered riffles or runs.
V_{10}:	Percent pools.	Visual estimate based upon the entire study reach.
V_{11}:	Vegetative index.	Visual estimate of canopy closure by vegetation types and percent bare ground along riparian transect. Length of transect varied depending on the probability of material entering the stream.
V_{12}:	Average percent rooted vegetation and stable rocky ground cover along streambank for erosion control.	Used data collected for V_{11}.

V_{13}:	Annual maximal or minimal pH.	Used an average of highest or lowest readings from most recent USGS records.
V_{14}:	Average annual base flow during low flow period as a percentage of average annual flow.	Used the formula: $\frac{\text{mean 30-day low flow}}{\text{mean annual daily flow}}$ Based on an average of most recent USGS flow data.
V_{15}:	Pool class rating during low water period.	Visual estimates of pools over which transects traversed. Average rating for entire reach weighted by transect widths.
V_{16}:	Percent fines in riffle-run and spawning areas.	Visual estimates made in areas containing spawnable substrate. Estimates made in observable areas which were wadable.
V_{17}:	Percent of average daily flow during adult migration.	Average daily flow as a percent of annual daily flow during Jan. - April for North Fork Newaukum and White rivers and Dec. - July on Kalama River. Based upon an average of the most recent USGS flow data.

APPENDIX B

Life history stage component and the overall HSI scores were calculated as follows:

Adult (C_A)

Case 1: If $V_6 > (V_{10} \times V_{15})^{1/2}$

Then $C_A = [V_4 \times V_6 (V_{10} \times V_{15})^{1/2}]^{1/3}$

Case 2: If $V_6 \leq (V_{10} \times V_{15})^{1/2}$

Then $C_A = [V_4 (V_{10} \times V_{15})^{1/2}]^{1/2}$

$C_{AS} = (C_A \times V_{1B} \times V_{18})^{1/3}$ or,

if V_4 or $(V_{10} \times V_{15})^{1/2} \leq 0.4$ then C_A = lowest factor score

Juvenile (C_J)

$$C_J = \frac{V_6 + V_{10} + V_{15}}{3}$$

$C_{JS} = (C_J \times V_{2A})^{1/2}$ or,

if V_6, V_{10}, V_{15}, or $V_{2A} \leq 0.4$, then C_J = lowest variable score

Fry (C_F)

$C_F = [V_{10} (V_8 \times V_{16})^{1/2}]^{1/2}$ or,

if V_{10} or $(V_8 \times V_{16})^{1/2} \leq 0.4$, then C_F = the lowest factor score

Embryo (C_E)

A. Derive a spawning site suitability index (V_S)

$V_S = (V_5 \times V_7 \times V_{16})^{1/3}$

No data was collected for V_5 and the following formula was used instead:

$V_S = (V_7 \times V_{16})^{1/2}$

B. Derive a weighted average ($\overline{V}_S$) for each reach up to 5% of the total habitat.

$$\overline{V}_S = \frac{\sum_{i=1}^{n} A_i V_{Si}}{\text{total habitat area}} \div 0.05$$

where: A_i = the area of each spawning site in m^2 up to 5% of the total area

V_{Si} = the individual spawning site suitability index scores from the best spawning areas up to 5% of the total area

C. C_E = the lowest score of V_{2B}, V_3, or $\overline{V}_S$.

Other (C_O)

$$C_O = \left[\frac{(V_9 \times V_{16})^{1/2} + V_{11}}{2} \times (V_{1A} \times V_3 \times V_{12} \times V_{13} \times V_{14} \times V_{17})^{1/N} \right]^{1/2}$$

where N = the number of variables within the parenthesis

Habitat Suitability Index (HSI)

$$HSI = (C_{AS} \times C_{JS} \times C_F \times C_E \times C_O)^{1/N}$$

where N = the number of components included in the evaluation or,

if any component score ≤ 0.4, then the HSI = the lowest component value