THE DEVELOPMENT OF GEOMORPHOLOGICAL COMPLEXITY AND ITS INFLUENCE ON FISH HABITAT

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ABSTRACT

Fluvial geomorphology plays a pivotal role in determining stream complexity and hydraulic variation, which in turn influence biodiversity (Bartley and Rutherford, 2005). To date, research focusing on the rate by which stream complexity develops through geomorphological change has been limited. Rapid glacial recession within Glacier Bay National Park and Preserve, Alaska, has created a unique opportunity to fill this research gap by studying the development of stream complexity and associated biotic communities over time.

Detailed mapping and characterisation of channel geomorphic units (CGUs) within six streams covering a 200-year chronosequence, and subsequent analysis using Hydrosignature software, has identified changes in hydraulic characteristics from younger to older streams. Water depth, current velocity and Froude number decreased with stream age, whilst older streams contained a greater number of slower flowing CGUs. Older streams also contained greater hydraulic variation and smaller CGU size than younger streams.

Analysis of the location, orientation and hydraulic characterisation of coarse woody debris has shown that it plays an important role in producing hydraulic and habitat diversity, promoting channel stability (and the creation of pool habitat) and creating velocity shelters, all of which benefit fish populations.

Analysis of geomorphological complexity over a chronosequence has enabled the study to evaluate the development of geomorphic composition and hydraulic complexity over time, and identified the importance of coarse woody debris in initiating these changes. Determination of these changes over a large (kilometres) scale provides new information on the process and timescale of riverscape development.

Keywords: *Channel geomorphic units, stream development, hydraulic habitat, coarse woody debris, geomorphological complexity, Glacier Bay, Alaska*

INTRODUCTION

The geomorphic diversity of a river determines the amount and diversity of physical habitat within that river as it is the interaction of geomorphology and hydrology which determine the quantity and quality of physical habitat (Brierley et al., 1999; Maddock, 1999; Thomson et al., 2001). Changes in the diversity and complexity of geomorphic and hydraulic features can therefore influence habitat and species diversity (Bartley and Rutherford, 2005; Sullivan et al., 2006), yet despite this knowledge, little is known about how geomorphological complexity develops, and how it affects hydraulic and habitat diversity (Yarnell et al., 2006).

Geomorphological complexity may be defined as the complexity in both composition and configuration of geomorphological elements within a river channel. Recent research has found that changes in the geomorphic composition of a river influence the structuring of community diversity, productivity and condition (Beisel et al., 2000) as geomorphic complexity creates spatial heterogeneity which instream biota, such as macroinvertebrates (Beisel et al., 2000) and fish (Inoue and Nakano, 1999; Walters et al., 2003) can utilise.

Coarse woody debris has been shown to play a role in creating favourable instream conditions for salmonid species (Lisle, 1986; Neumann and Wildman, 2002; Dolloff and Warren, 2003). Recent research has focused on how CWD influences hydraulic variation, resulting in increased habitat and species diversity (Brooks et al., 2004), yet the potential role of CWD in creating geomorphic complexity which colonising salmonids may utilise in a newly formed stream has not been studied.

Rapid glacial recession within Glacier Bay National Park, Alaska, has created a unique opportunity to monitor the geomorphological development of streams and associated physical and ecological responses over time. Detailed historical, geological and dendrochronological data allows glacial recession within Glacier Bay to be accurately dated, whilst extreme disturbance to the area following deglaciation provides the opportunity to study habitat and community development via primary colonisation processes (Crocker and Major, 1955; Reiners et al., 1971; Chapin et al., 1994). Stream age is related to the distance of a stream from the retreating glacier termini (Figure 1), and thus temporal changes in stream complexity can be studied on the basis of temporal differences (Milner, 1988). Five streams were chosen for study according to their similarity in catchment and geological characteristics (Table 1), and together, represent approximately 200 years of stream development.

Identification of channel geomorphic units (CGUs; e.g.- riffle, run, pool etc) using a hierarchical description of the morphological and hydraulic properties provides an ecologically meaningful measure of the geomorphic and physical diversity of the instream environment. Analysis of differences in the habitat and hydraulic environments within five streams representing a 200-year chronosequence will assist in identifying changes in instream habitat which occur as streams develop over time. Assessment of these changes over a large, or 'meso' scale will provide an assessment over the entire riverscape, allowing identification of landscape and hydraulic features at scales relevant to the entire lifecycle of instream biota such as fish, whilst detailed mapping and assessment of smaller representative reaches identified from meso scale mapping is able to quantify the hydraulic and habitat changes which occur as the streams age.

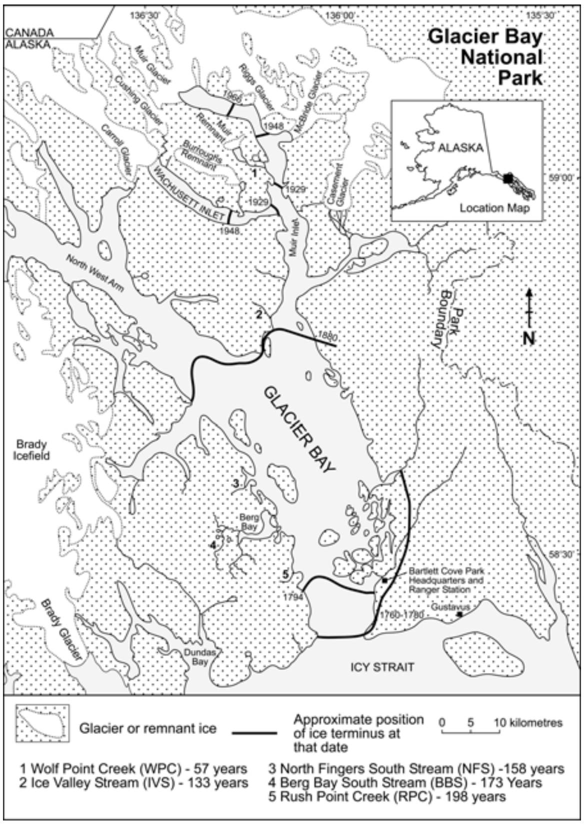

Figure 1: Map of Glacier Bay National Park, Alaska, including the study streams and dates of glacial recession.

Table 1: Summary of physical characteristics of the five study streams. Bo- boulder, Co- cobble, Gr- gravel. A/W- Alexander/ Wrangellia Terrane. Data sources- *(Milner et al., 2000); **(Robertson and Milner, 2006); *** (Hill et al., 2008)

	Stream age	Gradient (%) *	Stream length (km)**	Drainage area (km^2)***	Mean elevation (m)***	Ave discharge (m^3/s)	Stream order **	Dom substrate	Geology
WPC	57	3.3	5.6	29.8	317	2.29	2	Bo	A/W
IVS	133	6.2	8.3	19.4	310	3.02	2	Co	A/W
NFS	158	4.5	8.0	16.8	333	5.65	2	Bo	A/W
BBS	173	3.4	7.2	33.1	208	4.95	3	Gr	A/W
RPC	198	4.5	6.6	23.3	234	7.51	2	Co	A/W

METHODS

Fieldwork conducted in 2006 and 2007 focused on the identification and quantification of the geomorphic composition within the study streams. Channel geomorphic units (CGUs) were identified over a minimum distance of 1.3km using a modified version of the Hawkins et al. (1993) classification system, and mapped using a mapping grade GPS unit (Trimble GeoXT; accurate to the sub metre level) in order to identify the geomorphic composition and structure within each stream. Mapping at this level allowed the stream to be characterised at the ‘meso’ habitat scale which represents the full scale of habitats utilised by fish (Fausch et al., 2002). Representative reaches a minimum of 300m in length were identified from mapping at the meso scale, and studied in greater detail in order to assess differences in habitat and hydraulic structure across the stream chronosequence.

Hydraulic variation within the representative reaches were assessed by taking thirty random depth and velocity measurements (at the 0.6 depth, averaged over 30 seconds) within each CGU type. This data was then analysed using Hydrosignature software (Le Coarer, 2005) in order to quantify the hydraulic diversity present within each CGU. Hydrosignature is free-to-use software, which classifies depth and velocity percentages into cross-classed grids, displaying the hydraulic diversity within a site as a velocity/ depth plane, or hydraulic signature. The data was input as NOXY 2 (non-spatialised data; (Scharl and Le Coarer, 2005)), using Froude number as the sorting factor. Surveyed CGUs were grouped together within each stream according to their CGU type, creating a 'CGU total' hydraulic signature across the range of observed CGU types within each river. These were then used to compare hydraulic signatures of CGU types across the stream chronosequence (i.e.- 'run' from Stream A vs. 'run' from Stream B) using HydroSignature's inbuilt 'Hydrosignature Comparison Index' (HSC; Scharl & Le Coarer, 2005). The HSC provides a relative scale of comparison of two hydraulic signatures, creating HSC values ranging from 0-100 (0 implies two hydraulic signatures are identical, or homogenous, whilst a value of 100 suggests that the hydraulic signatures have no similar properties, or are heterogeneous).

Coarse woody debris (CWD) located within or adjacent to the study streams was identified, quantified and tagged using a metal tree tag in order to assess its movement over subsequent years. CWD properties, including dam character (type, position, class, control and anchorage), dimensions (channel coverage, number and size of key pieces and horizontal orientation) and structure (distance from bank, complexity and decay state) were assessed using criteria outlined by Abbe and Montgomery (2003). Subsequent changes in CWD properties were assessed in over a two year period.

RESULTS

Geomorphic composition and diversity were found to be lowest in the youngest streams surveyed, which were dominated by fast flowing CGUs such as rapids and riffles, whilst the eldest streams contained a greater number of slower flowing CGUs such as glides and pools. (Figure 2). Hydraulic composition and variation within the CGUs was also found to change over the chronosequence, with the younger streams characterised by higher velocities and Froude numbers, whilst older streams were dominated by slower flowing CGUs, greater in depth with lower Froude values (Figure 3).

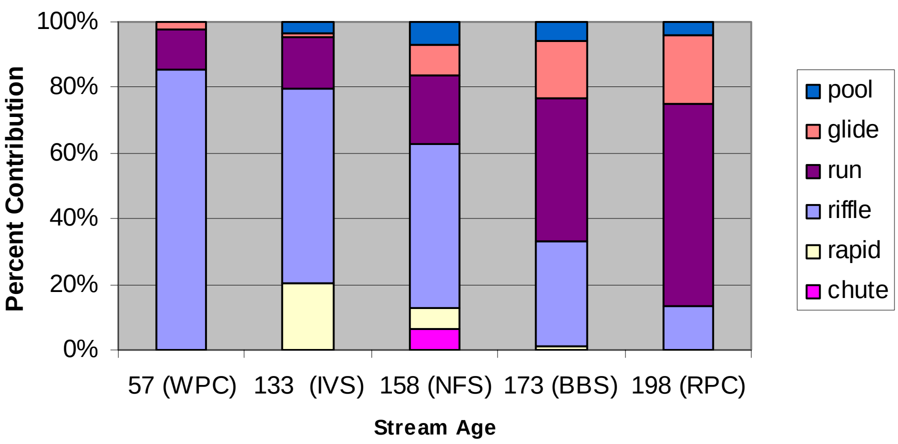

Figure 2: Percent contribution of CGU types within the study streams

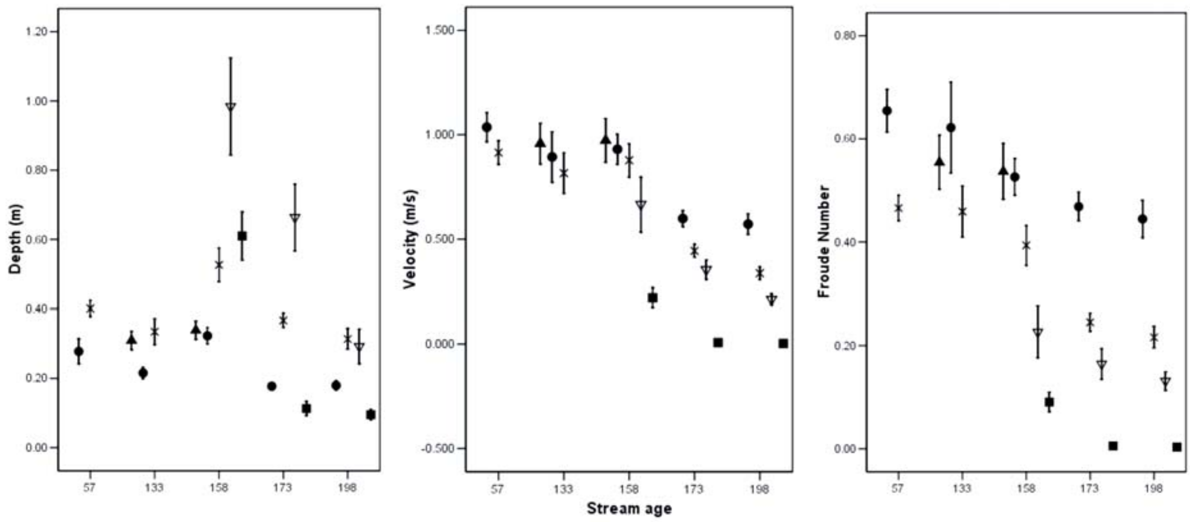

Figure 3: CGU depth, velocity and Froude number values across the stream chronosequence. ▲ Rapid; ● Riffle; ✕ Run; ▽ Glide; ■ Pool. Bars represent 95% C.I.

Analysis of the hydraulic variation within CGU types across the chronosequence revealed that the mean HSC value in fast flowing CGUs was low (Figure 4), indicating little difference in hydraulic characteristics between streams, whilst the HSC values for slower flowing CGUs was high, suggesting a growing disparity in the hydraulic characteristics of these CGUs, in those streams which contained them (NFS, BBS and RPC). Comparison of stream hydraulic signatures reveals a growing disparity between streams as age difference increases, whilst the two oldest streams have the highest similarity (i.e.- the lowest HSC value. Figure 5 illustrates this phenomenon for ‘run’ CGUs).

CGU type	Mean HSC value
Rapid	14
Riffle	34
Run	46
Glide	69
Pool	56

Figure 4: Mean HSC values within CGU types (all streams amalgamated). Key to HSC colour coding:

N/A	1-20	21-40	41-60	61-80	81-100

	WPC- 57	NUN- 68	IVS- 133	NFS- 158	BBS- 173	RPC- 198
WPC- 57	0					
NUN- 68	50	0				
IVS- 133	26	39	0			
NFS- 158	32	54	37	0		
BBS- 173	56	14	48	60	0	
RPC- 198	71	35	65	78	25	0

Figure 5: Hydrosignature Comparison Values (HSC) of ‘run’ CGUs across the stream chronosequence. Results show that runs within the youngest streams, and signatures become more heterogeneous as stream difference increases.

Coarse woody debris characteristics were also found to differ along the stream chronosequence (Table 2). The amount of CWD within the stream increased as stream age increased, with RPC, the eldest stream, containing nearly two CWD structures per 100m of mapped stream, whilst the youngest stream, WPC, contained an average of 1.2 structures per 100m (Figure 6). The position of CWD within the channel varied over the study site, with the majority of CWD falling into the instream or marginal categories, with very few bridging the water channel. The complexity and channel coverage of CWD structures were found to increase with stream age; most likely due to the occurrence of larger, more mature riparian vegetation at older sites.

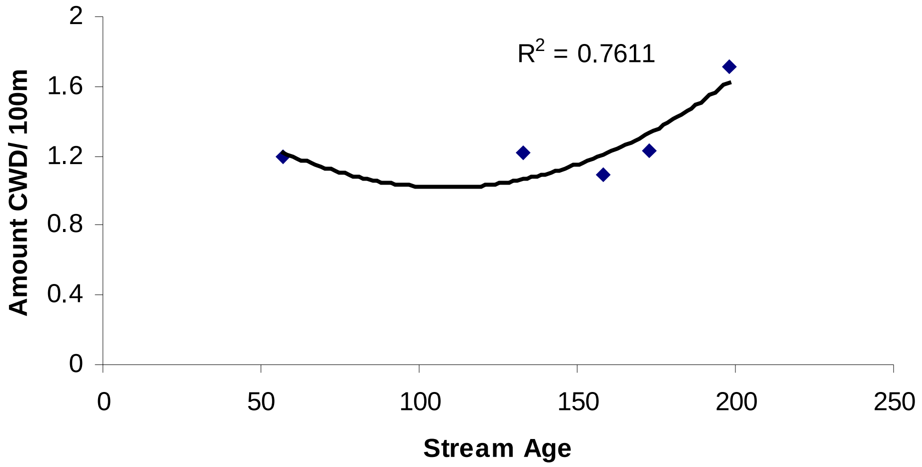

Figure 6: Relationship between stream age and amount of CWD/ 100m of mapped stream.

Table 2: Characteristics of CWD within the six study streams, Summer 2006 and 2007. Percentage contribution of each characteristic is displayed in ( ).

CWD characteristic		WPC	IVS	NFS	BBS	RPC
Number CWD	2006	10	10	6	24	21
	2007	24	16	12	30	27
	Missing	2	1	1	3	4
Position of CWD	Instream	12 (52)	9 (53)	3 (25)	12 (41)	6 (22)
	Marginal	10 (44)	7 (41)	9 (75)	13 (45)	19 (70)
	Bridging	1 (4)	1 (6)	0	4 (14)	2 (8)
CWD class	Complete	-	-	-	1 (4)	-
	Active	14 (61)	14 (88)	8 (67)	22 (74)	14 (52)
	Partial	3 (13)	1 (6)	3 (25)	2 (7)	7 (26)
	High Water	6 (26)	1 (6)	1 (8)	4 (14)	6 (22)
CWD complexity index	1	2 (12)	1 (6)	1 (8)	2 (8)	2 (7)
	2	8 (47)	7 (44)	2 (17)	11 (42)	12 (40)
	3	7 (41)	4 (25)	7 (58)	7 (27)	13 (43)
	4	-	4 (25)	2 (17)	6 (23)	3 (10)

DISCUSSION

Hydraulic and geomorphic composition differed between the study streams. These differences in channel geomorphology may be due to inherent differences between the streams, such as catchment geology, sediment load, stream discharge and gradient, however differences in these primary driving variables were taken into account when study streams were selected. The scouring action of glacial advance and retreat results in the removal of all previous biological and physical features from the stream catchments, effectively creating a 'clean slate' from which a new habitat can develop from, using primary successional processes and current hydraulic regimes to form instream geomorphic features. Stream variables as described in Table 1 do not appear to vary substantially; stream size, gradient and geology are similar across the chronosequence, indicating that inherent differences between the study streams are unlikely. It is therefore proposed that the differences in channel geomorphology within the study streams are due to differences which have occurred as a result of changes in geomorphic composition which result from stream development over time.

Geomorphic complexity did appear to alter as stream age increased. The youngest streams were characterised by large, fast flowing, shallow CGUs such as rapids and riffles, whilst the eldest streams contained smaller, slower flowing CGUs such as glides and pools. Analysis of hydraulic variation using Hydrosignature software revealed an increasing difference in hydraulic characteristics between CGUs as stream age increased. CGU characteristics were also found to alter over the stream chronosequence. Runs, glides and pools became more heterogeneous as stream age difference increased (e.g.- Figure 5). These changes may be driven by changes in coarse woody debris characteristics, which were observed between the streams. CWD within the youngest streams was characterised by small, transient alder boles typically arranged parallel to the flow, with little structural complexity. Older streams, however, contained larger, more complex CWD, often arranged perpendicular to the flow, resulting in increased hydraulic and geomorphic diversity. CWD within the older streams was shown to alter hydraulic variation by altering the position of the thalweg, creating areas of lower velocity upstream and downstream of the structures. Observed differences in CWD characteristics between streams are likely to be due to the differences in adjacent riparian habitat. Riparian vegetation in the youngest streams is characterised by alder and willow scrub on established banks and vegetated islands, whilst the older streams typically contain a mixture of mature cottonwood, spruce and hemlock. These differences in potential CWD recruitment therefore limit the CWD influence within each of the streams. Differences in stream power and sediment loading may also influence CWD permanence and recruitment.

Observed changes in geomorphic and CWD characteristics over the stream chronosequence suggest that the river environment alters as the stream ages, creating habitats beneficial to fish. Deep, slower flowing CGUs characteristic of older streams provide cover and velocity shelters which juvenile and adult fish may utilise, whilst the introduction of CWD creates instream cover and hydraulic variation, which would otherwise be in short supply. These observations support previous work (Lisle, 1986; Inoue and Nakano, 1998) which has found that the introduction of CWD into streams results in the creation of favourable fish habitat, however the observation of the geomorphic changes which occur to streams following deglaciation and the introduction of CWD has helped to quantify how geomorphic complexity develops over time, allowing the identification of those features necessary for the successful colonisation of newly formed streams by salmonids to be assessed.

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