***Exxon Valdez* Oil Spill**
Restoration Project Final Report

Use of Aerial Photograph, Channel-Type Interpretations to Predict Habitat Availability in Small Streams

Restoration Project 95505B
Final Report

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Study History: The *Exxon Valdez* oil spill drew attention to the need for comprehensive habitat inventories to conduct protection and restoration planning. Stream habitat data were needed to evaluate lands considered for protection acquisition as a part of the oil spill restoration process. Channel-typing through interpretations from aerial and satellite photographs was used to characterize and rate the relative importance of stream habitats throughout the entire Oil Spill Area (Oil Spill Restoration Project #95505B). Field ground verifying was conducted as a part of that study, to establish the accuracy of channel-typing, and to collect preliminary habitat data with which to characterize the channel-types. This study establishes the correlation between channel-type designations and actual in-stream habitat.

Abstract: In-stream habitats were quantified and qualified for nine stream channel-types. the channel types were identified using interpretations from stereo pairs of color and infrared aerial photographs. A total of 70 sites were sampled for streams located on the northwest portion of the Kenai Peninsula, in south-central Alaska. Channel-types were a significant predictor ($P < 0.05$) of the area (m^2) for 9 of 13 habitat types. When habitats were grouped into 6 categories which roughly describe depth and water flow in the habitat, channel-types accounted for 55 to 92% of the variability observed in the area (m^2) of these habitats. Channel-types that had similar habitat composition, differed in the size and depth of those habitats. Spawning habitat also appeared to be correlated to channel-type, however the within channel-type variability caused the differences to test non-significant at $P < 0.05$. Overall, channel-types appear to be a good management tool for inventorying and cataloguing stream habitat. Channel-types can allow for useful comparisons of fish production in similar habitats under different settings.

Key Words: Channel-type, Exxon Valdez, Stream habitat, Aerial Photograph Interpretations.

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Executive Summary

Anadromous salmon, cutthroat, and dolly varden were injured by the *Exxon Valdez* oil spill of 1989. A fundamental problem facing fishery managers, given that the species migrate widely throughout drainage basins in the oil spill area, is the need to incorporate an ecosystem perspective into protection and restoration planning, while still focusing on the objective of increasing productivity. An ecosystem approach requires an ecosystem-based inventory to develop capabilities for identifying habitat limiting to production. To date, fishery managers have lacked methods to adequately identify representative reaches within streams. As a result, short of cataloguing every habitat feature in an entire stream or drainage basin, our abilities to conduct comprehensive ecosystem based habitat analyses have been somewhat limited.

Over the past ten years hydrologists have developed channel-typing systems to classify streams into hydrologically, and geologically similar reaches. Channel-types incorporate physical features such as gradient, width, sinuosity, incision, and adjacent slopes which can be readily discerned by studying stereo pairs of aerial, and satellite photographs. Features such as beaver dams, and logging, which may alter habitat composition in a stream, are also apparent on the photographs. In its broadest capacity channel-typing can be used to map streams into geographical information system (GIS) data bases, and to divide the streams into similar reaches prior to conducting expensive field surveys. As such, channel-typing provides fishery habitat managers with a valuable tool for: making evaluations of land management decisions; designing habitat and fish sampling schemes; and cataloguing those data into meaningful groupings. In this study, we establish that channel-types can be significant predictors of the kind and area of habitat to be found in the wetted portions of a stream.

In-stream habitat were quantified and qualified for nine channel-types that were identified from interpretations of stereo pairs of color and infrared aerial photographs. A total of 70 sites were sampled for streams located on the northwest portion of the Kenai Peninsula, in south-central Alaska. Channel-types were a significant predictor ($P < 0.05$) of the area (m^2) for 9 of 13 habitat types. When habitats were grouped into 6 categories which roughly describe depth and water flow in the habitat, channel-types accounted for 55 to 92% of the variability observed in the area (m^2) of these habitats. Channel-types that had similar habitat composition, differed in the size and depth of those habitats. Spawning habitat also appeared to be correlated to channel-type, however the within channel-type variability caused the differences to test non-significant at $P < 0.05$. Overall, channel-types appear to be a good management tool for inventorying, cataloguing, and evaluating stream habitat. Channel-types allow for useful comparisons of fish production in similar habitats under different settings.

Introduction

Techniques that predict habitat availability in small streams are essential to identify those factors that limit production of salmonid fishes. It is known, for example, that rates of mortality among stream dwelling salmonids are high during early life stages (Chapman 1965, Murphy and Meehan 1991, Heifetz et al. 1986), and that up to 84% of the ova may die in natural spawning gravel (Coble 1961). Because salmon mortality is high during early life stages in streams, and because the mortality is often related to the condition and availability of In-stream habitat, it is critical that freshwater stream habitat essential to juvenile salmon survival be identified, maintained, and restored.

Biotic and abiotic factors that limit the productivity of a stream may vary spatially and temporally among drainage basins. In one stream, fish production may be highly correlated to flow, cover, width, and substrate (Binns and Eiserman 1979), whereas in a second stream, the productivity may be dependent upon available spawning area, and riparian vegetation (Barber et al. 1981). The differences do not necessarily imply that species possess differing habitat requirements from stream to stream, but rather, that the factors limiting fish production may vary. Accordingly, a fundamental problem facing salmon managers, given that the species migrate widely throughout a drainage basin, is the need to incorporate an ecosystem perspective into protection, and restoration planning while still focusing on the objective of increasing productivity (Lichatowich et al. 1995). An ecosystem approach requires an ecosystem-based inventory to develop predictive capabilities for identifying habitat limiting to production.

Several methods have been developed to quantify and qualify habitat in sections of streams (Bisson et al. 1982, Barber et al. 1981). Although these surveys may allow habitat estimations in specific stream segments, habitat patchiness may preclude estimates of total habitat available within the full length of stream, or basin (Hankin 1984). Hankin and Reeves (1988) developed techniques to visually estimate total habitat within streams. Their techniques proved to be "extremely effective for estimation of habitat" in small streams. However, their methods require that the entire stream be surveyed, an often impractical technique when trying to quantify habitat in large drainages, and in inaccessible streams commonly found throughout Alaska. Additionally, these methods do not demonstrate differences between the productivity of similar habitats is different settings, (e.g., a rapid in a flood plain channel vs. a rapid in a high gradient mountainous channel). A hierarchical approach that lends itself to the use of photographic interpretations, and differentiates similar habitats in different channel-types would greatly increase the efficiency, and practicality of large-scale stream habitat inventories.

Paustian (1992) developed a "channel-typing" system for southeast Alaska that is used to break streams into hydrologically, and geologically similar segments, based on interpretations from stereo pairs of aerial and satellite photographs. The channel-typing system contains 39 distinct channel-types that range from high-gradient, bedrock-confined mountain channels, to placid broad-valley, organic-bank, palustrine channels. Channel-types are largely defined by gradient, channel width, channel incision, channel pattern, area of drainage, and surrounding landforms (e.g., valley, beach, mountains, footslopes). Identifying the channel-type of streams is repeatable, and the accuracy is statistically definable. A person who is highly experienced with channel-typing is 85 to 90 % accurate prior to ground verifying (USDA-Forest Service, unpubl. data).

This study was conducted to establish correlations between channel-types and fish habitat. We quantified habitat (Bisson et al. 1982) within stream segments for nine different channel-types that were identified from interpretations of color aerial photographs Based on the data obtained, I describe a technique to predict habitat availability in small streams from interpretations of aerial photographs.

Study Area

Study streams were located on the northwest portion of the Kenai Peninsula, in south-central Alaska, and include portions of Resurrection Creek, Sixmile Creek, Kenai River, Snow River, and Resurrection River drainage's. The streams were all located within a similar geologic, and geographic area. All study streams were channel-typed (Paustian 1992) based on interpretations from 1:15,000 scale color aerial photographs, and 1:63,360 scale USGS topographic quadrangle maps, and digitized into a Geographical Information System (GIS) data base. Channel-typed streams were ground checked to verify the accuracy of photographic interpretations. Of 30 different channel-types found within the project area, nine were selected for habitat surveys (Table 1). The channel-types chosen for our study are representative of the variety of channel-types that exist within the study area. A total of 70 stream sites were surveyed during June, and July 1991. Due to the rare occurrence of some channel-types (e.g., FP4 and PA1) within the study area, they were not sampled numerically as much as others, however, the rate of sampling was greater for the less prevalent channel-types.

Methods

Sample sites were located by demarcating the upper and lower limits of stream channel-type segments on 1:63,360 scale USGS topographic maps, and on 1:15,000 scale color aerial photographs. Orienteering with maps and compass, field crews hiked into, and located the downstream limit of the channel-type for each sample site. The crews then moved approximately 0.1 km upstream to avoid sampling within the transition area between two channel-types. The sample reach consisted of the next 300 m of habitat in an upstream direction. The 300 m sample reach was divided into six consecutive 50 m sub-reaches for comparison purposes. All wetted stream habitat within the 300 m sample reach were measured.

Methods for the stream habitat surveys were adapted from Bisson et al. (1982; Table 2). An edgewater pool, typically observed as shallow, slow water along the stream margin, often in conjunction with rapids and riffles was added to Bisson et al's. (1982) habitat types. Four persons conducted habitat surveys at each site. Two people quantified and recorded available habitat and cover. A third person took photographs and a forth person sketched the sub-reach habitat and cover. First, the boundaries of contiguous habitat type were identified (Bisson et al. 1982, Table 2). Using a 2 m measuring rod marked at decimeter increments as a visual aid, one person estimated the length, average width, average depth, and maximum depth for the habitat type. All wetted areas within the 300 m stream study reach were similarly classified into one of the 13 habitat types. Cover available (Table 2) within each habitat type were then identified. For each cover type identified, the percentage area it occupied within that habitat was estimated. Finally, the percentage of the habitat containing spawning substrate was estimated based on the following four criteria: 1) an average particle size < 125 mm; 2) < 30% silt and sand; 3) the substrate could not be highly compacted or "cemented" together (i.e., the gravel could be readily moved when twisting one's foot into it); and 4) > 2 m^2 in size. An estimate of percent composition for 5 sediment sizes (silt <0.06 mm, sand 0.06 - 2 mm, gravel 2 - 64 mm, small cobble 64 - 128 mm, and large cobble 128 - 256 mm) was determined for substrate meeting the spawning criteria.

SAS procedures (SAS Institute Inc. 1990) were used to produce summary statistics, and to conduct comparative analyses. The frequency of Bisson habitat occurrence per 300 m reach; the area (m^2) coverage of Bisson habitat per 300 m reach; the area (m^2), average depth, and maximum depth of individual habitats; the mean area (m^2) of spawning habitat per 300 m reach; and the mean area (m^2) of cover per 300 m reach were determined for each of the nine channel-types. SAS PROC GLM for multivariate analyses of variance was used to test the significance of channel-type as a predictor of the area (m^2) of Bisson Habitat coverage. For those channel-types which appeared to have similar Bisson habitat coverage per 300 m stream reach, SAS PROC t-test was used to test the difference in means for area (m^2), average depth, and maximum depth of their predominant habitat types. Using the depth data, and field knowledge of relative water speed, the 13 Bisson habitats were grouped into six habitat types that roughly describe depth and speed of water flow (i.e., shallow slow, shallow fast, shallow moderate, deep slow, deep fast, and deep moderate) (Barber 1981). The SAS PROC GLM for multivariate analyses of variance was used to test the significance of channel-types as a predictor of area coverage (m^2) of these six Barber habitats.

Results

Using aerial photographs, in conjunction with topographic maps, field crews easily located stream study sites on the ground. Landmarks such as mountains, groups of trees, and individual trees were identifiable on the aerial photographs

A percentage frequency distribution of the 13 Bisson habitats plotted by channel-type showed considerable amounts of overlap between channel-types. Rapids, riffles, edgewater pools, and runs occurred frequently in all samples except the two palustrine channel-types (Figure 1). Other habitat types, such as lateral scour pools, and upsurge pools were rare in the channel-types that we examined. Despite the similarities between channel-types in frequency of habitat occurrence, there were definable differences. Each of the channel-types contained habitats, or combinations of habitats that were specific to that channel-type. For example, the high gradient contained (HC3) channel-type typically contained numerous cascades in conjunction with plunge pools that were seldom present in the other channel-types. Similarly, the two palustrine (PA1 and PA5) channel-types had large numbers of glides, riffles and corner pools; and dammed pools, respectively; combinations that were not found in the other channel-types. The small flood plain channel (FP3) contained corner pools in conjunction with riffles, rapids, and runs. In spite of the overlap in habitat characteristics; channel-types provided a relative indicator of the frequency of occurrence of habitats, and combinations of habitats.

A plot of the percentage area of Bisson habitats by channel-types more readily depicts some of the habitat differences between the channel-types (Figure 2). The steep gradient HC3 channels predominated in areas of cascades and rapids. Runs predominated in large flood plain (FP5) channels. Rapids and riffles were the predominant habitat in the MM1, MM2, and FP4 channel-types. The PA1 channels contained large areas of glides, dammed pools, and riffles; and as expected, the beaver dammed PA5 channels were entirely dammed pools. Pool habitats made up < 10% of the total stream area for all but the two palustrine (PA1 and PA5) channel-types. A separate plot of percent pool area by channel-type suggests a correlation between the increasing gradient and flow from FP3 to HC3 channel-types; and the increase in area of plunge pools, a habitat type which is mostly associated with cascading falls (Figure 3). Similarly, the low gradient palustrine and flood plain channels contained increasingly more area of dam, edgewater, corner, and backwater pools. A multivariate analysis of variance (MANOVA), testing for the effect of channel-type on the area (m^2) of Bisson habitats in 300 m reaches of stream, indicated that channel-type was a significant predictor for nine of the thirteen habitats (Table 3). The null hypothesis of no overall channel-type effect on the area of Bisson habitats was rejected at $P < 0.0001$. Channel-types accounted for 22 to 81% of the variability in mean area of Bisson habitats per 300 m reach of stream.

For those channel-types that showed considerable frequency of occurrence, and area of coverage overlap in Bisson habitat types (e.g., MM1, MM2, and FP4; Figures 2 and 3) t-tests showed significant differences in the average size and depth of the habitat types (Table 4 and 5). The average area of individual rapids and riffles in MM2 channel-types were three to four times the size of those in MM1 channel-types. Likewise, the average and maximum depths of riffles and rapids in MM2 channels were almost twice that found in MM1 channel riffles and rapids. Based on frequency of occurrence and area coverage of Bisson habitats, MM1 channels were also quite similar to FP4 channels, but once again, the riffles and rapids were much larger and deeper in FP4 channels (Tables 4 and 5). An analysis of variance indicated that channel-type and habitat type combined account for 37, 45, and 69% of the variability seen in the average depth, the maximum depth, and the average size of an individual habitat type, respectively ($P < 0.0001$). Habitat within the 9 channel-types that we examined could be differentiated based on the frequency of habitat occurrence, the total area of habitat types by channel-type, the average size of a habitat type, and the depth of habitat types.

The average amount of spawning habitat (m^2) per 300 m reach of stream varied widely between channel-types (Figure 4). The well flushed, but low gradient flood plain channels (FP4 and FP5) contained substantial areas of spawning substrate, whereas the poorly flushed palustrine channels and the high gradient mountain slope channels contained relatively minor amounts of spawning substrate.
Notwithstanding the apparent differences in amount of spawning habitat between channel-types, the high degree of variability within channel-types caused the probability of between channel-type differences to test non-significant at $P = 0.079$ (ANOVA).

These data also suggest a difference (ANOVA $P=0.0086$) in the amount of total cover by channel-type. High velocity, and flow streams contained more area of cover than other channel-types.

Using depth, and relative speed of water flow, the 13 Bisson habitats were grouped into six Barber et al. (1982) habitats which ranged from "shallow slow" to "deep fast" water (Table 4). As with the Bisson habitats, channel-types were a significant predictor ($P < 0.0001$) for the six Barber habitats. By using the new groups, which in effect incorporate the area, the depth, and the water speed into the habitat equation, channel-types by themselves accounted for 55 to 92 percent of the variability in actual on-the-ground habitat area (Table 6).

Discussion

Fishery managers conducting habitat inventories have lacked methods to adequately identify representative reaches within streams (Hankin and Reeves 1988; Kershner et al. 1992). A common approach has been to classify streams into orders (i.e., primary, secondary, tertiary, and so forth) and then to use personal knowledge of the streams to define representative segments. Several hydrologically different channel-types may exist in a single stream order (Olson and Zemke 1993). Selecting a sample site, or a series of sample sites based on stream order, and personal knowledge are unlikely to portray a representative picture of what is truly present for habitat and thus, fish in the entire stream (Hankin and Reeves 1988). As a result, short of cataloguing every habitat feature in an entire stream or drainage basin, our abilities to conduct comprehensive ecosystem based habitat analyses have been somewhat limited.

Over the past 10 years hydrologists (Paustian 1992, Rosgren 1985) have developed channel-typing systems to classify streams into hydrologically, and geologically similar reaches. Channel-types incorporate physical features such as gradient, width, sinuosity, incision, adjacent slopes, and adjacent landforms which can be readily discerned by studying stereo pairs of aerial, and satellite photographs. Features such as beaver dams, and logging, which may alter habitat composition in a stream (Kershner 1992) are also apparent on the photographs. In its broadest capacity channel-typing can be used to map streams into GIS data bases, and to divide the streams into similar reaches prior to conducting expensive field surveys (Olson and Zemke 1993). As such, channel-typing provides fishery habitat managers with a valuable inventory tool for: making evaluations of land management decisions; designing habitat and fish sampling schemes; and cataloguing those data into meaningful groupings. Channel-typing from interpretations of aerial photographs proved extremely useful for rating general stream habitat quality throughout the 94,000 sq. miles of the Exxon Valdez oil spill area (Olson and Zemke 1993). In this study we establish that channel-types can be significant predictors of the kind and area of habitat to be found in the wetted portions of a stream channel.

Kershner et al. (1992) studied habitats found in channel-types described by Rosgren (1985), and also established that there were differences in percent area of habitat by channel-type. However, they raised caution regarding the large variability of habitat area within a single channel-type, and hence the applicability of using channel-types as an indicator of representative reaches. At least a portion of the variability they found may have been attributable to the fact that they used only Rosgren's broadest channel-type delineation's (i.e., A, B, and C), and failed to use Rosgren's channel-type subdivisions (e.g., A1, A2, and A3) which contain significant physical differences among units.

Using Paustian's (1992) channel-typing system, which by design considers fisheries concerns, we documented habitat characteristics for nine of the thirty-nine channel-types described. Despite some of the habitat similarities between channel-types, we determined that the kind and amount of habitat varied between channel-types, and that channel-types are a significant predictor of that habitat. To be expected in a natural environment, there were substantial variations in the amount of habitat found within different reaches of streams having the same channel-type designation, however the between channel-type variations were significantly larger than the within variations, hence our positive test results. A large amount of the within channel-type habitat area variation was reduced when we grouped the thirteen Bisson habitats into six Barber habitats. The Barber habitats took into consideration the velocity, and depth of the water, thereby, allowing channel-types to account for up to 92% of the observed variability in habitat type and area.

Habitat important to salmonid production may represent only a small portion of the total stream area (Kershner 1992) and therefore, it could be overlooked when using broad based indicators of stream reaches such as channel-types, to estimate habitat availability. However, laboratory and field studies (Meehan 1991) already provide considerable knowledge of the types of habitat essential to salmonids. When identifying what limits the production of fish the objective is to determine what essential habitats are limited in availability, regardless of whether they are absent or present in small quantities. Channel-typing, even though it may miss the presence of an essential habitat, would by default identify that habitat as being limited.

In addition to the variability of habitat area between and within channel-types, not all riffles, rapids, runs, glides, and pools are sculpted equally. As an example, rapids and riffles in the mid-size flood plain channels (FP4) were much larger, and deeper than those in the moderate gradient, mixed control (MM1) channels. Large woody debris, and other obstructions further affect the size and depth of habitats (Heifetz et al. 1986). Accordingly, it is reasonable to expect that the rearing, or spawning capacity of riffles, rapids, runs, glides, and pools will vary from channel-type to channel-type. Expectations that fish production in a flood plain scour pool should be similar to that of a moderate-gradient, confined-channel scour pool may not be valid, much less expectations of similar fish production in one reach verses another.

Observations of naturally occurring habitat variation within hydrologically similar sections of streams need not preclude the usefulness of channel-typing to conduct comprehensive ecosystem based habitat analyses. The problem with stream habitat inventories is not that variability exists from stream to stream, and from reach to reach, rather that adequate means of cataloguing that variability, so that meaningful comparisons could be made, have not existed. Without channel-types, or a similar cataloguing tool, each habitat inventory stands alone as a data point in time, with no reliable means of comparing the production capability of streams. With channel-typing however, a single data base can be continually supplemented. Also, Inventories in one basin can be compared to inventories in another. Fish densities in a scour pool in a small flood plain channel for example, can be compared to densities in a scour pool in a palustrine channel, with little or no ambiguity. Any variation can help explain why two streams having seemingly similar hydrologic and geologic characteristics possess different productive capabilities. By collecting tiered habitat data for broad channel-type designations, over time, capabilities can be defined for combinations of channel-types, improving management capabilities. The data in this study for example, indicate that pool habitat comprised < 10% of the total habitat in our study streams. Most of those pools were, on average, < 0.5 m deep. During winter, salmonids prefer deep pools with cover (Heifetz 1986), suggesting that efforts to increase productivity should consider winter rearing habitat. Channel-typing through interpretations of aerial, and satellite photographs does not eliminate the need for intensive ground surveys, but it can help to make the surveys more efficient, and allow for a more realistic comparison of similar habitats.

Classifying stream habitat types should be done by as few people as possible, preferably one well trained individual (Hankin and Reeves 1988). Several crews conducted surveys in this study, almost certainly introducing observer variability. Though channel-types represent similar hydrologic and geologic stream reaches, bioclimatic variations between regions will likely effect the type of habitat to be found in those channel-types. Future studies relating habitat types to channel-types should consider bioclimatic variables such as riparian vegetation, and precipitation. Color photographs used to conduct channel-typing in this study were produced 20 years ago (1975), with existing technology. Recent developments in optics, and multi-spectral light technologies, should greatly improve abilities to conduct meaningful stream habitat inventories using aerial and satellite photographs. In combination with vegetation overlays, stream habitat inventories should allow us to predict large woody debris, and other cover components that contribute to habitat function.

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Table 1. Description of physical characteristics for nine channel types (Paustian 1992) sampled in this study.

CHANNEL TYPE	STREAM GRADIENT	CHANNEL WIDTH (m)	HYDROLOGIC PROCESS	SUBSTRATE	ADJACENT SIDESLOPE	CHANNEL INCISION (m)	BANK CONTROL
PA1 (N=4)	< 2 %	< 10	DEPOSITIONAL	ORGANIC SILT	FLAT	< 2	ALLUVIUM
PA5 (N=4)	0 - 1 %	> 10	DEPOSITIONAL	ORGANICS	VARIABLE	< 2	ORGANICS
FP3 (N=8)	< 2 %	< 10	DEPOSITIONAL	SAND TO SM. COBBLE	SHORT SHALLOW	<= 2	SAND TO GRAVEL
FP4 (N=8)	< 2 %	10 - 20	DEPOSITIONAL	SAND TO COBBLE	SHORT SHALLOW	<= 2	ALLUVIUM
FP5 (N=3)	<2 %	> 20	DEPOSITIONAL	SAND TO COBBLE	SHORT SHALLOW	<= 3	ALLUVIUM
MM1 (N=24)	2 - 6 %	<= 10	SEDITMENT TRANSPORT	GRAVEL TO LG. COBBLE	avg. = 14 %	<= 4	ALLUVIUM COLLUVIUM
MM2 (N=5)	2 - 6 %	> 10	SEDIMENT TRANSPORT	GRAVEL TO SM. BOULDER	avg. = 12 %	<= 4	ALLUV., COL., BEDROCK
MC2 (N=5)	2 - 6 %	< 20	SEDIMENT TRANSPORT	COBBLE TO BEDROCK	avg. = 75 %	4 - 20	BEDROCK TO MIXED
HC3 (N=9)	6 - 15 %	avg. = 7	SEDIMENT TRANSPORT	COBBLE TO BEDROCK	avg. = 62 %	< 50	BEDROCK AND COBBLE

Key: PA1 = narrow, placid flow; PA5 = beaver impounded; FP3 = narrow flood plain; FP4 = mid-size flood plain; FP5 = wide flood plain channel, MM1 = narrow, moderate-gradient, mixed-control; MM2 = wide, moderate-gradient, mixed control; MC2 = moderate-gradient, contained; HC3 = high-gradient, contained.

Table 2. habitat and cover types used to describe wetted stream areas within this study. Habitat and cover types are adapted from Bisson et al. (1982).

Bisson Habitat Types	**Cover Types**
Cascade = CAS	Root Wads
Rapid = RAP	Large Woody Debris
Riffle = RIF	Overhanging Vegetation
Run = RUN	Undercut Bank
Glide = GLI	Boulders
Plunge Pool = PLP	Beaver Dam
Lateral Scour Pool = LSP	Aquatic Vegetation
Upsurge Pool = UPS	
Corner Pool = CRP	
Secondary Channel Pool = SCP	
Backwater Pool = BWP	
Edgewater Pool = EWP	
Dammed Pool = DAM	

Table 3. Multivariate ANOVA testing the effect of nine channel-types on the average total area (m^2) of Bisson (1982) habitats in 300 m stream reaches. The level of significance is indicated by asterisks: * significant at P<0.05, ** significant at P<0.01, *** significant at P < 0.0001.

Dependent Variable	R-Square	P-value
Cascade	0.348	0.0006***
Rapid	0.398	0.0001***
Riffle	0.170	0.1553
Run	0.376	0.0002***
Glide	0.509	0.0001***
Secondary Channel Pool	0.222	0.0417*
Upsurge Pool	0.090	0.6438
Backwater Pool	0.285	0.0060**
Dam Pool	0.812	0.0001***
Corner Pool	0.261	0.0133**
Edgewater Pool	0.211	0.0558
Plunge Pool	0.221	0.0435*
Lateral Scour Pool	0.050	0.9170

Hypothesis of no overall channel type effect on the area (m^2) Bisson habitats: **P < 0.0001 Reject the null hypothesis.**

Table 4. Mean and N values for the size (m^2), and the average and maximum depths (m) of Bisson (1982) habitats sampled in this study. Values are listed by channel-type. For DPL's marked ** the depths were > 1.5 m and were not measured. Corresponding Barber (1981) habitats are: ss= shallow slow, sf=shallow fast, sm=shallow moderate, dm=deep moderate, df=deep fast, and ds=deep slow.

CHANNEL TYPE		HABITATS BWP	CAS	CRP	DPL	EWP	GLI	LSP	PLP	RAP	RIF	RUN	SCP	USP
PA1	ave. depth	....	....	0.19	1.33	0.17	0.81	....	....	....	0.19	0.30	0.15	....
	max. depth	....	....	0.34	2.67	0.26	1.26	....	....	....	0.22	0.35	0.20	....
	size (m^2)	....	10	350	8	139	....	....	....	32	4	6	....	
	N	..	..	13 sm	3 ds	11 ss	18 ds	..	..	..	36 sf	1 sm	1 ss	....
PA5	ave. depth	....	....	....	**	....	....	....	....	....	....	....	....	....
	max. depth	....	....	....	**	....	....	....	....	....	....	....	....	....
	size (m^2)	....	....	2520	....	....	....	....	....	....	....	....	....	
	N	..	..	..	4 ds	..	..	..	..	..	..	..	..	....
FP3	ave. depth	0.22	0.18	0.36	....	0.24	0.36	....	0.45	0.18	0.14	0.29	0.17	....
	max. depth	0.33	0.30	0.53	....	0.30	0.41	....	0.55	0.29	0.23	0.56	0.21	....
	size (m^2) 7	31	13	....	7	32	....	8	76	37	216	8	....	
	N	14 ss	6 sf	30 sm	..	15 ss	13 ss	..	2 ss	24 sf	42 sf	22 sm	10 ss	....
FP4	ave. depth	0.30	....	0.30	0.40	0.26	0.30	1.50	0.70	0.53	0.34	0.57	0.21	1.50
	max. depth	0.43	....	0.50	0.50	0.44	0.43	1.90	0.88	0.68	0.45	0.64	0.22	1.75
	size (m^2) 10	....	8	25	26	51	36	9	386	300	385	27	24	
	N	19 ss	..	1 sm	1 ss	35 ss	3 ss	1 dm	12 ds	32 df	30 sf	10 dm	7 ss	1 df.
FP5	ave. depth	0.50	....	0.60	....	0.36	....	0.1	0.69	0.83	0.16	0.60	0.30	0.80
	max. depth	0.82	....	0.60	....	0.49	....	0.15	0.82	0.98	0.24	0.79	0.43	0.90
	size (m^2) 31	....	12	....	25	....	2	17	56	183	380	65	4	
	N	10 ds	..	1 dm	..	8 ss	..	1 sm	6 ds	4 df	8 sf	21 dm	6 ss	1 df.
MM1	ave. depth	0.25	0.26	0.29	0.50	0.21	0.24	0.39	0.47	0.28	0.19	0.29	0.23	0.49
	max. depth	0.32	0.45	0.40	0.77	0.29	0.36	0.61	0.59	0.40	0.27	0.40	0.33	0.77
	size (m^2) 5	57	6	20	7	29	17	8	114	72	58	19	6	
	N	18 ss	29 sf	13 sm	3 ds	152 ss	12 ss	9 sm	78 ss	128 sf	161sf	69 sm	20 ss	8 df.
MM2	ave. depth	1.00	....	0.30	0.50	0.36	....	0.80	0.75	0.49	0.33	0.31	0.27	....
	max. depth	1.00	....	0.40	0.70	0.50	....	0.98	0.83	0.69	0.42	0.37	0.40	....
	size (m^2) 4	....	5	15	11	....	4	6	427	183	45	23	....	
	N	1 ds	..	1 sm	1 ds	22 ss	..	4 dm	23 ds	25 sf	21 sf	12 sm	9 ss	....
MC2	ave. depth	0.30	0.81	....	....	0.22	....	0.10	0.53	0.52	0.16	0.37	0.24	0.50
	max. depth	0.40	1.28	....	....	0.36	....	0.25	0.81	0.62	0.21	0.38	0.33	0.60
	size (m^2) 7	124	....	....	16	....	3	19	115	69	223	16	10	
	N	24 ss	8 df	..	..	24 ss	..	1 sm	9 ds	19 df	24 sf	18 sm	6 ss	3 df.
HC3	ave. depth	0.08	0.34	0.50	....	0.27	....	0.30	0.50	0.30	0.26	0.34	0.19	....
	max. depth	0.40	0.55	0.60	....	0.37	....	0.30	0.76	0.45	0.30	0.54	0.39	....
	size (m^2) 14	96	8	....	11	....	4	15	152	45	45	30	....	
	N	2 ss	46 sf	1 dm	..	27 ss	..	1 sm	40 ds	47 sf	21 sf	10 sm	7 ss	.... .

Table 5. T-test of equal means for size, average depth, and maximum depth of Bisson habitats (1982) for the listed channel-type comparisons. The level of significance is indicated by asterisks. * significant at $P<0.05$, ** significant at $P<0.01$, *** significant at $P<0.0001$.

		PROBABILITY OF EQUAL MEANS		
CHANNEL TYPE COMPARISON	**HABITAT TYPE**	**SIZE**	**AVE. DEPTH**	**MAX. DEPTH**
MM1 VS. FP4	RAPID	0.0001***	0.0001***	0.0001***
MM1 VS. FP4	RIFFLE	0.0001***	0.0001***	0.0007**
MM1 VS. MM2	RIFFLE	0.0313*	0.0001***	0.0001***
MM1 VS. MM2	RAPID	0.0001***	0.0001***	0.0001***
FP3 VS. MC2	RAPID	0.0589	0.0001***	0.0002**
FP3 VS. MC2	RIFFLE	0.1275	0.4990	0.0917
FP3 VS. MC2	RUN	0.0467*	0.5169	0.4169
FP3 VS. FP5	RUN	0.0273*	0.0001***	0.0039**
FP3 VS. FP5	RIFFLE	0.0255*	0.5975	0.9784

Table 6. Multivariate ANOVA testing the effect of channel-types on the total area (m^2) of six Barber (1981) habitats in 300 m stream reaches. Levels of significance are indicated by asterisks: *** significant at P<0.0001.

Dependent Variable	R-Square	P-value
Shallow Slow	0.759	0.0001***
Deep Slow	0.804	0.0001***
Shallow Moderate	0.618	0.0001***
Deep Moderate	0.914	0.0001***
Shallow Fast	0.554	0.0001***
Deep Fast	0.917	0.0001***

Hypothesis of no overall channel type effect on the area (m^2) of Barber habitats: **P<0.0001 Reject the null hypothesis.**

Figure 1. Percent frequency of occurrence for thirteen Bisson (1982) habitats found in 300 m wetted stream reaches, listed by channel-type. DPL=dammed pool, EWP=edgewater pool, BWP=backwater pool, SCP=secondary channel pool, CRP=corner pool, USP=upsurge pool, LSP=lateral scour pool, PLP=plunge pool, GLI=glide, RIF=riffle, RAP=rapid, RUN=run, CAS=cascade.

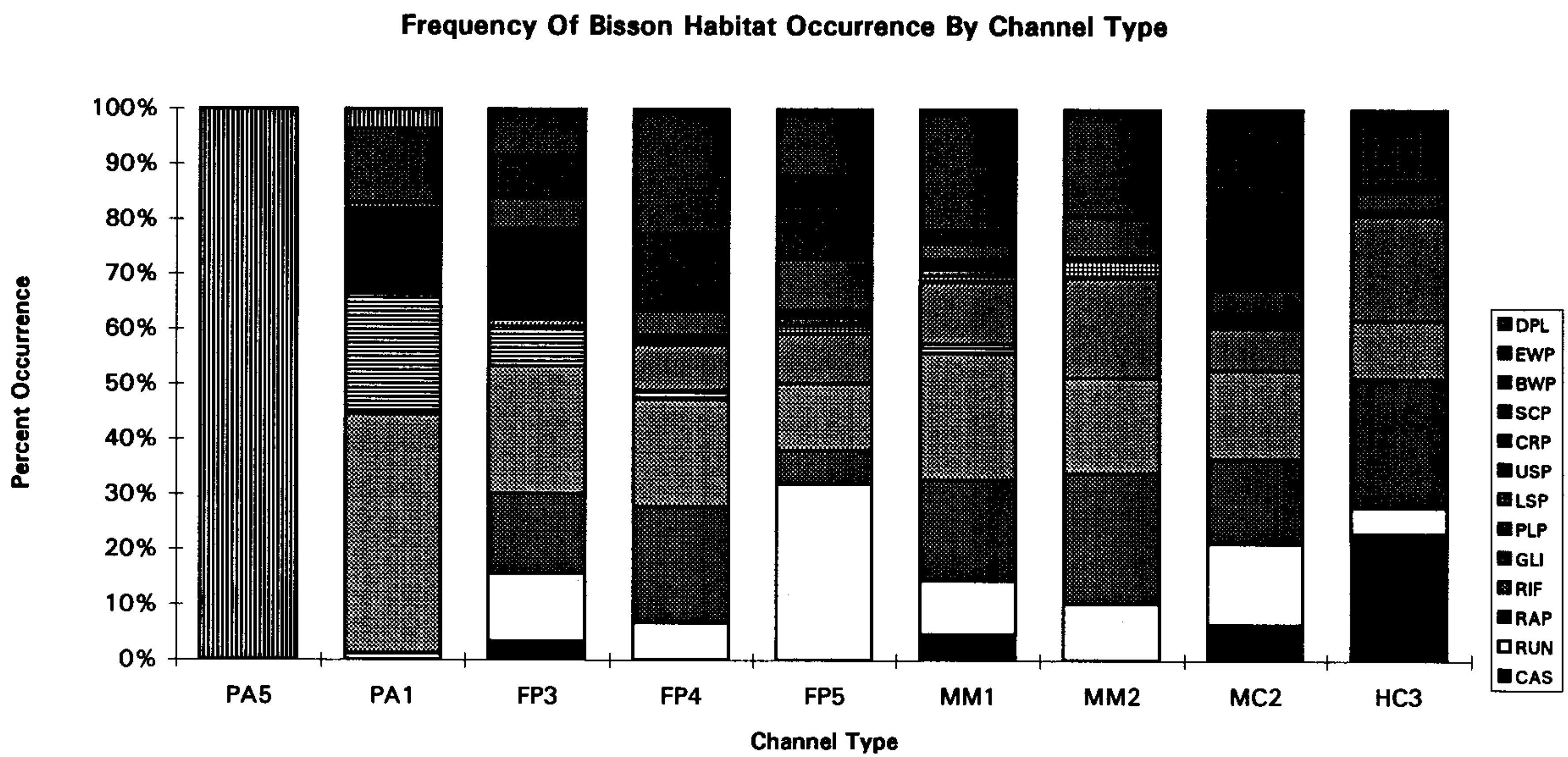
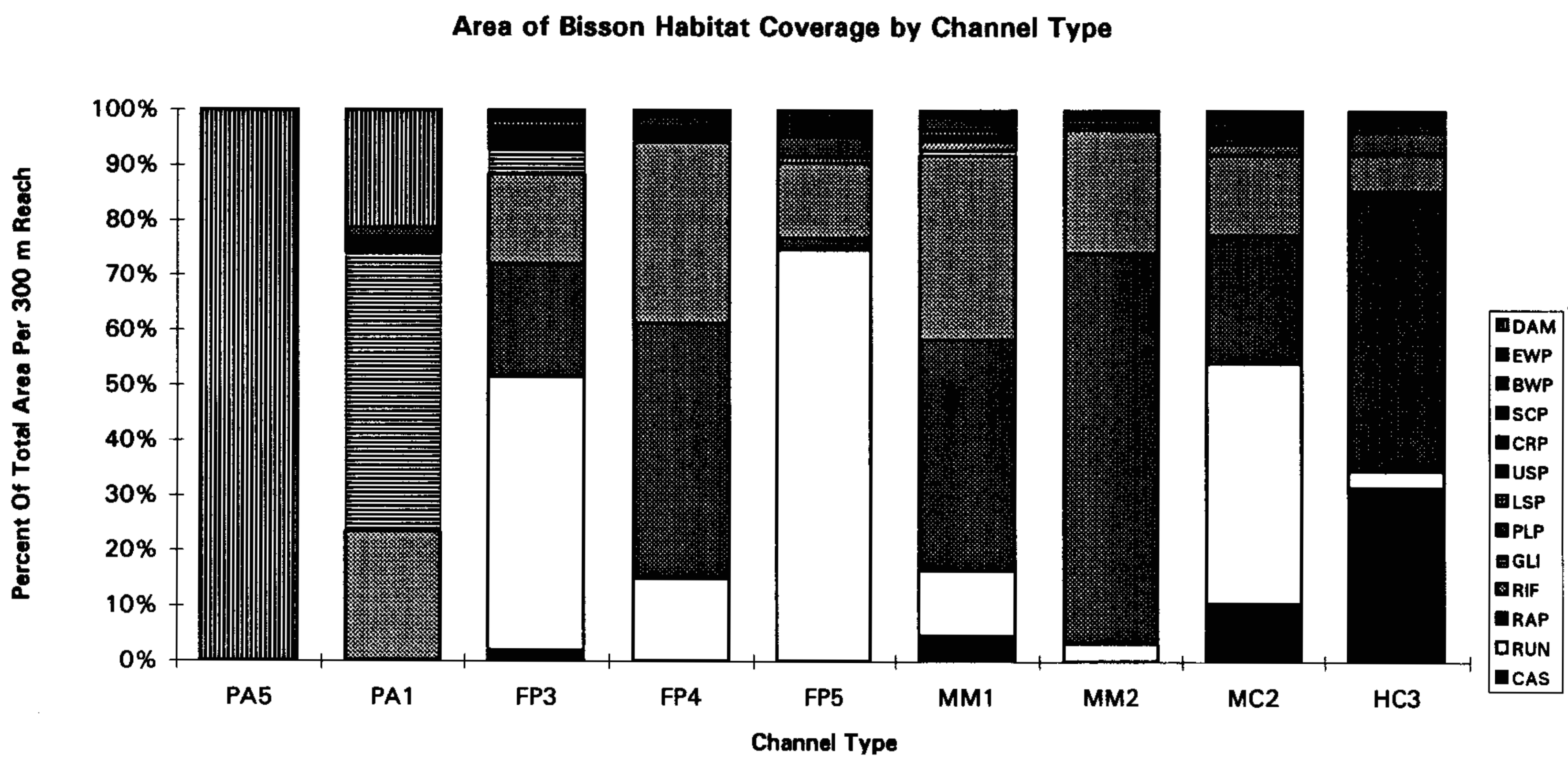

Frequency Of Bisson Habitat Occurrence By Channel Type
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
Percent Occurrence
PA5
PA1
FP3
FP4
FP5
MM1
MM2
MC2
HC3
Channel Type
DPL
EWP
BWP
SCP
CRP
USP
LSP
PLP
GLI
RIF
RAP
RUN
CAS

Figure 2. Percent of the total wetted area (m^2) that Bisson (1982) habitats cover for each of nine channel-types sampled. DPL=dammed pool, EWP=edgewater pool, BWP=backwater pool, SCP=secondary channel pool, CRP=corner pool, USP=upsurge pool, LSP=lateral scour pool, PLP=plunge pool, GLI=glide, RIF=riffle, RAP=rapid, RUN=run, CAS=cascade.



Area of Bisson Habitat Coverage by Channel Type
Percent Of Total Area Per 300 m Reach
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
PA5
PA1
FP3
FP4
FP5
MM1
MM2
MC2
HC3
Channel Type
DAM
EWP
BWP
SCP
CRP
USP
LSP
PLP
GLI
RIF
RAP
RUN
CAS

Figure 3. Percent of the total Bisson (1982) pool area (m^2) within the wetted stream channel for each of nine channel types. In all but the two palustrine channel-types (i.e., PA1 and PA5) pools represented < 10 % of the total habitat area. DPL=dammed pool, EWP=edgewater pool, BWP=backwater pool, SCP=secondary channel pool, CRP=corner pool, USP=upsurge pool, LSP=lateral scour pool, PLP=plunge pool.

Area of Bisson Pool Habitat Coverage by Channel Type

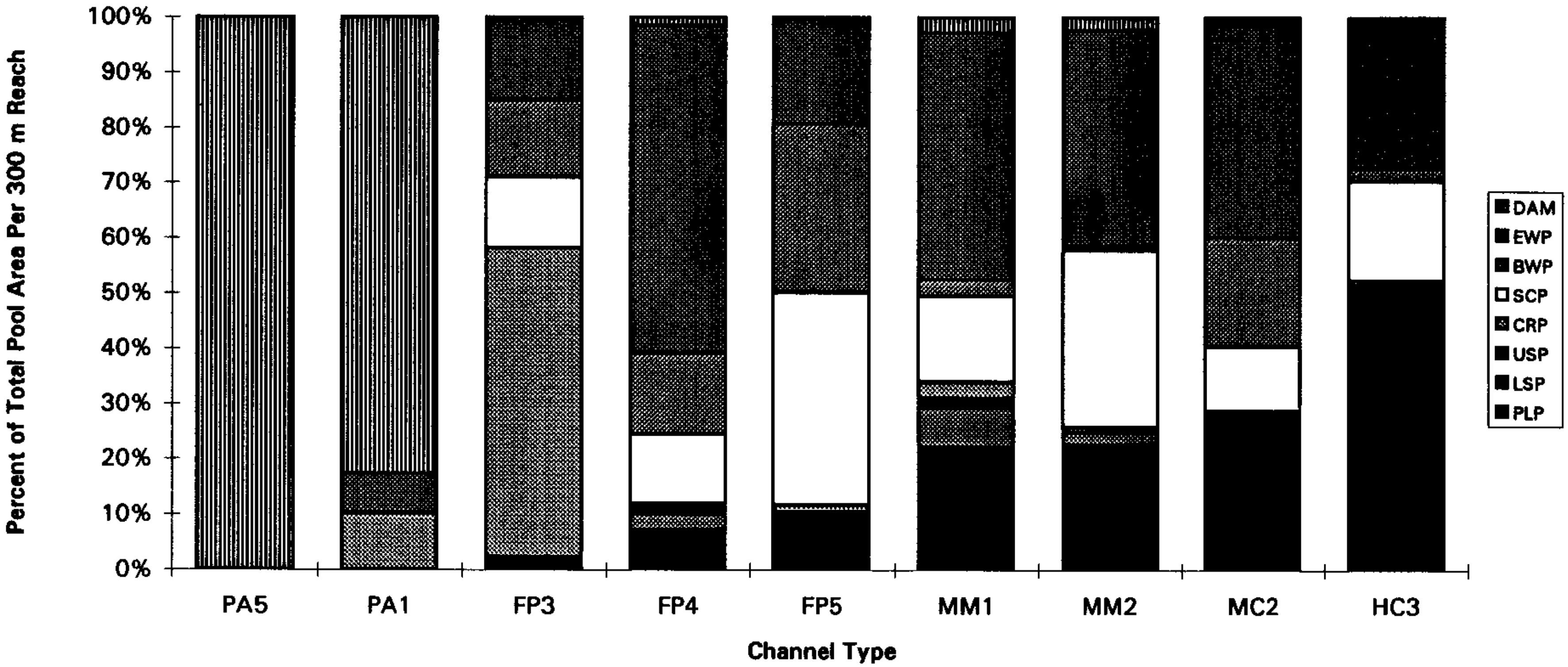
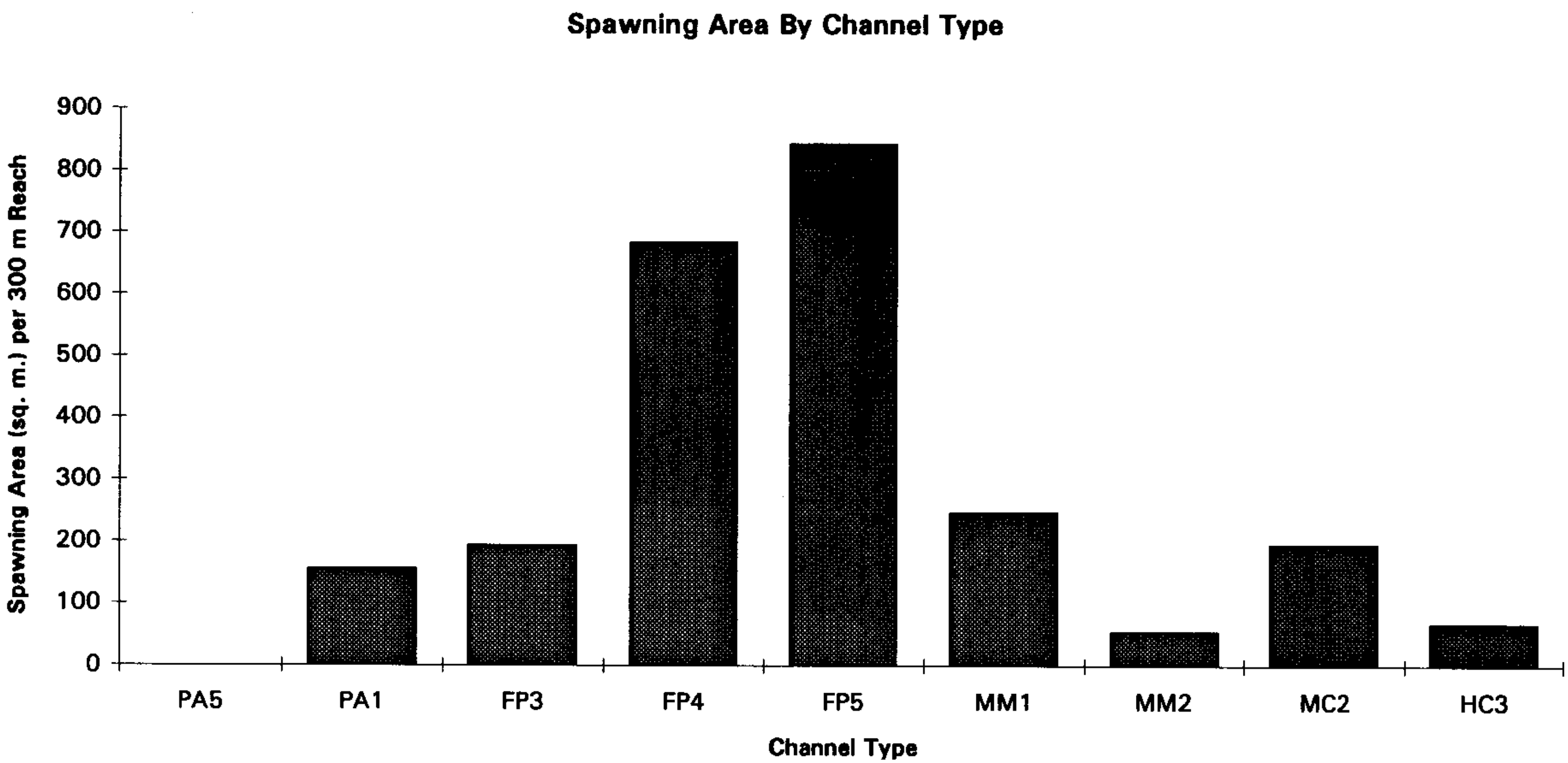
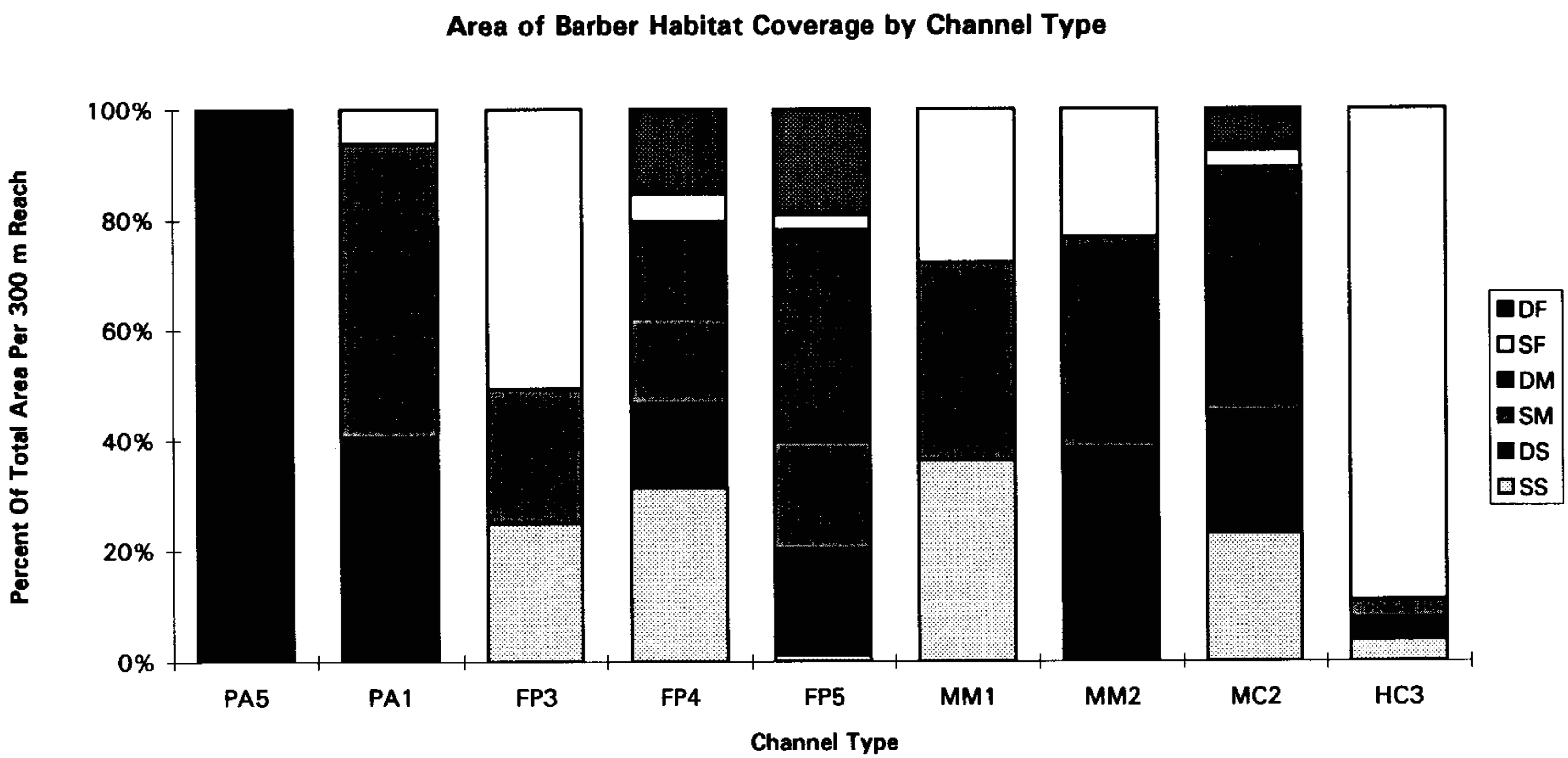


Figure 4. The area (m^2) of spawning habitat per 300 m reach of wetted stream channel. The data are listed by channel-type. An analysis of variance testing for equality of means showed a P=0.079 of equal means.



Spawning Area By Channel Type
Spawning Area (sq. m.) per 300 m Reach
900
800
700
600
500
400
300
200
100
0
PA5
PA1
FP3
FP4
FP5
MM1
MM2
MC2
HC3
Channel Type

Figure 5. Percent of the total area (m^2) within a 300 m stream reach that six Barber (1981) habitats occupy. Data are listed by channel-type. DF=deep fast, SF=shallow fast, DM=Deep moderate, SM=shallow moderate, DS=deep slow, SS=shallow slow.


Area of Barber Habitat Coverage by Channel Type
Percent Of Total Area Per 300 m Reach
100%
80%
60%
40%
20%
0%
PA5
PA1
FP3
FP4
FP5
MM1
MM2
MC2
HC3
Channel Type
DF
SF
DM
SM
DS
SS