ASSESSMENT OF STREAMFLOW NEEDS FOR SUPPORTING RECREATIONAL WATER USES ON THE CRYSTAL RIVER.

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Summary

This recreational use assessment provides baseline information relating streamflows and recreational boating use. This work supplements previously completed strategic water planning efforts that did not consider impacts of water management and/or climate change on recreational use opportunities on the Crystal River. This report discusses study locations, and methods used to collect and analyze streamflow preference information from recreational users. User survey responses provided by 43 respondents were used to delineate acceptable and optimal streamflow thresholds for supporting recreational use activities on seven segments on the Crystal River (Table ES.1). Threshold identification supported quantification of the Boatable Days metric for each assessment reach across wet and dry hydrological year types. The assessment followed recommendations the State of Colorado's Basin Implementation Plan guidance documents for quantifying non-consumptive recreational needs.

Respondent numbers for the flow preference study conducted in 2020-2021 are robust for a remote or sparsely populated mountain region of western Colorado. The number of responses to flow related questions for most reaches made delineation of flow acceptability thresholds fairly straightforward. There were relatively lower response rates among survey participants (<15 respondents) for Reaches 1, 2, 4, and 7, which may introduce some uncertainty into flow preference thresholds delineated for those sections. Lower response rates may indicate there is less use on these sections during most times of the year. Alternatively, it may indicate that the survey distribution did not reach the typical users of this reach. Future recreational use assessments may benefit from targeted outreach to users known to recreate on these reaches and inquiries into whether or not they have companions or are aware of additional users/groups that recreate at those locations. It may also be useful to explore why some reaches receive less use and whether or not there is opportunity or interest to increase recreational activity through awareness and marketing campaigns, development of river access points, or other means.

Table ES.1. User-defined flow preferences for reaches included in the Boatable Days assessment.

Reach	River	Reach Description	Min. Navigable	Min. Acceptable	Min. Optimal	Max. Optimal	Max. Acceptable
1	Crystal	Crystal Mill Falls to Crystal Gorge	100	300	400	500	2000
2	Crystal	Crystal Gorge	100	225	300	350	450
3	Crystal	Marble to Redstone	100	550	800	2000	3000
4	Crystal	Meatgrinder	100	450	600	900	2250
5	Crystal	The Narrows	100	450	800	1300	3500
6	Crystal	Avalanche Crk to BRB Campground	100	550	800	1900	3500
7	Crystal	BRB Campground to the Roaring Fork	100	500	900	1500	3500

Variable streamflow conditions impact use opportunities on all reaches. The total number of Boatable Days generally increase throughout the assessment area as hydrological conditions transition from dry to wet. However, river segments differed in whether the number of Optimal Boatable Days were highest in wetter years or drier years. Segments with higher numbers of Optimal Boatable Days in drier years generally were highly technical and difficult reaches with

small opportunity windows of optimal flows. Typical daily streamflows rarely exceed the upper flow acceptability threshold on the majority of river segments. However, on the Crystal Gorge segment (Reach 2), the upper limit is exceeded in all year types.As result Boatable Days on this segment generally are only available in the spring and later summer. The majority of Boatable Days at all other segments are in peak flow months of May through July. In drier years at these segments, this seasonal boating window shrinks as there are fewer Boatable Days available in July.

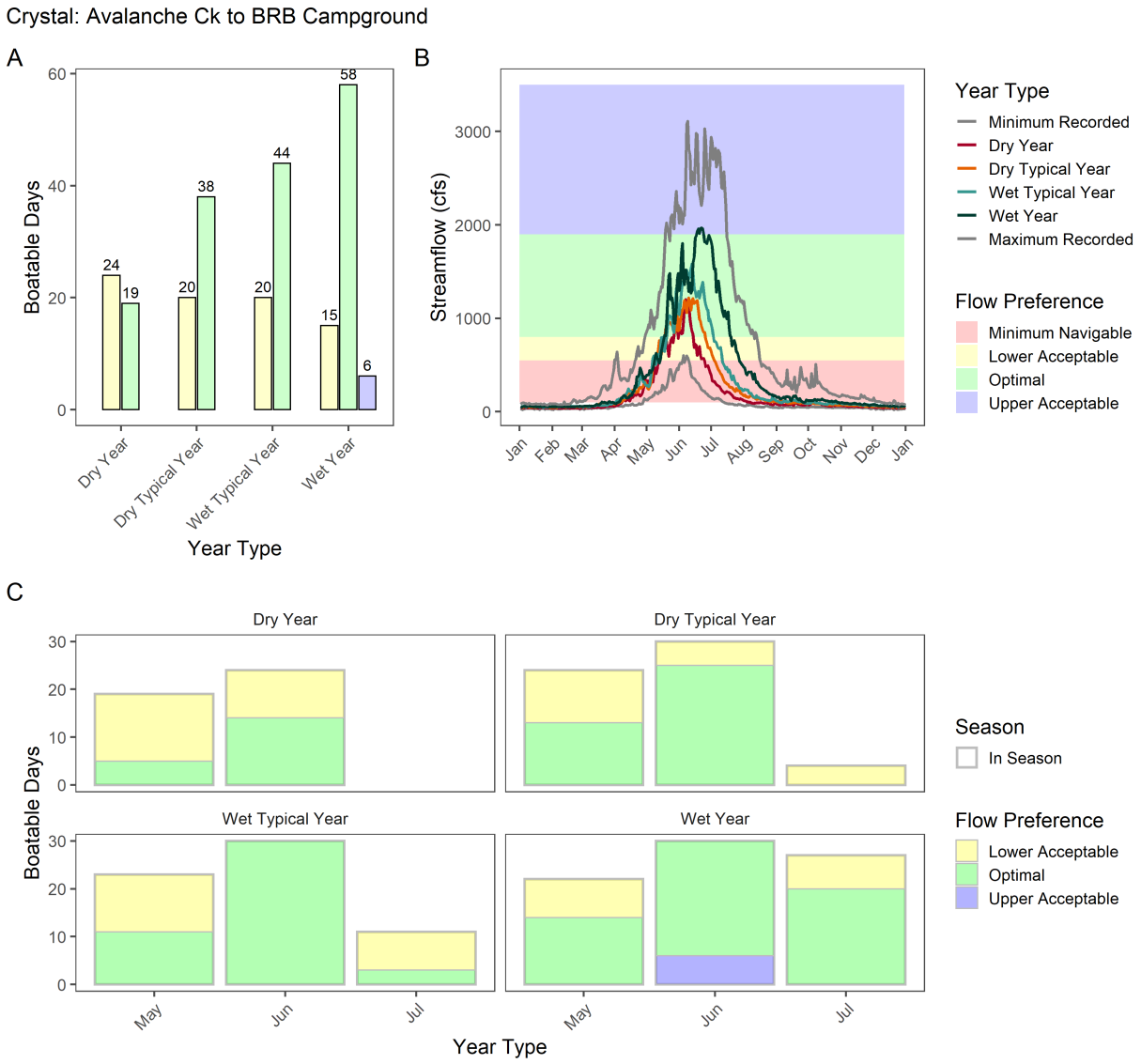

Figure ES.1. Boatable Days totals for the Crystal River: Avalanche Crk to BRB Campground. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.

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1. Introduction

Considerable work evaluating relationships between streamflow and recreational use opportunities occurred over the last several decades (Brown et al., 1991; Shelby, Brown, & Taylor, 1992; Whittaker and Shelby, 2002). Many flow-recreation studies focus on whitewater boating, such as rafting, kayaking, and canoeing, as flow often determines whether people have opportunity to successfully complete a trip. On many river segments, flow level contributes to the risk, challenge, and/or aesthetic attributes of on-water activities (Whittaker & Shelby, 2000). Natural and man-made changes in streamflow can have direct and indirect impacts on recreational boating experiences. Direct effects include navigation, safety/difficulty, travel times, quality of whitewater stretches, and beach and camp access (Brown, Taylor, & Shelby, 1991; Whittaker et al., 1993; Whittaker & Shelby, 2002). Indirectly, variability in streamflow affects wildlife viewing, scenery, fish habitat, and riparian vegetation over the long term as a result of changes in flow regime (Bovey, 1996; Richter et al., 1997; Jackson & Beschta, 1992; Hill et al., 1991).

Streamflow is often manipulated through releases from dams and reservoirs, pipelines, and diversions. Additional scenarios, such as climate change, drought, and new water rights development can all impact flows and recreation quality. Decision-makers within land and resource management and regulatory agencies, and state and local governments are increasingly interested in the extent that flow regimes can be managed to provide desirable recreational resource conditions. The various recreational use opportunities provided by different flow ranges can be delineated into "niches" (Shelby et al., 1997). These flow niches may include: unacceptably low flow; minimum navigable flows, technical, but enjoyable flows; optimal flows; challenging high flows; and unacceptably high flows. Methodologies developed by American Whitewater are regularly used to delineate user-defined streamflow niches and subsequently quantify recreational user opportunities under different hydrological conditions. Implementation of these assessment methodologies aims to support water management decision-making. Specific evaluative information on how flow affects recreation quality is often critical, particularly where social values are central to decision-making (Kennedy and Thomas 1995). American Whitewater's Boatable Days assessment methodology is recognized as a best practice for defining recreation flow needs and opportunities (Stafford et al., 2016).

American Whitewater is currently undertaking a river recreation assessment to supplement completed strategic water planning efforts in the Crystal River watershed. The characterization of Boatable Days provides an objective, science-based measure of existing whitewater recreation opportunities related to variability in streamflow on reaches throughout the assessment area (Figure 1). This information aims to support conversations about how hydrologic conditions impact whitewater recreation opportunities and how these might change under future hydrological conditions and water management scenarios. Boatable Days analysis can further be used to identify opportunities and constraints with implementation of future water projects in the Crystal River watershed.

In addition to meeting objectives of local watershed planning efforts, the results of this assessment advance implementation of the Colorado Water Plan[1]. The State's draft Basin Implementation Plan Guidance document[2] recommends quantification of recreational values (e.g., boating and fishing). Section 2.1 of the Guidance calls for the evaluation of non-consumptive needs in terms of

[1] https://www.colorado.gov/pacific/cowaterplan/plan

[2] http://cwcbweblink.state.co.us/WebLink/0/doc/172522/Electronic.aspx?searchid=da8f2c6c-3efa-48d6-a43e-892b5c2bd750

'measurable outcomes', data, and assessment using methods described in CWCB's Non-consumptive Toolbox (CWCB, 2013). Appendices C and D of the toolbox identify the flow-evaluation methodology developed and used by American Whitewater as an example of a recreation tool that can produce measurable outcomes. This assessment aims to 1) address gaps in data and understanding regarding flow conditions necessary to sustain recreational values on the Crystal river and 2) improve stakeholders' collective understanding of existing recreational use opportunities and how these opportunities may be impacted by climate change and consumptive water projects.

2. Study Area

River reaches considered in this assessment were identified collaboratively between American Whitewater and Lotic Hydrological staff. Seven segments on Crystal River were determined to have significant recreational values and were, therefore, included in the assessment (Table 1). Each segment was mapped to an existing United State Geological Society (USGS) streamflow gauging station. Mapping streamflow gauge locations to each assessment reach considered: 1) the historical period of record (POR) for streamflow observations, 2) the distance between the gauge and river segment, and 3) the gauge most commonly used by recreationalists to inform their use of the segment. Stream gauges are sparse on the Crystal River. As a result, a single stream gauge was used to represent flows for all river segments. Flow thresholds used in the Boatable Days analysis correspond to streamflow at the single gauge and may not always reflect accurate streamflow levels at the reach.

Table 1. River segments and corresponding streamflow measurement gauges considered in this study.

Reach	River	Reach Description	USGS Gage ID	USGS Gage Description
1	Crystal	Crystal Mill Falls to Crystal Gorge	09081600	Crystal River Abv Avalanche Crk, Near Redstone
2	Crystal	Crystal Gorge	09081600	Crystal River Abv Avalanche Crk, Near Redstone
3	Crystal	Marble to Redstone	09081600	Crystal River Abv Avalanche Crk, Near Redstone
4	Crystal	Meatgrinder	09081600	Crystal River Abv Avalanche Crk, Near Redstone
5	Crystal	The Narrows	09081600	Crystal River Abv Avalanche Crk, Near Redstone
6	Crystal	Avalanche Ck to BRB Campground	09081600	Crystal River Abv Avalanche Crk, Near Redstone
7	Crystal	BRB Campground to the Roaring Fork	09081600	Crystal River Abv Avalanche Crk, Near Redstone

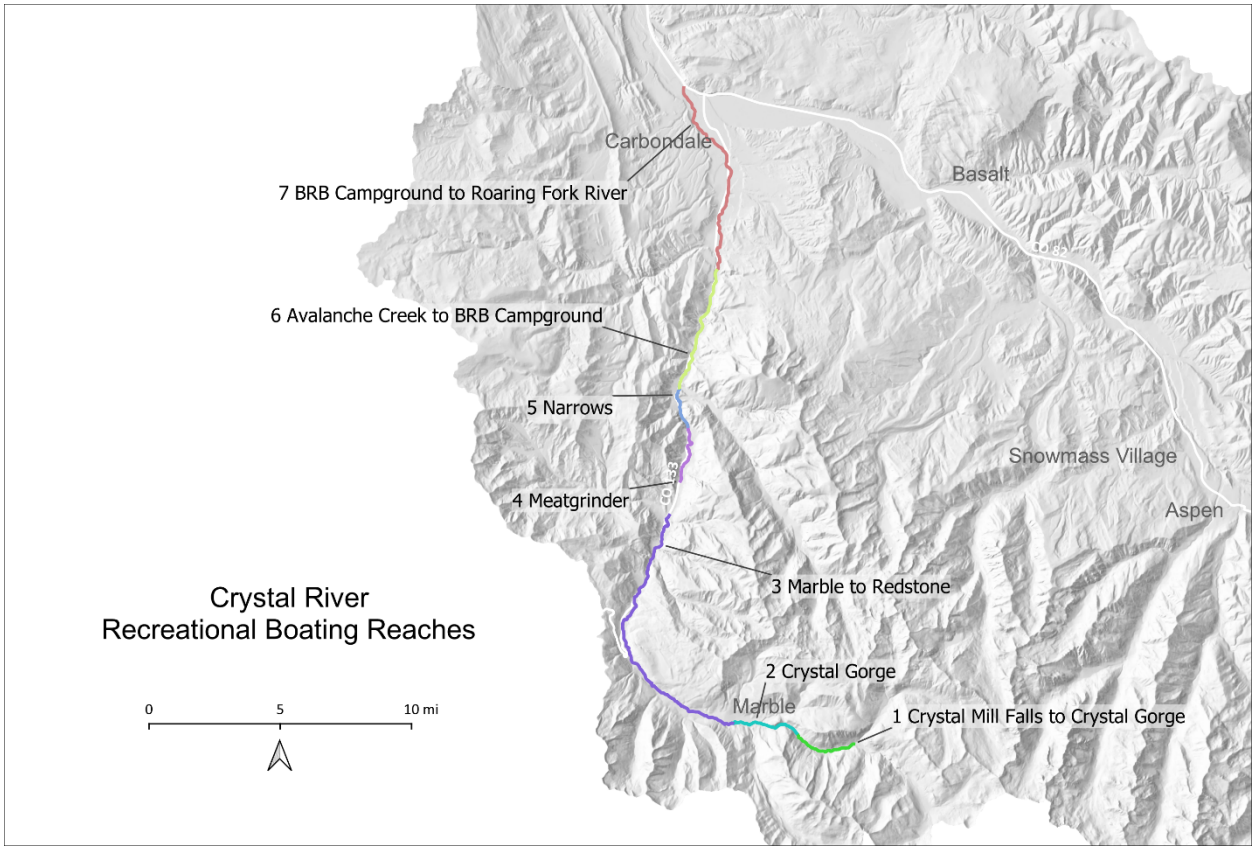

Figure 1: Crystal River Recreational Assessment Map.

3. Methods

American Whitewater collected recreational user feedback through a web-based survey (Appendix B). Three types of questions were included in the survey. The first type of question captured demographic information about each participant's skill level, frequency of participation in river-related recreation, etc. The second type of question allowed users to assign use-acceptability rankings to various streamflows. The third question type asked users to identify flows associated with different trip types (technical low-water, standard, challenging high-flow, etc.). These questions were organized around each assessment reach and were supported with general mapping and narrative information about that reach from American Whitewater's website. The survey also clearly defined which streamflow measurement gauge to reference when assigning acceptability rankings for conditions on the reach. An announcement of the survey was emailed to American Whitewater's members, posted on the website and distributed via American Whitewater's online newsletter.

The flow acceptability questions included in the user-survey are the principal focus of this assessment. These questions asked respondents to evaluate recreational use acceptability for a range of measured flows on each study segment using a five-point scale that included the following rankings: Unacceptable, Moderately Unacceptable, Marginal, Moderately Acceptable, and Acceptable. Each ranking in the scale was mapped to an integer value between -2 and 2 where an

'Unacceptable' ranking mapped to a value of -2, a 'Marginal' ranking mapped to a value of 0, and an 'Acceptable' ranking mapped to a value of 2. To further explore and characterize the relationship between flows and recreational use opportunities, the survey posed a series of open-ended questions about streamflows associated with distinct niche experiences. These niche experiences included: lowest navigable flow (minFlow), minimum acceptable flow (lowAcceptable), technical but navigable flows (technicalTrip), flows experienced during a standard trip (standardTrip), challenging high-water (highChallenge), and highest safe flow (highSafe).

The flow options provided in the flow acceptability questions were directly informed by historical hydrology data from each individual stream gauge. Both the minimum flow option and the maximum flow option were informed by historical minimums and maximums.

Flow-acceptability rankings provided through the survey were used to describe preferences among recreational users for various ranges of streamflow. Researchers collecting and organizing survey-based evaluative information often employ a normative approach for analyzing results. The normative approach considers each individual's evaluation (personal norms) of a range of potential conditions. Aggregation of many individuals' personal norms describe a group's collective evaluation (social norms) of resource condition. This approach has been applied extensively in natural resource management settings, often with respect to instream flows for recreation (Shelby and Whittaker, 1995; Shelby et al., 1992a; Vandas et al., 1990; Whittaker and Shelby, 2002b) and is particularly useful for developing thresholds that define low, acceptable, and/or optimal resource conditions (Shelby et al. 1992). Other applications have extended this approach to different indicators and impacts, including: evaluation of how many people are considered too many in a given setting (refer to Donnelly et al., 2000; Manning, 2011; Shelby et al., 1996; Vaske & Donnelly, 2002; Vaske et al., 1986, for reviews), campsite impacts or site sharing (Heberlein and Dunwiddie, 1979; Shelby, 1981), fishing site competition (Martinson and Shelby, 1992; Whittaker and Shelby, 1993), discourteous behavior (Whittaker and Shelby, 1988, 1993; Whittaker et al., 2000), and resource indicators such as litter and campsite impacts (Shelby et al., 1988; Vaske et al., 2002). Notably, the normative approach was employed to understand user preferences for various streamflows on the Grand Canyon (Shelby et al. 1992) and on several other rivers in Colorado (Vandas et al. 1990, Shelby & Whittaker 1995, Fey & Stafford 2009, Fey & Stafford 2010).

Defining management standards is often more efficient if there is a high degree of consensus (or "norm crystallization") among users regarding acceptable and unacceptable resource conditions. Traditional measures of norm crystallization have included the standard deviation, coefficient of variation, and interquartile range of survey responses (Krymkowski et al., 2009; Manning, 2011; Shelby and Vaske, 1991). The Potential for Conflict Index-2 (PCI2) was developed to help address some of the shortcomings associated with traditional measures of norm crystallization when applied to ordinal data. A detailed description of the PCI2 metric is provided by Vaske et al. (2010). Briefly, computed PCI2 values range from 0 to 1.0 where the least amount of consensus (PCI2 = 1.0) occurs when responses are equally divided between two extreme values on a Likert response scale (e.g. 50% Highly Unacceptable and 50% Highly Acceptable). A set of responses with unanimous consensus among respondents yields a PCI2 value of zero.

The normative approach was the basis for describing use acceptability ranges for streamflows on different reaches within the assessment area. The numerical representations of flow acceptability preference rankings were used to compute PCI2 scores for each flow included in the survey. The central tendency of survey responses was computed as the mean value of the flow acceptability preference ranking for each streamflow on each reach. Computed PCI2 values were plotted against the central tendency of survey responses to create use acceptability curves for each of the study reaches.

Use acceptability curves, tabular data summaries, and responses to open-ended questions about niche conditions were used to delineate various normative streamflow characteristics. These characteristics included a minimum acceptable streamflow, a range of acceptable streamflow conditions, and a range of optimum streamflow conditions. The upper and lower thresholds delineated for acceptable, optimal and minimum navigable streamflow conditions were then compared under Wet, Wet Typical, Dry Typical, and Dry hydrological conditions in order to complete a Boatable Days analysis.

The computation of Boatable Days is the dominant quantitative approach used by American Whitewater to characterize recreational use opportunities on rivers (Fey and Stafford, 2009; Shelby and Whittaker, 1995; Whittaker et al., 1993). The metric itself reflects the number of days in a given year that fall within certain defined flow ranges (i.e., lower acceptable flows, optimal flows, upper acceptable flows). The Boatable Days analysis performed on reaches within the assessment area responded to the inter-annual natural and management-induced variability in streamflows by computing the number of Boatable Days that occur in each of four hydrological year types: Wet, Wet Typical, Dry Typical, and Dry.

Representative streamflow time series for the four year-types on each reach required synthesis of historical USGS streamflow data. Daily streamflow data was collected from a single streamflow gauge on the Crystal River throughout the assessment area for a 34-year period (1986 – 2020). Only a single gauge was used due to limited gauging on the Crystal River. Streamflow time series data from the gauge were then ordered by annual peak flow. Average daily streamflows across all years in the lower 25th percentile of the ordered list were computed to produce a representative dry year streamflow time series. The same approach was used to create representative streamflow series for dry typical years, wet typical years and wet years where dry typical years fell between the 25th and 50th percentiles of annual peak flows, wet typical years fell between the 50th and 75th percentiles of annual peak flows, and wet year types were those years that fell above the 75th percentile of the ordered list.

4. Results

The web-survey captured completed responses from 43 recreational users. Survey respondents were generally very experienced boaters. 84% of respondents indicated they were somewhat comfortable or very comfortable reporting flows, 91% of respondents identified themselves as advanced or expert paddlers, 100% identified as Class III or greater paddlers, and 61% recreate on the Crystal River at least 5 days per season (Figure 2). The majority of respondents indicated their preferred craft types on Crystal River segments were kayaks (66%) or rafts (26%) while a minority indicated other crafts, including inflatable kayaks/rafts (6%) and canoes (2%).

Survey responses were aggregated by reach, reviewed for quality, and displayed graphically to aid in interpretation (Appendix A). Example summary graphics are included for survey responses for the Avalanche Crk to BRB Campground section of the Crystal River (Figure 3).

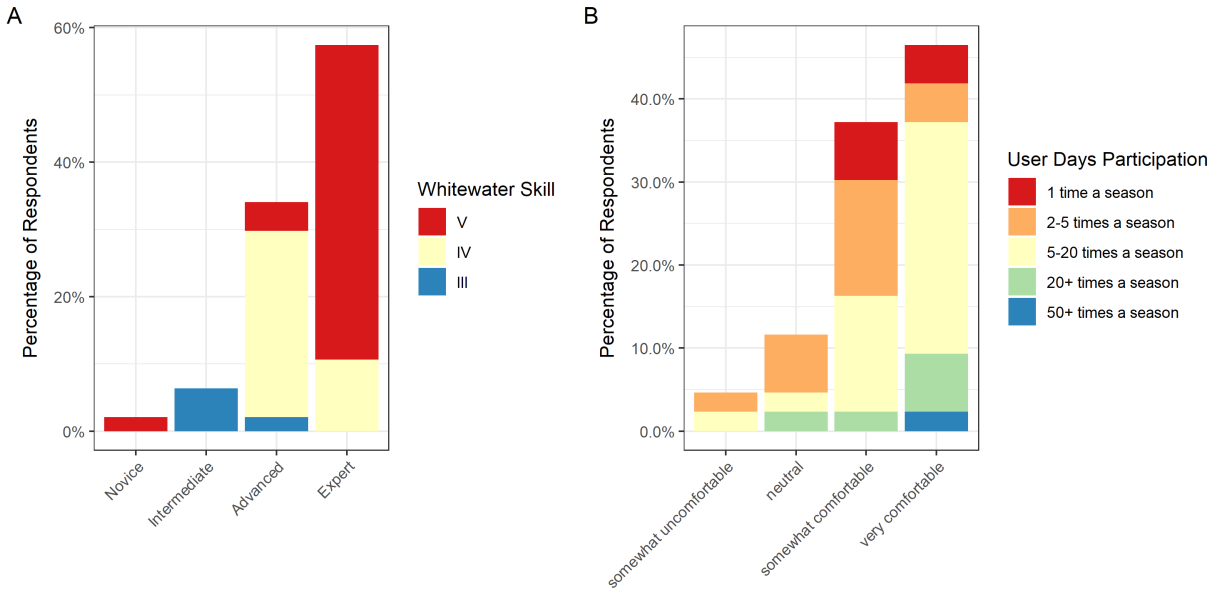

Figure 2: Survey responses from 43 users indicating (A) experience level and maximum comfortable whitewater class; (B) participant confidence in providing flow acceptability rankings for one or more reaches in the assessment area.

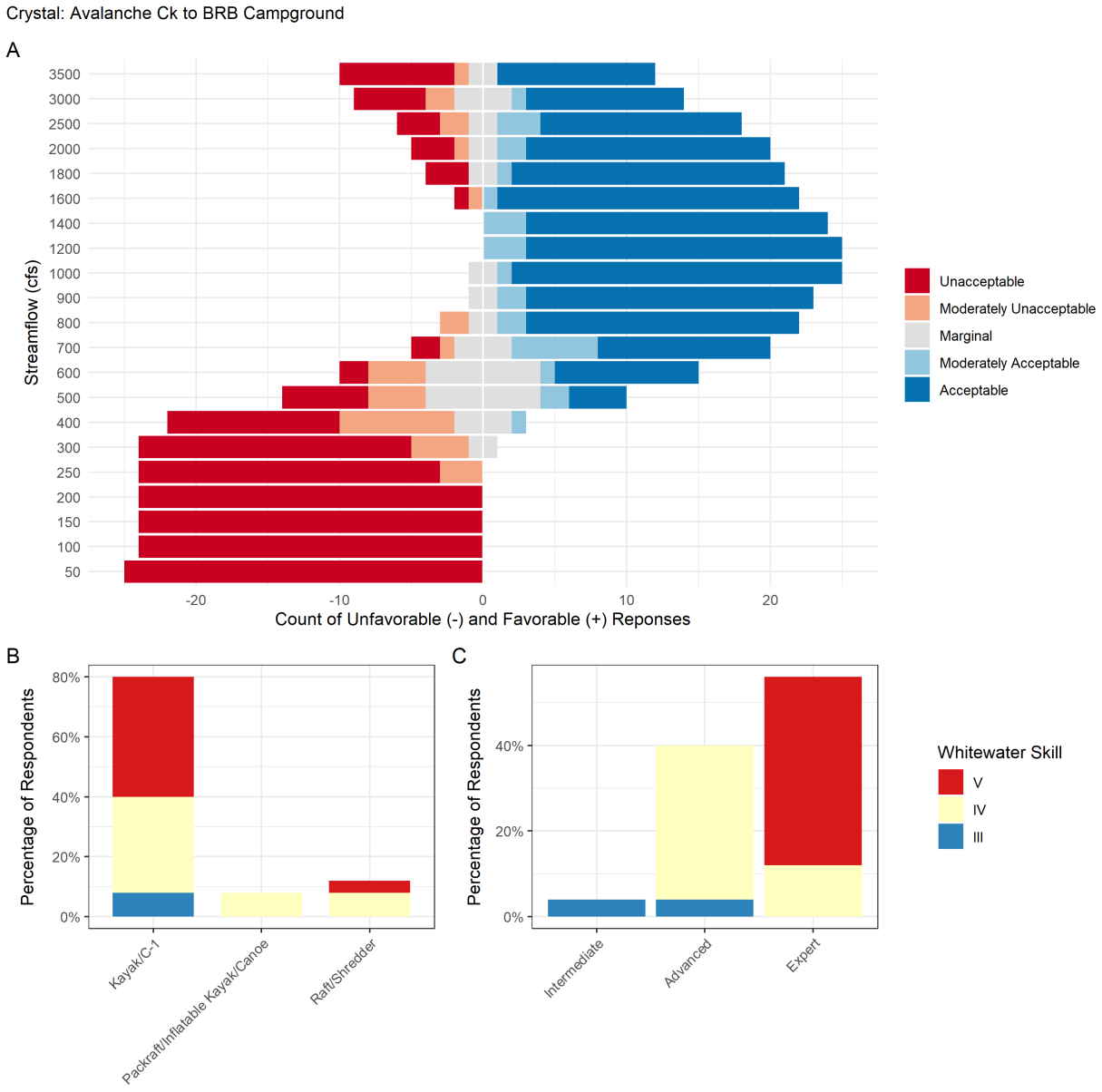

Figure 3: Survey responses for the Avalanche Crk to BRB Campground section of the Crystal River. (A) Counts of the various flow acceptability rankings provided by respondents where survey responses reflect streamflow variability as measured at the Crystal River Abv Avalanche Crk, Near Redstone (USGS Station ID: 09081600). (B) User identified craft types and whitewater skill level for the reach. (C) The self-identified experience and whitewater skill levels provided by survey respondents.

Use acceptability curves, tabular data summaries, and responses to open-ended questions about niche conditions were used to delineate various normative streamflow characteristics, including the 'Minimum Acceptable', 'Minimum Optimal', 'Maximum Optimal', and 'Maximum Acceptable' streamflow on each reach (Table 2). An example graphic of use acceptability curves and delineated flow preferences from is included the Avalanche Crk to BRB Campground section of the Crystal River (Figure 4).

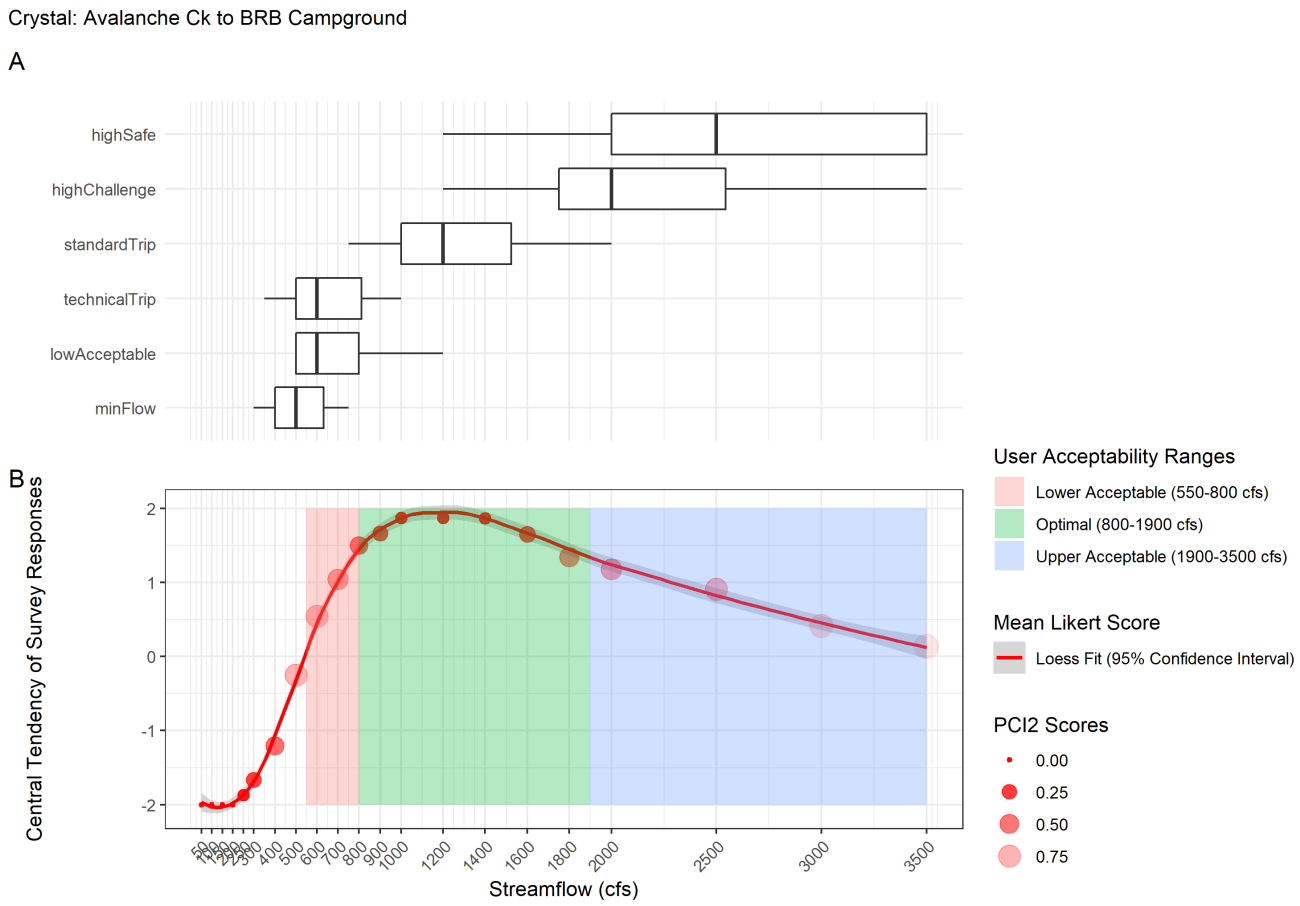

Figure 4: Flow preferences reported by users for the Crystal River: Avalanche Crk to BRB Campground. A) Boxplot of responses to open-ended questions about different categories of flow. B) PCI2 analysis results plotted against the central tendency of flow acceptability preference rankings at each flow category. A Loess curve was fit to support visualization of flow acceptability ranges.

Table 2. Flow preference thresholds delineated for each reach in the assessment area. All values are reported in cubic feet per second (cfs).

Reach	River	Reach Description	Min. Navigable	Min. Acceptable	Min. Optimal	Max. Optimal	Max. Acceptable
1	Crystal	Crystal Mill Falls to Crystal Gorge	100	300	400	500	2000
2	Crystal	Crystal Gorge	100	225	300	350	450
3	Crystal	Marble to Redstone	100	550	800	2000	3000
4	Crystal	Meatgrinder	100	450	600	900	2250
5	Crystal	The Narrows	100	450	800	1300	3500
6	Crystal	Avalanche Crk to BRB Campground	100	550	800	1900	3500
7	Crystal	BRB Campground to the Roaring Fork	100	500	900	1500	3500

Use acceptability curves from some reaches did not indicate an upper bound for the maximum acceptable flow. The upper bound was therefore estimated at some reaches as being above the streamflow categories on the survey. Responses to open ended questions suggest that navigation hazards due to bridges can increase at high flow at some segments but the risk may depend also the type of craft used. Further work may be needed to assess these navigation hazards to better constrain the upper bound of acceptable flows for differing crafts.

The advanced and expert skill levels reported among the majority of survey participants may be the primary reason that use acceptability curves fail to indicate an upper bound for desirable recreational flows. It is, therefore, most appropriate to view survey responses within the context of the user groups that participated in the survey. The upper flow acceptability thresholds delineated for reaches in the assessment area are, probably, most relevant to advanced and expert users and are not likely appropriate for novice or intermediate users. Additionally, novices or intermediate users often have not yet developed sufficient river and boating knowledge to understand what flows may constitute an upper safe level for themselves or other users at their level, further making the quantification of consensus upper limits difficult to completely resolve.

Streamflows preferred by users generally were lower on upstream segments and increased on downstream segments of the Crystal River. The Crystal Gorge segment (Reach 2) had distinctly lower thresholds from other reaches due to its steep, highly technical morpohology. Overall variability in flow thresholds between reaches also can be attributed to different user groups recreating in different locations, the unique geomorphic or hydraulic characteristics of each reach, and/or variability in the sample size of respondents providing flow rankings on each reach and for each listed streamflow.

Flow preference thresholds were used to compute the number of Boatable Days associated with different hydrological conditions on each reach in the assessment area (Table 3). The total number of Boatable Days generally increase throughout the assessment area as hydrological conditions transition from dry to wet. The response of Optimal Boatable Days to hydrologic year types was variable. The number of Optimal Boating Days at several segments (Reaches 3, 6, & 7) was highest on river segments either during Wet or Wet Typical years. However at other segments (Reaches 2, 4, & 5), the number of Optimal Boating Days were highest in Dry or Dry Typical years. On these segments, during wetter years, peak flows had longer durations that were in the Upper Acceptable category or in the case of Crystal Gorge, exceeded the Upper Acceptable limit. On two segments on the upper Crystal River (Reaches 1-2), the window for Optimal boating conditions was relatively small with the number of Optimal Days never exceeding 10-15 days across all year types.

On most segments, boatable days were mostly confined to peak flow season between May and July. At these segments, the boating window generally shrunk during drier years with fewer Boatable Days in July. At Crystal Gorge, where peak flows are above the upper limit, few to no boatable days were observed in June for all year types and were also not present in July in Wet years.

It is important to note the difference between a Boatable Day and a user-day. A Boatable Day describes when acceptable flows are met to provide an *opportunity* for recreation. User-days indicate the actual numbers of known recreational users present on a reach over a period of time. User-days are affected by numerous factors including weather, hazards, river access, etc. while Boatable Days are solely affected by flow conditions. When using the Boatable Days analysis results to inform management decisions it will be particularly useful to consider the monthly Boatable Days totals during the typical user-season rather than the annual totals. While no Boatable Days were observed in the winter months, especially at higher elevations, ice has potential to impact user days during the shoulder seasons.

Table 3. Boatable Days falling within each acceptability category calculated for reaches within the assessment area for dry, dry typical, wet typical and wet hydrological year types.

Reach	Reach Description	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
1	Crystal Mill Falls to Crystal Gorge	Lower Acceptable	12	9	13	16
		Optimal	9	4	7	15
		Upper Acceptable	45	61	68	84
		Total Days	66	74	88	115
2	Crystal Gorge	Lower Acceptable	9	23	20	9
		Optimal	11	6	8	3
		Upper Acceptable	5	6	8	23
		Total Days	25	35	36	35
3	Marble to Redstone	Lower Acceptable	24	20	20	15
		Optimal	19	38	44	64
		Total Days	43	58	64	79
4	Meatgrinder	Lower Acceptable	12	9	12	15
		Optimal	27	24	20	14
		Upper Acceptable	11	29	40	60
		Total Days	50	62	72	89
5	The Narrows	Lower Acceptable	31	24	28	25
		Optimal	19	38	28	27
		Upper Acceptable	0	0	16	37
		Total Days	50	62	72	89
6	Avalanche Ck to BRB Campground	Lower Acceptable	24	20	20	15
		Optimal	19	38	44	58
		Upper Acceptable	0	0	0	6
		Total Days	43	58	64	79
7	BRB Campground to the Roaring Fork	Lower Acceptable	34	32	28	24
		Optimal	11	29	37	35
		Upper Acceptable	0	0	3	25
		Total Days	45	61	68	84

Table 4. Boatable Days analysis results broken out by month for the Crystal River: Avalanche Crk to BRB Campground. Where an Acceptability Category (e.g. 'Optimal') is missing for a given month, zero days were observed to fall within that category and the row was left out of the table for brevity.

Month	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
May	Lower Acceptable	14	11	12	8
	Optimal	5	13	11	14
	Total Days	19	24	23	22
Jun	Lower Acceptable	10	5	0	0
	Optimal	14	25	30	24
	Upper Acceptable	0	0	0	6
	Total Days	24	30	30	30
Jul	Lower Acceptable	0	4	8	7
	Optimal	0	0	3	20
	Total Days	0	4	11	27

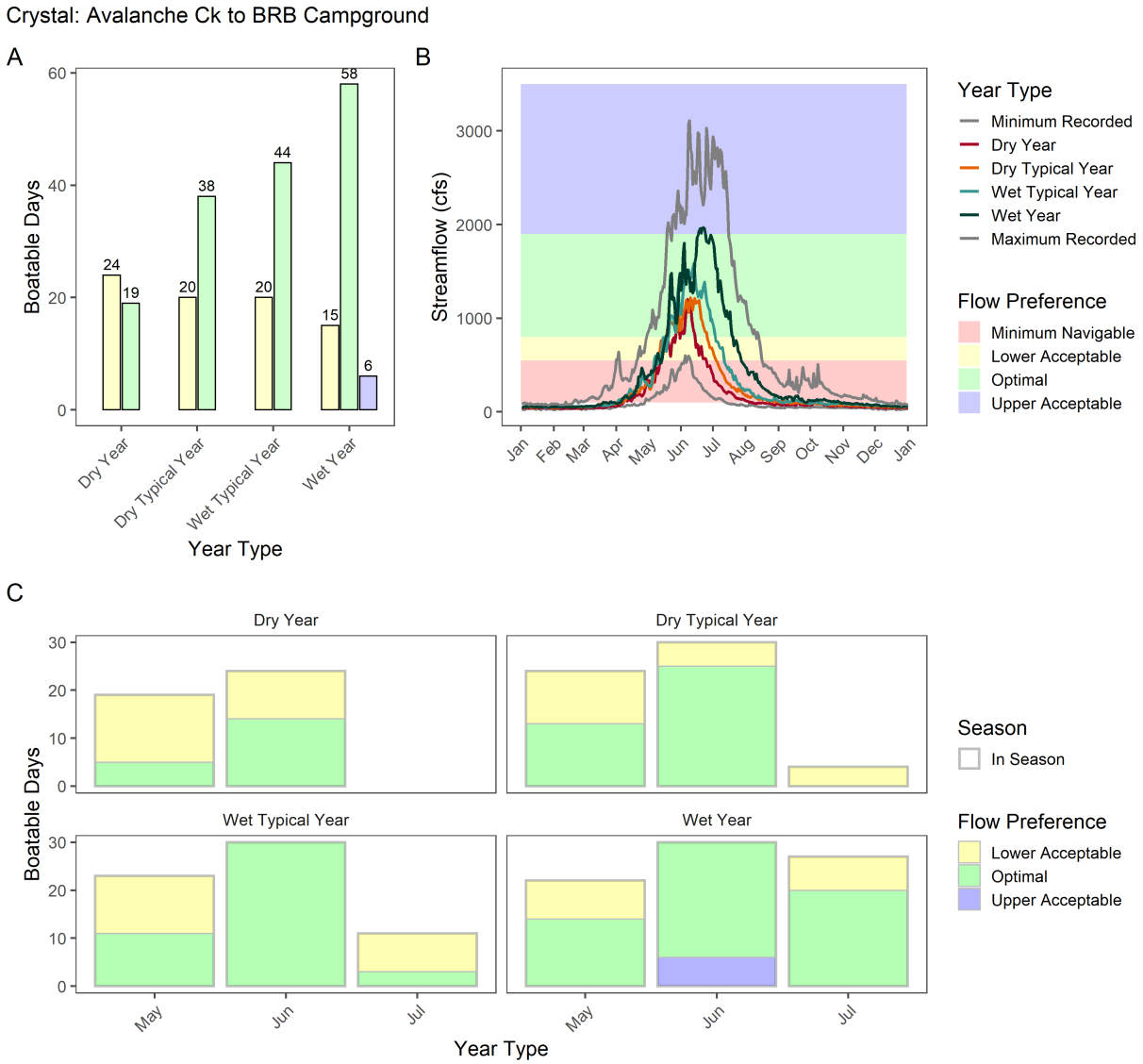

Figure 5: Boatable Days totals for the Crystal River: Avalanche Crk to BRB Campground. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.

5. Discussion and Conclusions

This report discusses study locations, and methods used to collect and analyze streamflow preference information from recreational river users. User survey responses provided by 43 respondents were used to delineate acceptable and optimal streamflow thresholds for supporting recreational use activities on 7 segments on the Crystal River. Threshold identification supported

quantification of the Boatable Days metric for each assessment reach under typical wet, average, and dry hydrological year types. The assessment followed recommendations in the State of Colorado's Basin Implementation Plan guidance documents for quantifying non-consumptive recreational needs.

Respondent numbers for the flow preference study conducted in 2020-2021 are robust for a remote or sparsely populated mountain region of Colorado. The number of responses to flow related questions for most reaches made delineation of flow acceptability thresholds fairly straightforward. However, lower response rates among survey participants for several reaches including Reaches 1, 2, 4, & 7 may introduce some uncertainty into flow preference threshold delineated for those sections. Lower response rates may indicate there is less use on these sections during most times of the year. Alternatively, it may indicate that the survey distribution did not reach the typical users of this reach. Future recreational use assessment activities may benefit from targeted outreach to those users known to recreate on this reach and inquiries into whether or not they have companions or are aware of additional users/groups that recreate at those locations (i.e., 'snowball' or referral sampling methods). It may also be useful to ascertain why this reach may be receiving less use and whether or not there is opportunity or interest to increase recreational activity through awareness campaigns, development of river access points, or through some other means.

Variable streamflow conditions impact use opportunities on all reaches. The total number of Boatable Days generally increase throughout the assessment area as hydrological conditions transition from dry to wet. However, segments differed in whether numbers of Optimal Boatable Days were highest in wetter years or drier years. Segments with higher numbers of Optimal Boatable Days in drier years generally were highly technical reaches that have relatively small flow preference ranges for Optimal conditions. On most reaches, typical daily streamflows rarely exceed the upper flow acceptability threshold. However on the Crystal Gorge segment (Reach 2), that upper limit is exceeded in all year types. As a result, the number of Boatable Days on this segment generally are only in the spring and later summer. The majority of Boatable Days at all other segments are in peak flow months of May through July. In drier years at these segments, Boatable Days are generally lower or not available in July.

The results presented in this report represent baseline information characterizing the relationships between flows and recreational use. As such, this body of work supplements complete strategic water planning efforts in the Crystal River watershed. Future efforts may choose to build upon this assessment by calculating the number of Boatable Days available in a greater diversity of hydrological year types, by different user groups or in anticipation of altered future hydrology due to changes water management and climate change.

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APPENDIX A: Analysis Results by Reach

Crystal River: Crystal Mills Falls to Crystal Gorge (Reach 1)

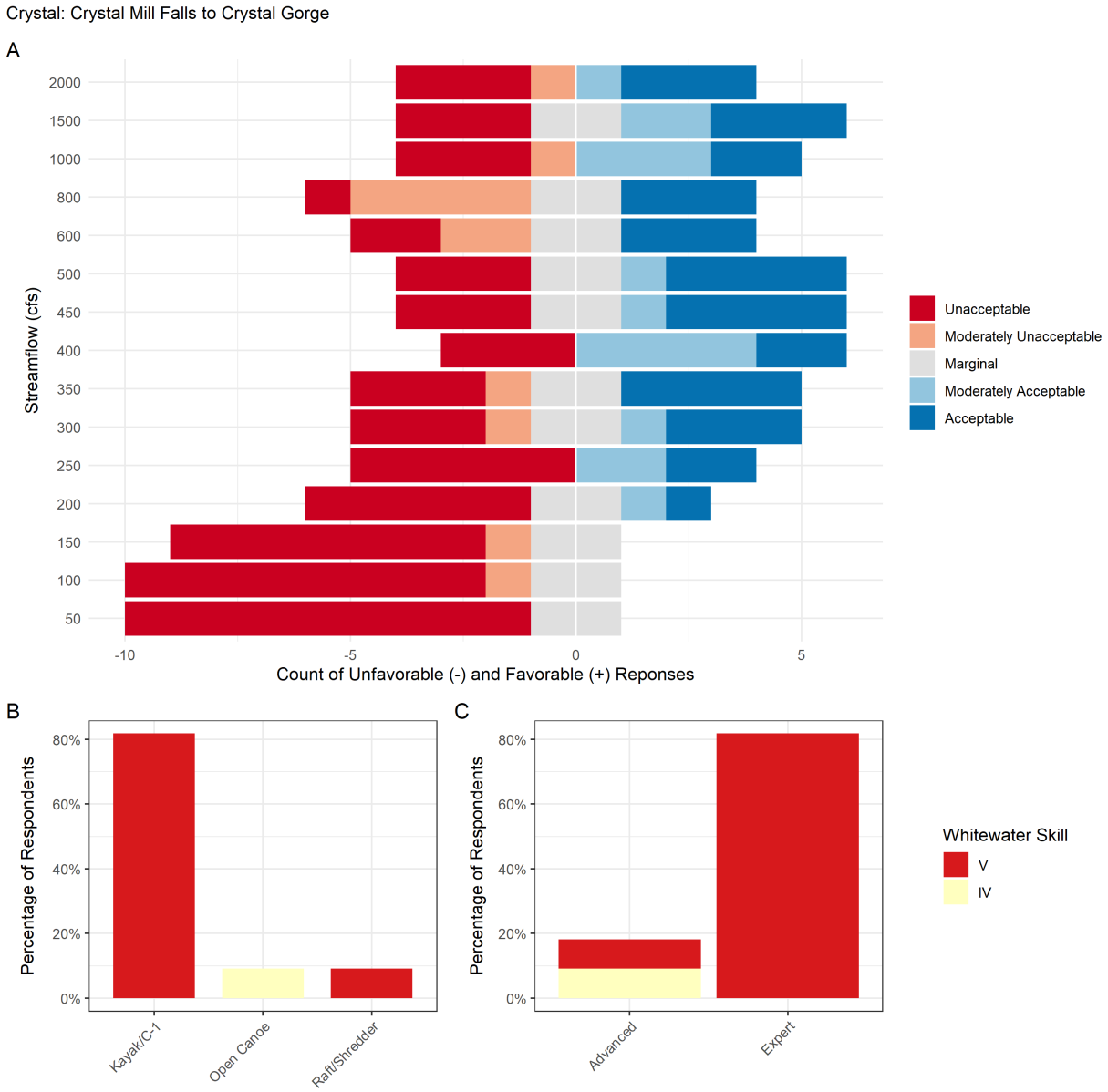
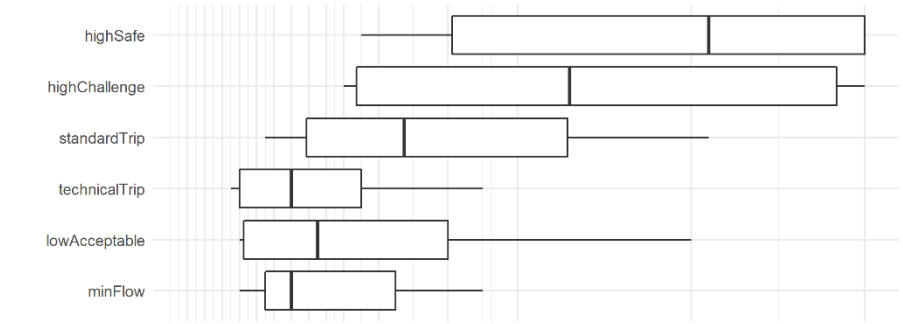


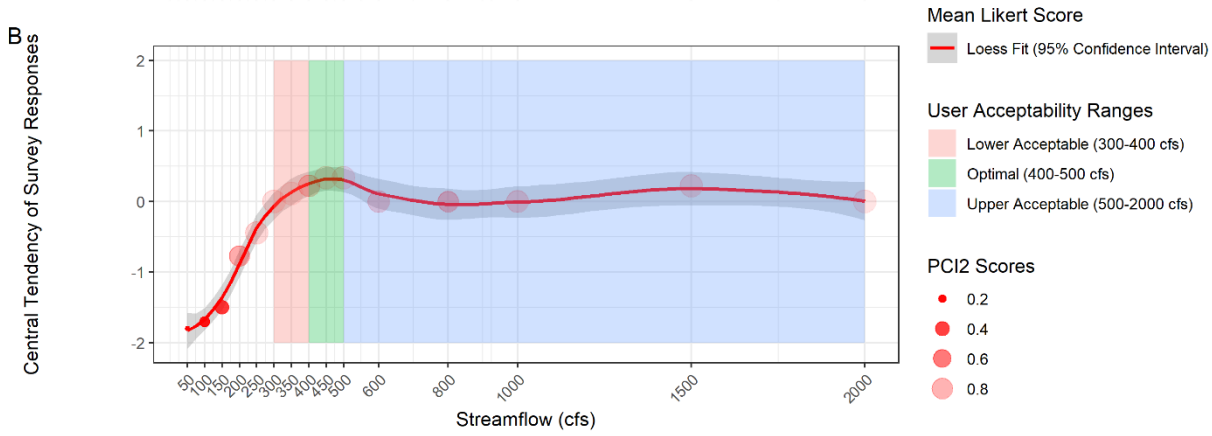
Figure 1: Survey responses for Crystal River: Crystal Mills Falls to Crystal Gorge. (A) Flow acceptability rankings. (B) User identified preferred craft types and whitewater skill level. (C) User identified expertise and whitewater skill level.

Crystal: Crystal Mill Falls to Crystal Gorge

A



B



C

Survey Question	25th Percentile	Median Response	75th Percentile	Response Count
Minimum Flow (cfs)	275	350	650	11
Low Acceptable Flow (cfs)	212	425	800	11
Technical Flow (cfs)	200	350	550	11
Standard Trip Flow (cfs)	394	675	1144	10
Challenging High Flow (cfs)	538	1150	1919	10
Highest Safe Flow (cfs)	812	1550	2000	10

Figure 2: Flow preferences reported by users for Crystal River: Crystal Mills Falls to Crystal Gorge. A) Boxplot of responses to open-ended questions about different categories of flow. B) PCI2 analysis results plotted against the central tendency of flow acceptability preference rankings at each flow category. Loess curve was fit to support visualization of flow acceptability ranges. C) Summarized open-format flow-preference question responses.

Table 1: PCI2 analysis results for Crystal River: Crystal Mills Falls to Crystal Gorge.

Flow (cfs)	Median Likert Response	n	Max. Distance	Total Distance
50	-1.80	10	200	36
100	-1.70	10	200	50
150	-1.50	10	200	74
200	-0.78	9	160	124
250	-0.44	9	160	148
300	0.00	9	160	152
350	0.11	9	160	156
400	0.22	9	160	136
450	0.33	9	160	152
500	0.33	9	160	152
600	0.00	9	160	140
800	0.00	9	160	128
1000	0.00	9	160	144
1500	0.22	9	160	148
2000	0.00	8	128	124

Table 2: Boatable Days analysis results broken out by month for the Crystal River: Crystal Mills Falls to Crystal Gorge. Where an Acceptability Category (e.g. 'Optimal') is missing for a given month, zero days were observed to fall within that category and the row was left out of the table for brevity.

Month	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
Apr	Lower Acceptable	1	2	6	7
	Optimal	0	0	0	2
	Total Days	1	2	6	9
May	Lower Acceptable	6	2	1	3
	Optimal	4	0	1	4
	Upper Acceptable	20	25	25	24
	Total Days	30	27	27	31
Jun	Optimal	5	0	0	0
	Upper Acceptable	25	30	30	30
	Total Days	30	30	30	30
Jul	Lower Acceptable	5	5	6	0
	Optimal	0	4	6	1
	Upper Acceptable	0	6	13	30
	Total Days	5	15	25	31
Aug	Lower Acceptable	0	0	0	6
	Optimal	0	0	0	8
	Total Days	0	0	0	14

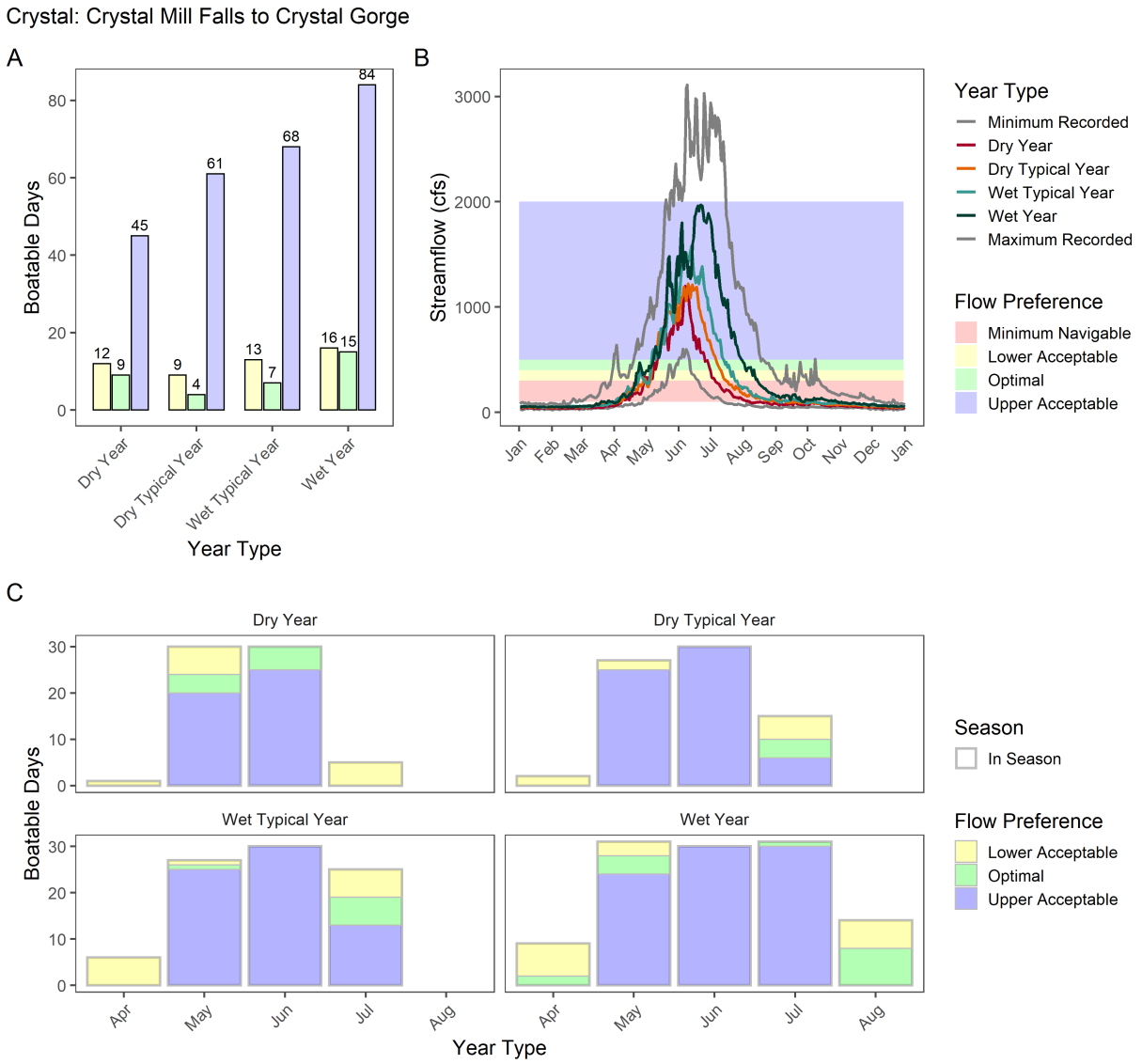


Figure 3: Boatable Days analysis results for the Crystal River: Crystal Mills Falls to Crystal Gorge. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.

Crystal River: Crystal Gorge (Reach 2)

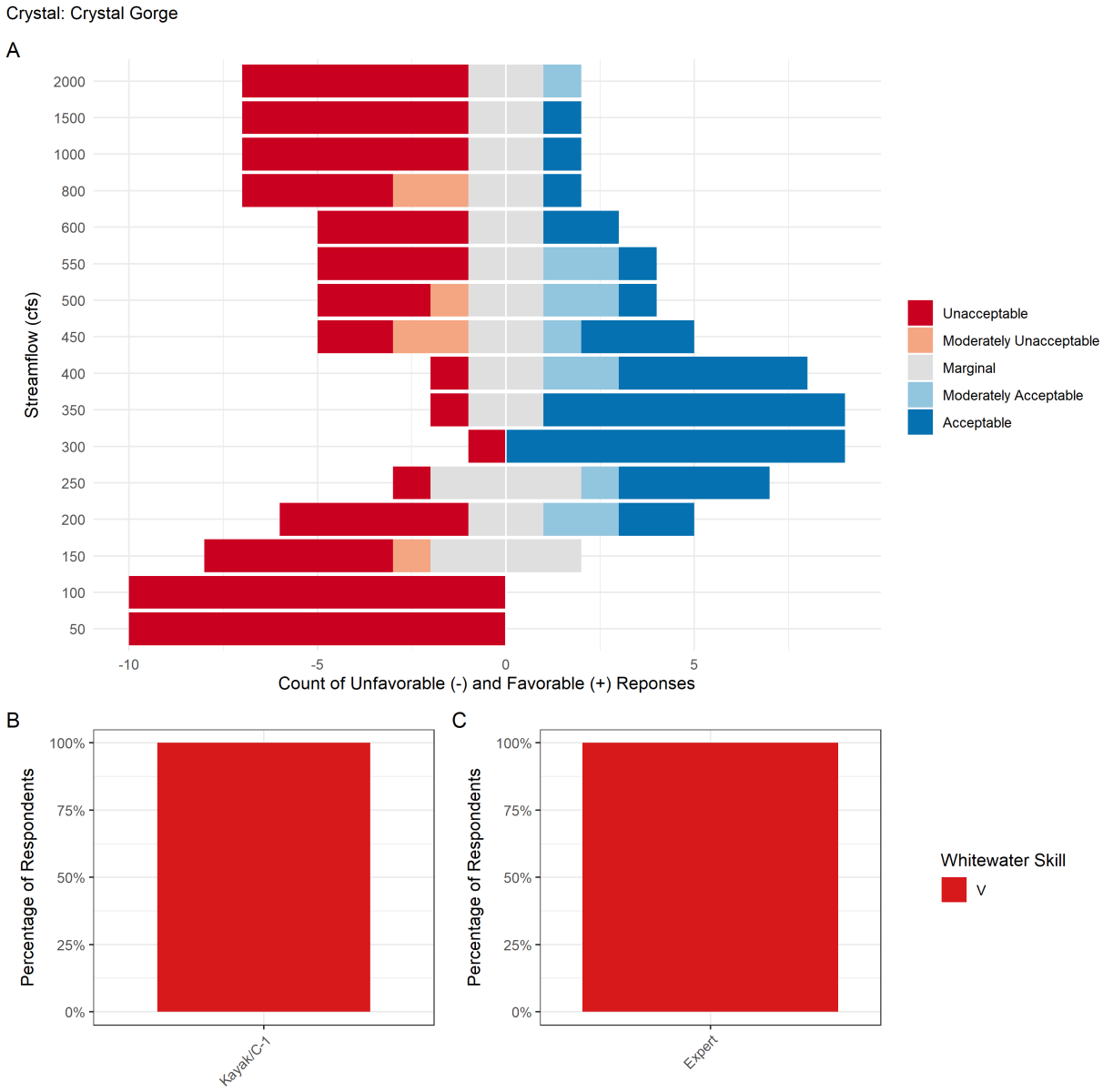
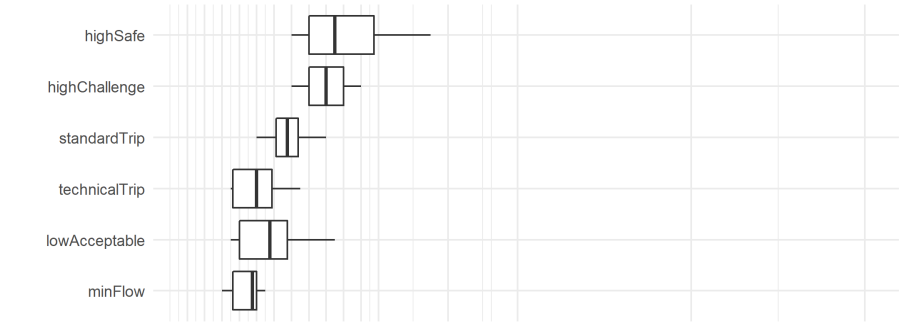


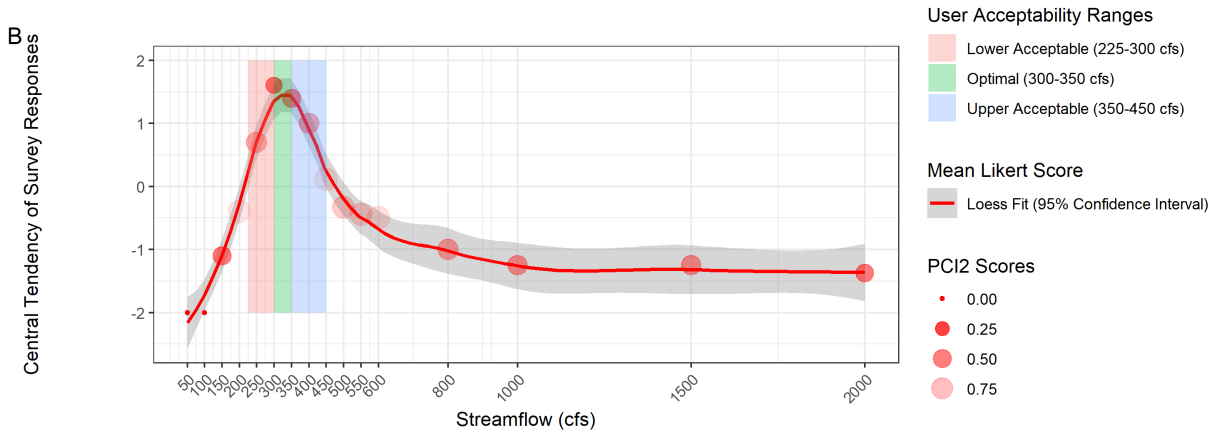
Figure 4: Survey responses for Crystal River: Crystal Gorge. (A) Flow acceptability rankings. (B) User identified preferred craft types and whitewater skill level. (C) User identified expertise and whitewater skill level.

Crystal: Crystal Gorge

A



B



C

Survey Question	25th Percentile	Median Response	75th Percentile	Response Count
Minimum Flow (cfs)	181	238	250	10
Low Acceptable Flow (cfs)	200	288	338	10
Technical Flow (cfs)	181	250	294	10
Standard Trip Flow (cfs)	306	338	369	10
Challenging High Flow (cfs)	400	450	500	10
Highest Safe Flow (cfs)	400	475	588	10

Figure 5: Flow preferences reported by users for Crystal River: Crystal Gorge. A) Boxplot of responses to open-ended questions about different categories of flow. B) PCI2 analysis results plotted against the central tendency of flow acceptability preference rankings at each flow category. Loess curve was fit to support visualization of flow acceptability ranges. C) Summarized open-format flow-preference question responses.

Table 3: PCI2 analysis results for Crystal River: Crystal Gorge.

Flow (cfs)	Median Likert Response	n	Max. Distance	Total Distance
50	-2.00	10	200	0
100	-2.00	10	200	0
150	-1.10	10	200	98
200	-0.40	10	200	180
250	0.70	10	200	134
300	1.60	10	200	72
350	1.40	10	200	100
400	1.00	10	200	128
450	0.11	9	160	144
500	-0.33	9	160	128
550	-0.44	9	160	132
600	-0.50	8	128	112
800	-1.00	8	128	84
1000	-1.25	8	128	76
1500	-1.25	8	128	76
2000	-1.38	8	128	62

Table 4: Boatable Days analysis results broken out by month for the Crystal River: Crystal Gorge. Where an Acceptability Category (e.g. 'Optimal') is missing for a given month, zero days were observed to fall within that category and the row was left out of the table for brevity.

Month	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
Apr	Lower Acceptable	2	7	6	2
	Optimal	1	2	4	0
	Upper Acceptable	0	0	2	8
	Total Days	3	9	12	10
May	Lower Acceptable	1	4	4	0
	Optimal	6	1	0	0
	Upper Acceptable	3	1	1	6
	Total Days	10	6	5	6
Jun	Upper Acceptable	1	0	0	0
	Total Days	1	0	0	0
Jul	Lower Acceptable	6	12	5	0
	Optimal	4	3	4	0
	Upper Acceptable	1	5	5	0
	Total Days	11	20	14	0
Aug	Lower Acceptable	0	0	5	7
	Optimal	0	0	0	3
	Upper Acceptable	0	0	0	9
	Total Days	0	0	5	19

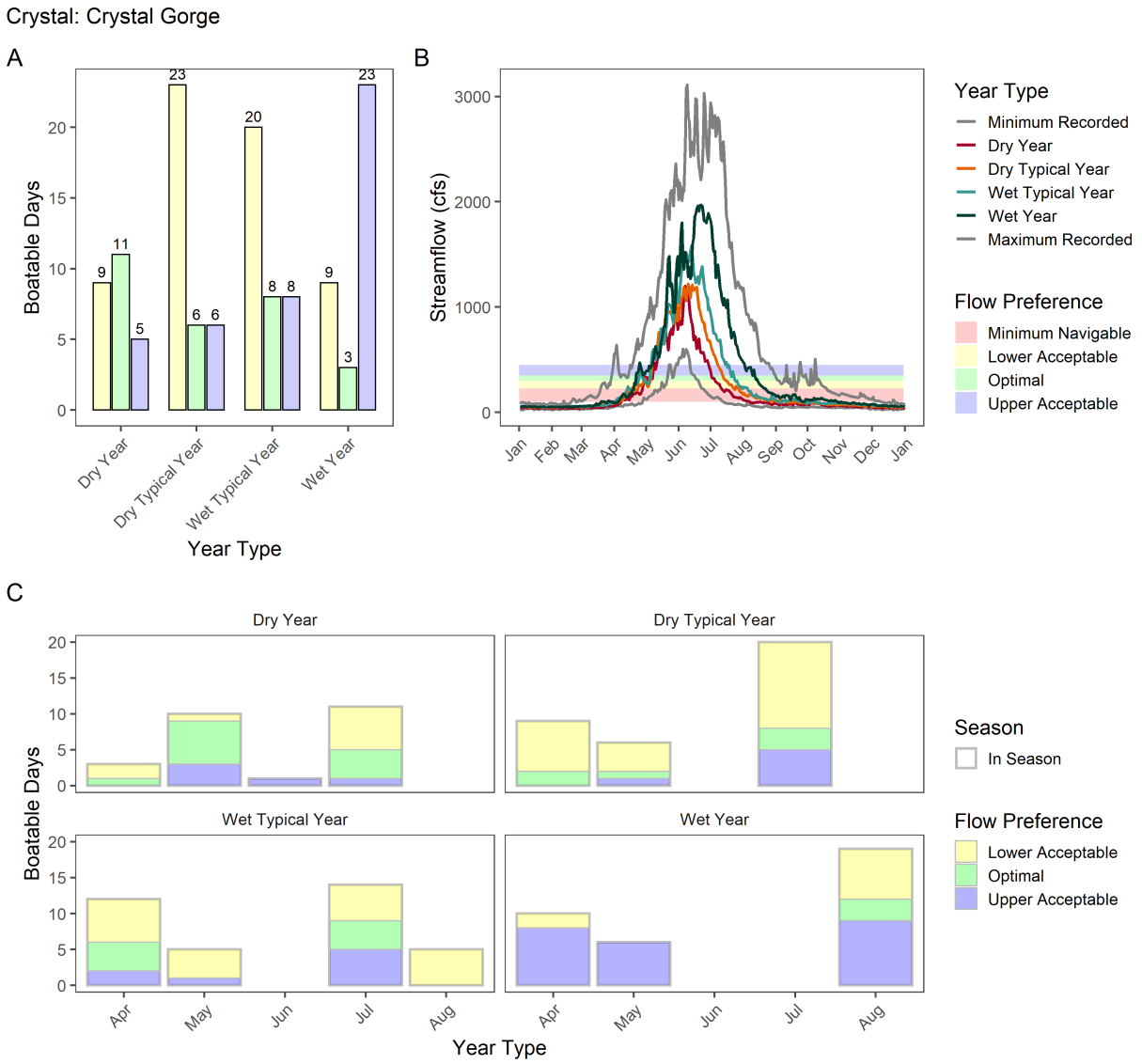


Figure 6: Boatable Days analysis results for the Crystal River: Crystal Gorge. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.

Crystal River: Marble to Redstone (Reach 3)

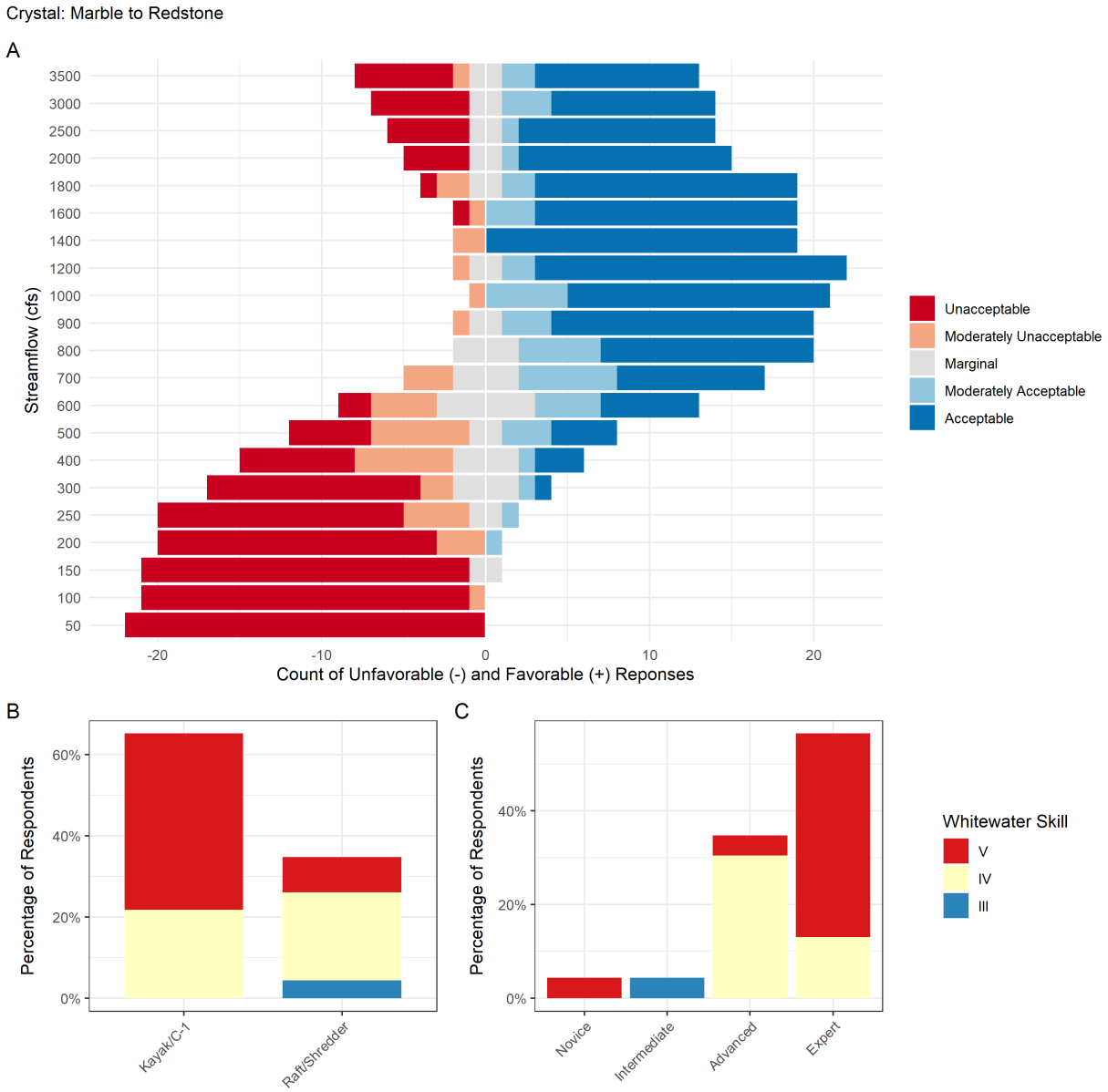
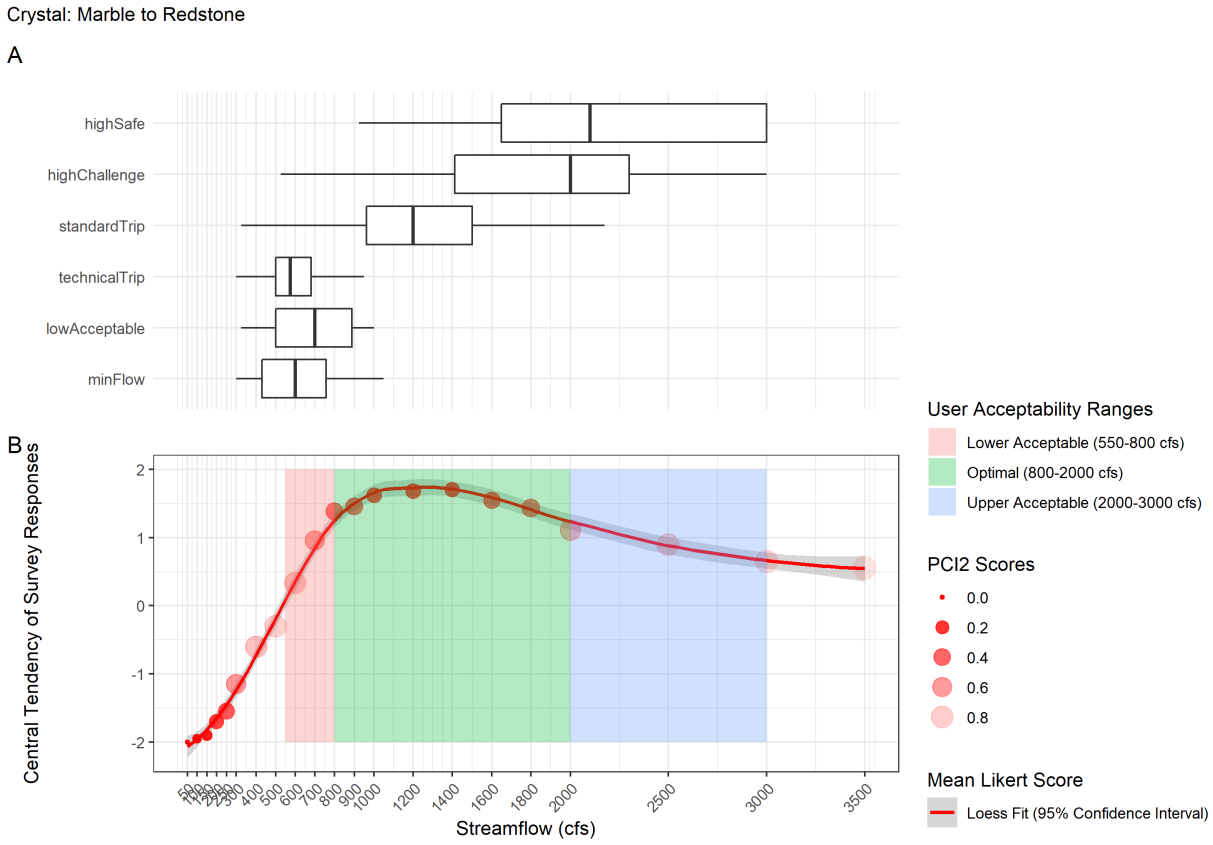


Figure 7: Survey responses for Crystal River: Marble to Redstone. (A) Flow acceptability rankings. (B) User identified preferred craft types and whitewater skill level. (C) User identified expertise and whitewater skill level.



C

Survey Question	25th Percentile	Median Response	75th Percentile	Response Count
Minimum Flow (cfs)	431	600	756	22
Low Acceptable Flow (cfs)	500	700	888	22
Technical Flow (cfs)	500	575	681	22
Standard Trip Flow (cfs)	962	1200	1500	22
Challenging High Flow (cfs)	1412	2000	2300	22
Highest Safe Flow (cfs)	1650	2100	3000	22

Figure 8: Flow preferences reported by users for Crystal River: Marble to Redstone. A) Boxplot of responses to open-ended questions about different categories of flow. B) PCI2 analysis results plotted against the central tendency of flow acceptability preference rankings at each flow category. Loess curve was fit to support visualization of flow acceptability ranges. C) Summarized open-format flow-preference question responses.

Table 5: PCI2 analysis results for Crystal River: Marble to Redstone.

Flow (cfs)	Median Likert Response	n	Max. Distance	Total Distance
50	-2.00	21	880	0
100	-1.95	20	800	38
150	-1.90	20	800	76
200	-1.70	20	800	204
250	-1.55	20	800	278
300	-1.15	20	800	470
400	-0.60	20	800	604
500	-0.30	20	800	644
600	0.33	21	880	652
700	0.95	21	880	520
800	1.38	21	880	352
900	1.45	22	968	396
1000	1.62	21	880	260
1200	1.68	22	968	266
1400	1.70	20	800	216
1600	1.55	20	800	310
1800	1.43	21	880	416
2000	1.11	19	720	488
2500	0.89	19	720	564
3000	0.65	20	800	682
3500	0.55	20	800	710

Table 6: Boatable Days analysis results broken out by month for the Crystal River: Marble to Redstone. Where an Acceptability Category (e.g. 'Optimal') is missing for a given month, zero days were observed to fall within that category and the row was left out of the table for brevity.

Month	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
May	Lower Acceptable	14	11	12	8
	Optimal	5	13	11	14
	Total Days	19	24	23	22
Jun	Lower Acceptable	10	5	0	0
	Optimal	14	25	30	30
	Total Days	24	30	30	30
Jul	Lower Acceptable	0	4	8	7
	Optimal	0	0	3	20
	Total Days	0	4	11	27

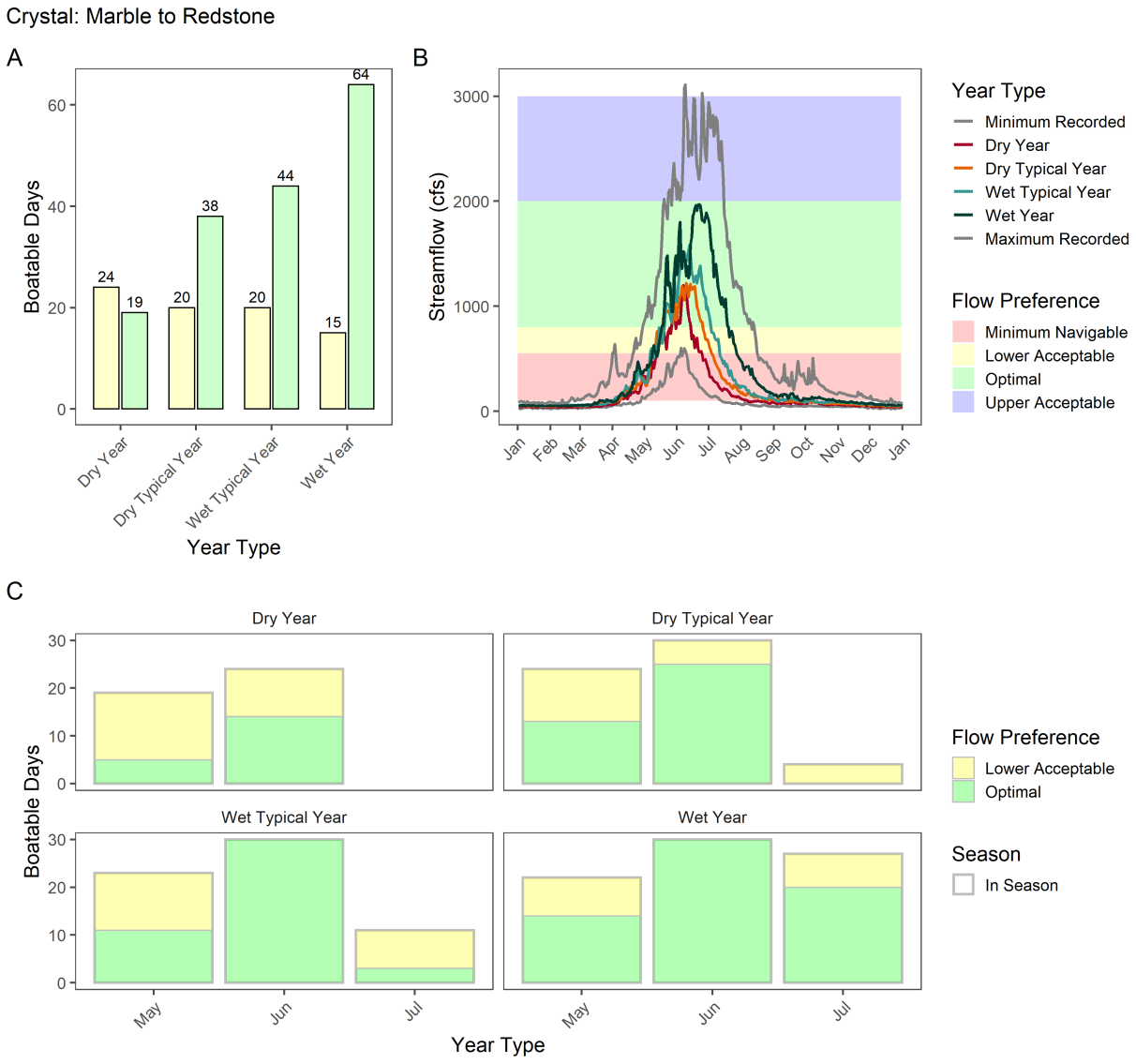


Figure 9: Boatable Days analysis results for the Crystal River: Marble to Redstone. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.

Crystal River: Meatgrinder (Reach 4)

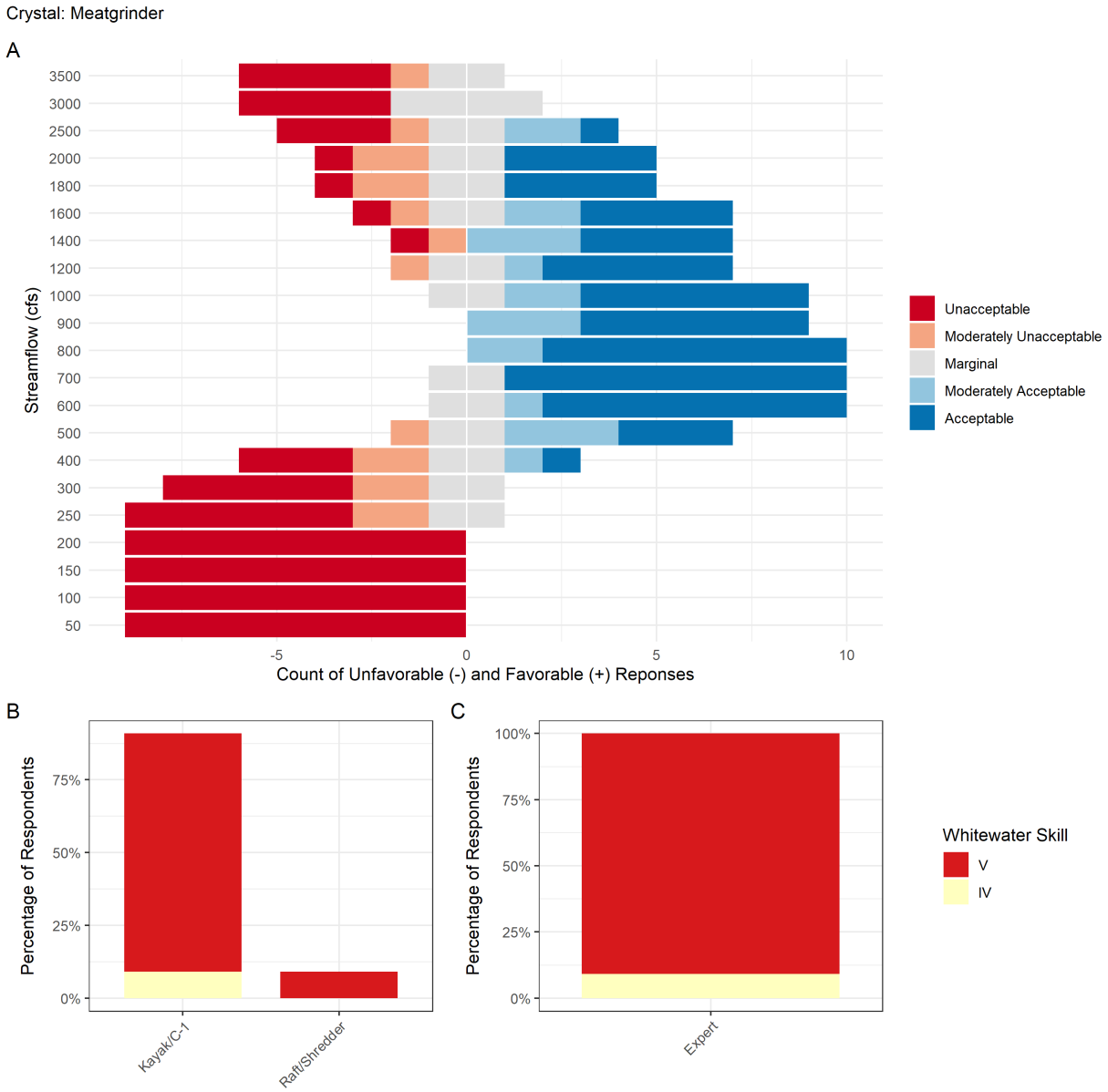
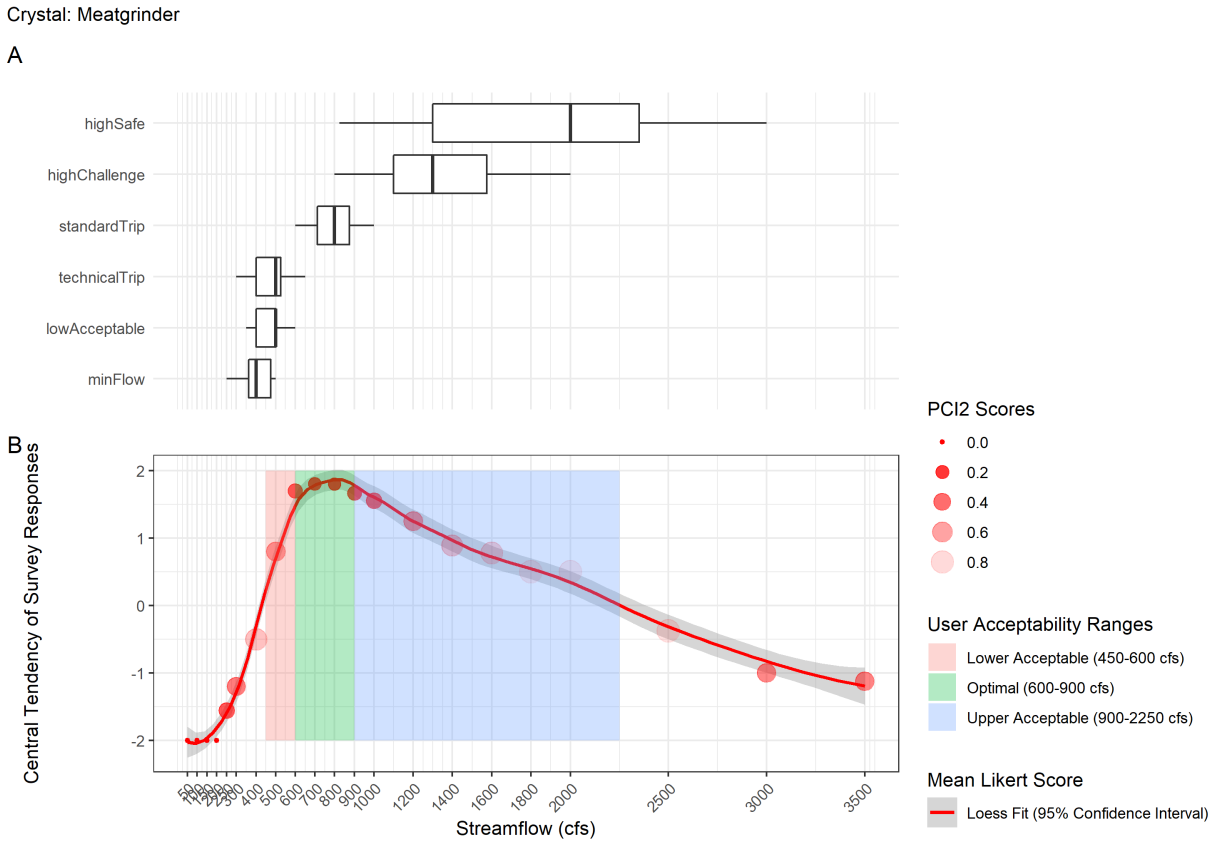


Figure 10: Survey responses for Crystal River: Meatgrinder. (A) Flow acceptability rankings. (B) User identified preferred craft types and whitewater skill level. (C) User identified expertise and whitewater skill level.



C

Survey Question	25th Percentile	Median Response	75th Percentile	Response Count
Minimum Flow (cfs)	362	400	475	11
Low Acceptable Flow (cfs)	400	500	500	11
Technical Flow (cfs)	400	500	525	11
Standard Trip Flow (cfs)	712	800	875	11
Challenging High Flow (cfs)	1100	1300	1575	11
Highest Safe Flow (cfs)	1300	2000	2350	11

Figure 11: Flow preferences reported by users for Crystal River: Meatgrinder. A) Boxplot of responses to open-ended questions about different categories of flow. B) PCI2 analysis results plotted against the central tendency of flow acceptability preference rankings at each flow category. Loess curve was fit to support visualization of flow acceptability ranges. C) Summarized open-format flow-preference question responses.

Table 7: PCI2 analysis results for Crystal River: Meatgrinder.

Flow (cfs)	Median Likert Response	n	Max. Distance	Total Distance
50	-2.00	9	160	0
100	-2.00	9	160	0
150	-2.00	9	160	0
200	-2.00	9	160	0
250	-1.56	9	160	52
300	-1.20	10	200	92
400	-0.50	10	200	142
500	0.80	10	200	108
600	1.70	10	200	50
700	1.80	10	200	36
800	1.80	10	200	32
900	1.67	9	160	36
1000	1.56	9	160	52
1200	1.25	8	128	68
1400	0.89	9	160	112
1600	0.78	9	160	120
1800	0.50	8	128	108
2000	0.50	8	128	108
2500	-0.38	8	128	106
3000	-1.00	8	128	64
3500	-1.13	8	128	62

Table 8: Boatable Days analysis results broken out by month for the Crystal River: Meatgrinder. Where an Acceptability Category (e.g. 'Optimal') is missing for a given month, zero days were observed to fall within that category and the row was left out of the table for brevity.

Month	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
Apr	Lower Acceptable	0	0	0	1
	Total Days	0	0	0	1
May	Lower Acceptable	4	4	7	7
	Optimal	14	13	10	6
	Upper Acceptable	3	8	9	12
	Total Days	21	25	26	25
Jun	Lower Acceptable	8	0	0	0
	Optimal	13	9	0	0
	Upper Acceptable	8	21	30	30
	Total Days	29	30	30	30
Jul	Lower Acceptable	0	5	5	5
	Optimal	0	2	10	8
	Upper Acceptable	0	0	1	18
	Total Days	0	7	16	31
Aug	Lower Acceptable	0	0	0	2
	Total Days	0	0	0	2

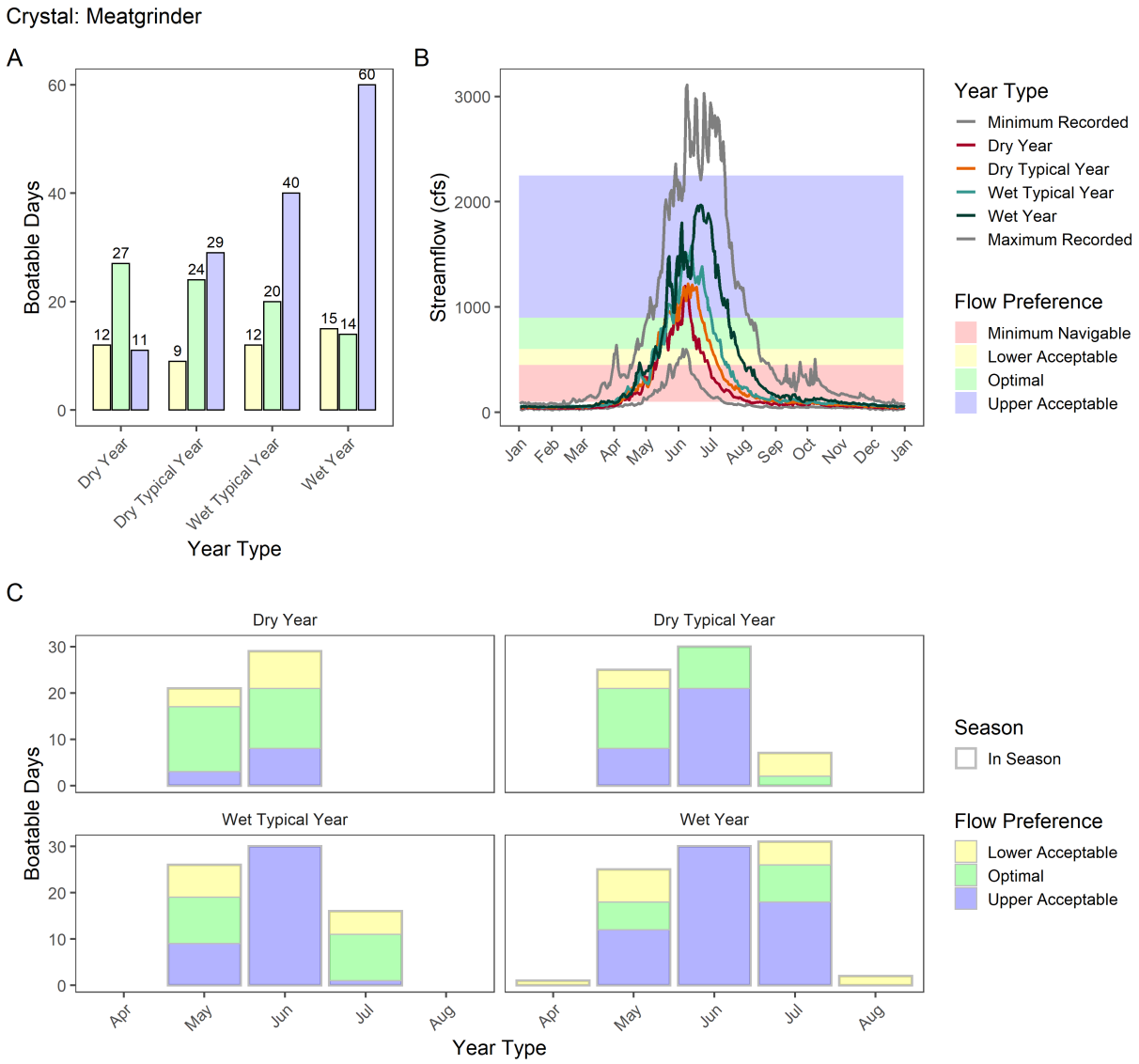


Figure 12: Boatable Days analysis results for the Crystal River: Meatgrinder. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.

Crystal River: The Narrows (Reach 5)

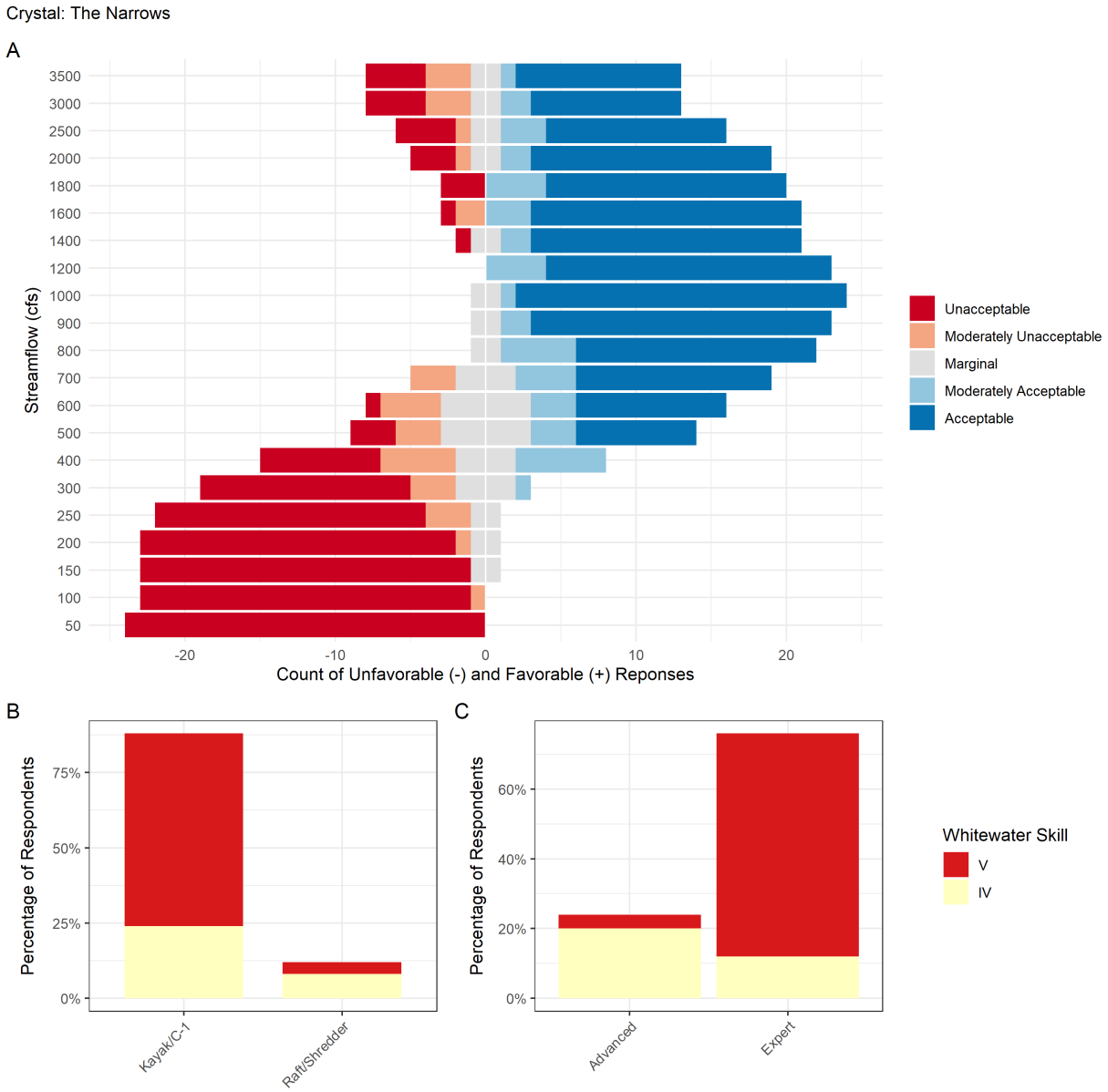
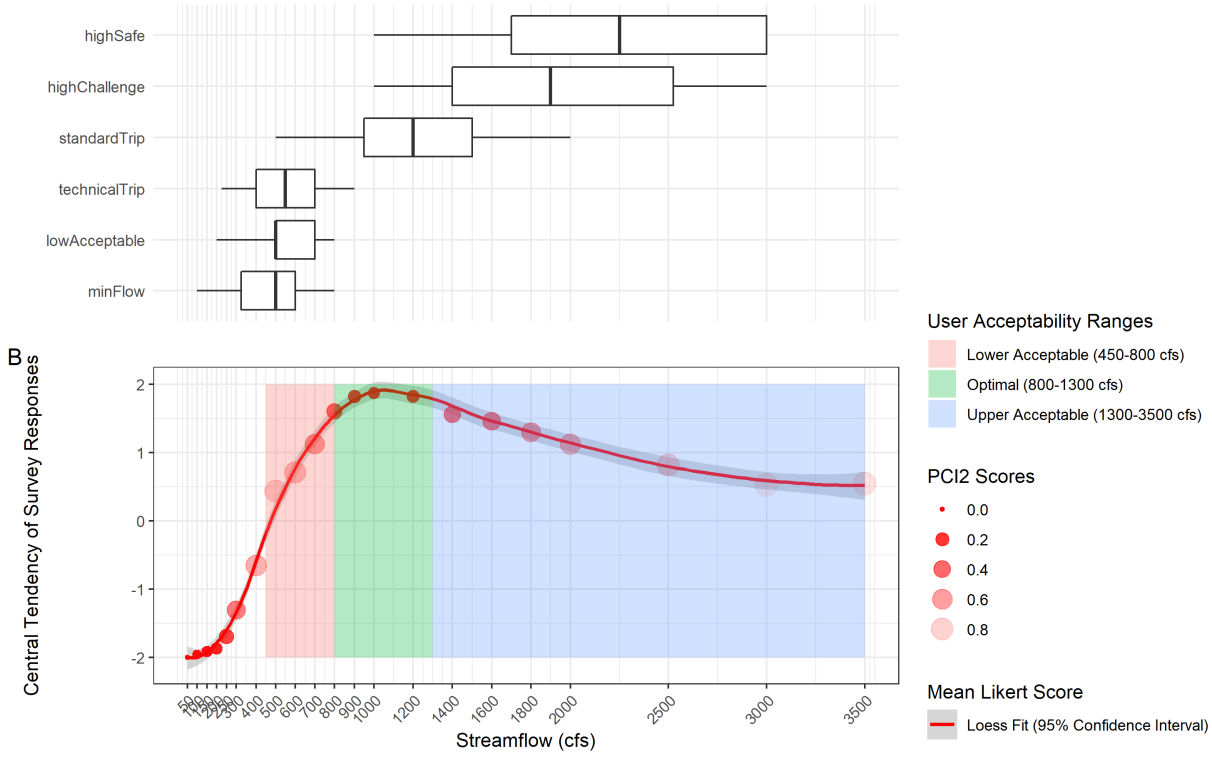


Figure 13: Survey responses for Crystal River: The Narrows. (A) Flow acceptability rankings. (B) User identified preferred craft types and whitewater skill level. (C) User identified expertise and whitewater skill level.

Crystal: The Narrows

A



C

Survey Question	25th Percentile	Median Response	75th Percentile	Response Count
Minimum Flow (cfs)	325	500	600	25
Low Acceptable Flow (cfs)	500	500	700	25
Technical Flow (cfs)	400	550	700	25
Standard Trip Flow (cfs)	950	1200	1500	25
Challenging High Flow (cfs)	1400	1900	2525	25
Highest Safe Flow (cfs)	1700	2250	3000	25

Figure 14: Flow preferences reported by users for Crystal River: The Narrows. A) Boxplot of responses to open-ended questions about different categories of flow. B) PCI2 analysis results plotted against the central tendency of flow acceptability preference rankings at each flow category. Loess curve was fit to support visualization of flow acceptability ranges. C) Summarized open-format flow-preference question responses.

Table 9: PCI2 analysis results for Crystal River: The Narrows.

Flow (cfs)	Median Likert Response	n	Max. Distance	Total Distance
50	-2.00	24	1152	0
100	-1.96	23	1056	44
150	-1.91	23	1056	88
200	-1.87	23	1056	128
250	-1.70	23	1056	264
300	-1.30	23	1056	500
400	-0.65	23	1056	704
500	0.43	23	1056	828
600	0.71	24	1152	802
700	1.13	24	1152	650
800	1.61	23	1056	308
900	1.83	23	1056	164
1000	1.88	24	1152	134
1200	1.83	23	1056	152
1400	1.57	23	1056	388
1600	1.46	24	1152	514
1800	1.30	23	1056	584
2000	1.13	24	1152	758
2500	0.82	22	968	764
3000	0.52	21	880	768
3500	0.55	22	968	836

Table 10: Boatable Days analysis results broken out by month for the Crystal River: The Narrows. Where an Acceptability Category (e.g. 'Optimal') is missing for a given month, zero days were observed to fall within that category and the row was left out of the table for brevity.

Month	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
Apr	Lower Acceptable	0	0	0	1
	Total Days	0	0	0	1
May	Lower Acceptable	16	12	15	11
	Optimal	5	13	10	10
	Upper Acceptable	0	0	1	4
	Total Days	21	25	26	25
Jun	Lower Acceptable	15	5	0	0
	Optimal	14	25	15	4
	Upper Acceptable	0	0	15	26
	Total Days	29	30	30	30
Jul	Lower Acceptable	0	7	13	11
	Optimal	0	0	3	13
	Upper Acceptable	0	0	0	7
	Total Days	0	7	16	31
Aug	Lower Acceptable	0	0	0	2
	Total Days	0	0	0	2

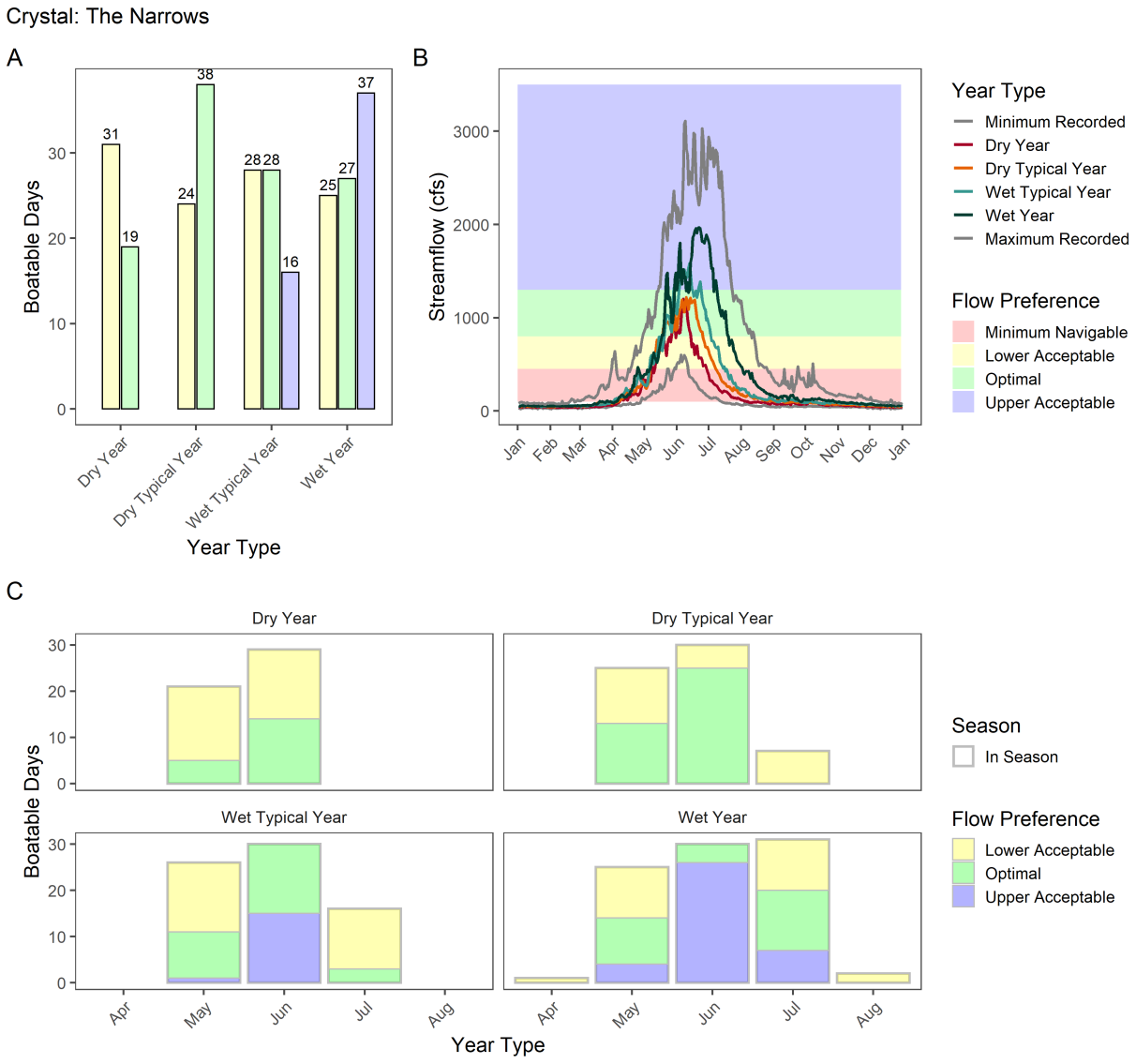


Figure 15: Boatable Days analysis results for the Crystal River: The Narrows. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.

Crystal River: Avalanche Crk to BRB Campground (Reach 6)

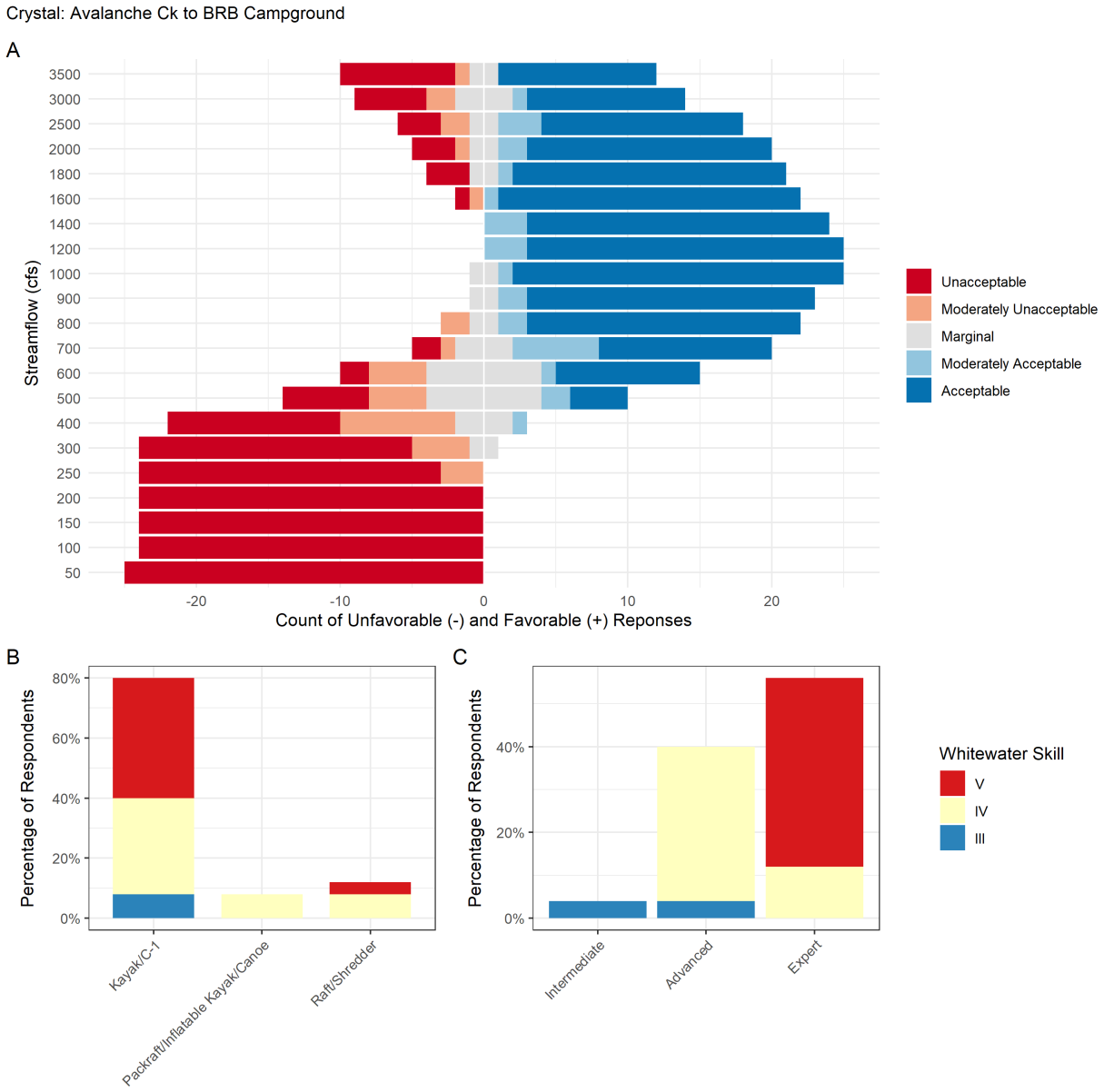
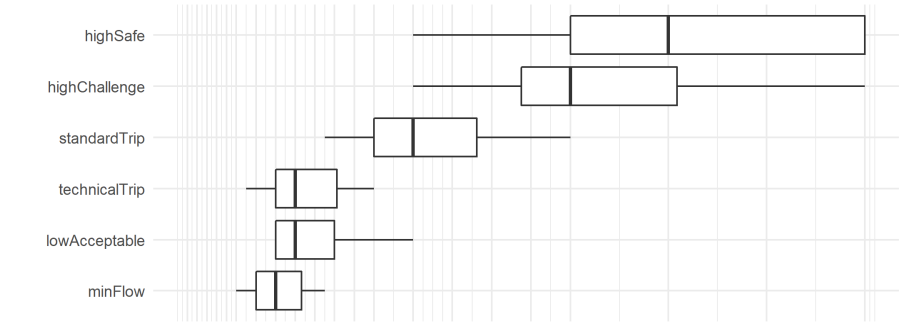


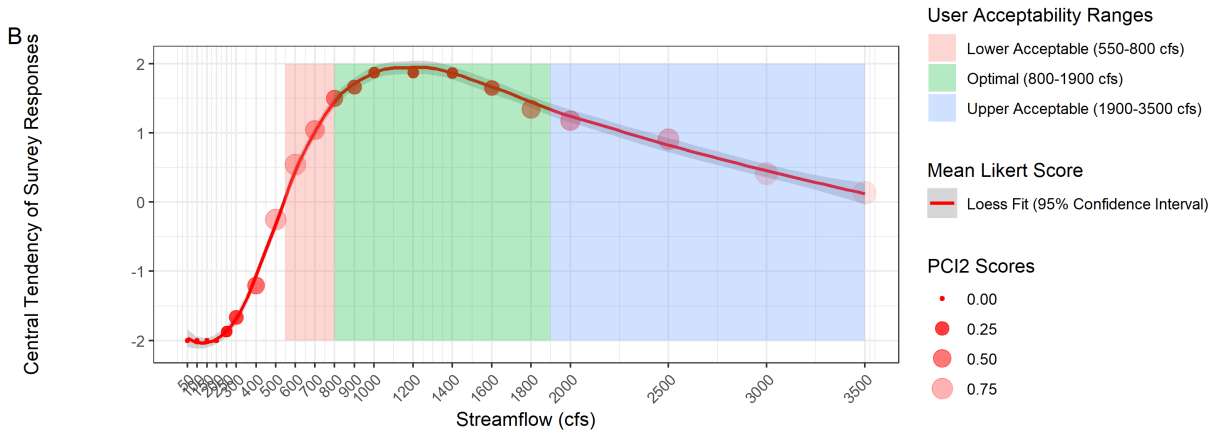
Figure 16: Survey responses for Crystal River: Avalanche Crk to BRB Campground. (A) Flow acceptability rankings. (B) User identified preferred craft types and whitewater skill level. (C) User identified expertise and whitewater skill level.

Crystal: Avalanche Ck to BRB Campground

A



B



C

Survey Question	25th Percentile	Median Response	75th Percentile	Response Count
Minimum Flow (cfs)	400	500	631	24
Low Acceptable Flow (cfs)	500	600	800	24
Technical Flow (cfs)	500	600	812	23
Standard Trip Flow (cfs)	1000	1200	1525	24
Challenging High Flow (cfs)	1750	2000	2544	24
Highest Safe Flow (cfs)	2000	2500	3500	22

Figure 17: Flow preferences reported by users for Crystal River: Avalanche Crk to BRB Campground. A) Boxplot of responses to open-ended questions about different categories of flow. B) PCI2 analysis results plotted against the central tendency of flow acceptability preference rankings at each flow category. Loess curve was fit to support visualization of flow acceptability ranges. C) Summarized open-format flow-preference question responses.

Table 11: PCI2 analysis results for Crystal Av Cr to BRB

Flow (cfs)	Median Likert Response	n	Max. Distance	Total Distance
50	-2.00	24	1152	0
100	-2.00	23	1056	0
150	-2.00	23	1056	0
200	-2.00	23	1056	0
250	-1.87	23	1056	120
300	-1.67	24	1152	304
400	-1.21	24	1152	522
500	-0.25	24	1152	872
600	0.54	24	1152	870
700	1.04	24	1152	718
800	1.50	24	1152	464
900	1.67	24	1152	316
1000	1.88	24	1152	134
1200	1.88	24	1152	126
1400	1.87	23	1056	120
1600	1.65	23	1056	332
1800	1.35	23	1056	572
2000	1.17	23	1056	676
2500	0.91	23	1056	784
3000	0.41	22	968	862
3500	0.14	22	968	938

Table 12: Boatable Days analysis results broken out by month for Crystal River: Avalanche Crk to BRB Campground. Where an Acceptability Category (e.g. 'Optimal') is missing for a given month, zero days were observed to fall within that category and the row was left out of the table for brevity.

Month	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
May	Lower Acceptable	14	11	12	8
	Optimal	5	13	11	14
	Total Days	19	24	23	22
Jun	Lower Acceptable	10	5	0	0
	Optimal	14	25	30	24
	Upper Acceptable	0	0	0	6
	Total Days	24	30	30	30
Jul	Lower Acceptable	0	4	8	7
	Optimal	0	0	3	20
	Total Days	0	4	11	27

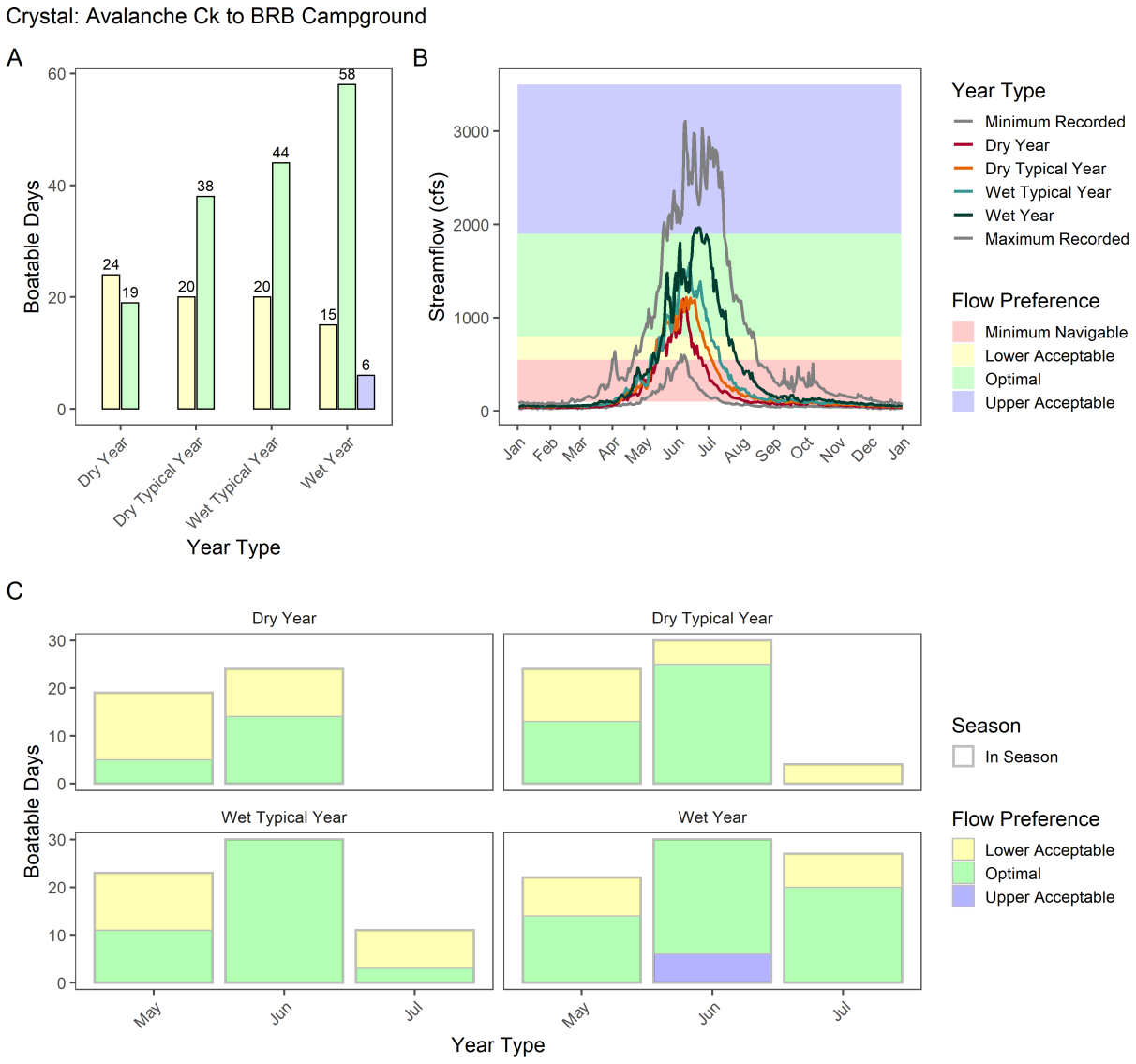


Figure 18: Boatable Days analysis results for the Crystal River: Avalanche Crk to BRB Campground. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.

Crystal River: BRB Campground to Roaring Fork (Reach 7)

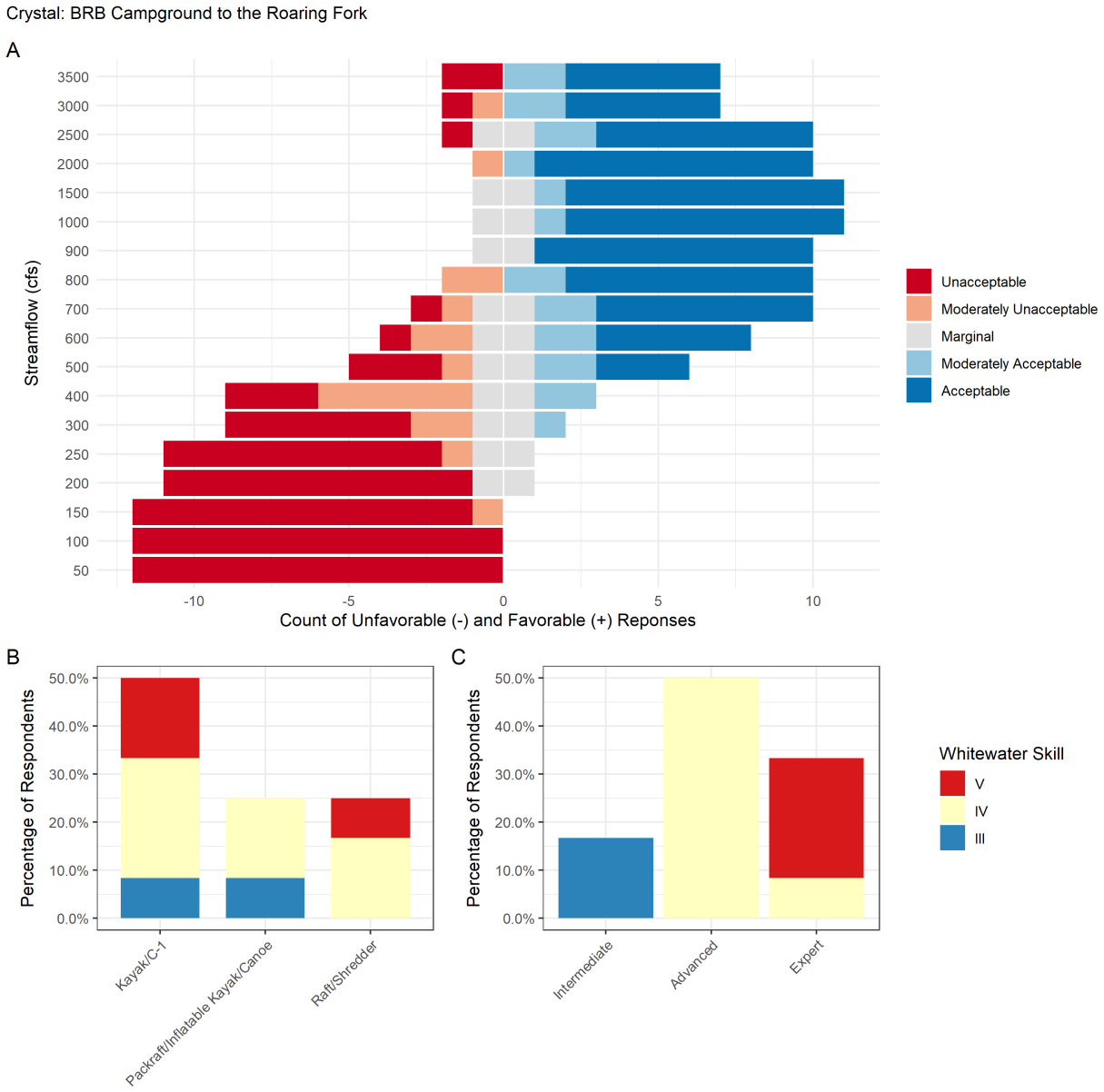
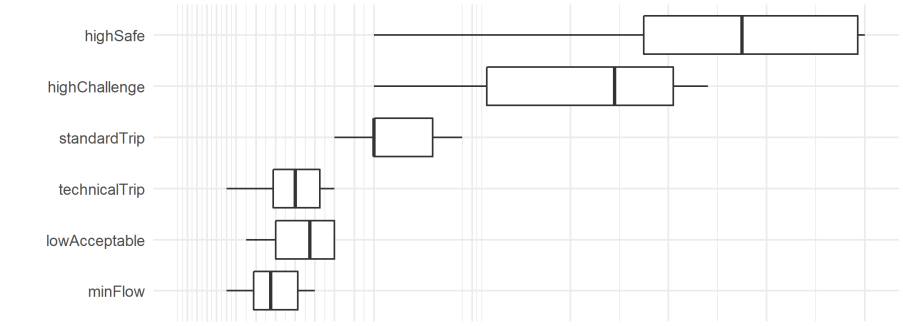


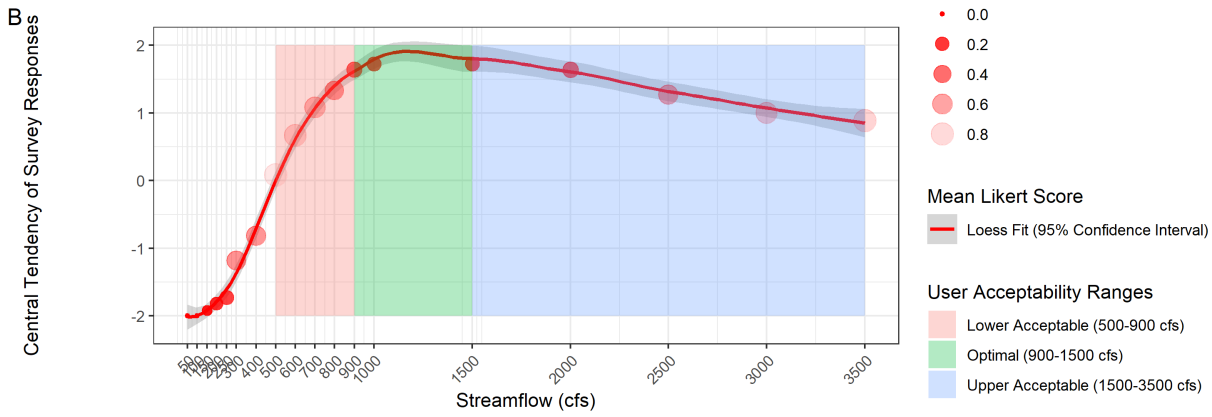
Figure 19: Survey responses for Crystal River: BRB Campground to Roaring Fork. (A) Flow acceptability rankings. (B) User identified preferred craft types and whitewater skill level. (C) User identified expertise and whitewater skill level.

Crystal: BRB Campground to the Roaring Fork

A



B



C

Survey Question	25th Percentile	Median Response	75th Percentile	Response Count
Minimum Flow (cfs)	388	475	612	12
Low Acceptable Flow (cfs)	500	675	800	12
Technical Flow (cfs)	488	600	725	12
Standard Trip Flow (cfs)	1000	1000	1300	12
Challenging High Flow (cfs)	1575	2225	2525	12
Highest Safe Flow (cfs)	2375	2875	3462	12

Figure 20: Flow preferences reported by users for Crystal River: BRB Campground to Roaring Fork. A) Boxplot of responses to open-ended questions about different categories of flow. B) PCI2 analysis results plotted against the central tendency of flow acceptability preference rankings at each flow category. Loess curve was fit to support visualization of flow acceptability ranges. C) Summarized open-format flow-preference question responses.

Table 13: PCI2 analysis results for Crystal River: BRB Campground to Roaring Fork.

Flow (cfs)	Median Likert Response	n	Max. Distance	Total Distance
50	-2.00	12	288	0
100	-2.00	12	288	0
150	-1.92	12	288	22
200	-1.82	11	240	40
250	-1.73	11	240	56
300	-1.18	11	240	128
400	-0.82	11	240	132
500	0.08	12	288	242
600	0.67	12	288	216
700	1.08	12	288	186
800	1.33	12	288	144
900	1.64	11	240	72
1000	1.73	11	240	56
1500	1.73	11	240	56
2000	1.64	11	240	76
2500	1.27	11	240	132
3000	1.00	9	160	112
3500	0.89	9	160	124

Table 14: Boatable Days analysis results broken out by month for the Crystal River: BRB Campground to Roaring Fork. Where an Acceptability Category (e.g. 'Optimal') is missing for a given month, zero days were observed to fall within that category and the row was left out of the table for brevity.

Month	Flow Preference Category	Dry Year	Dry Typical Year	Wet Typical Year	Wet Year
May	Lower Acceptable	17	17	16	12
	Optimal	3	8	9	12
	Total Days	20	25	25	24
Jun	Lower Acceptable	17	9	0	0
	Optimal	8	21	27	10
	Upper Acceptable	0	0	3	20
	Total Days	25	30	30	30
Jul	Lower Acceptable	0	6	12	12
	Optimal	0	0	1	13
	Upper Acceptable	0	0	0	5
	Total Days	0	6	13	30

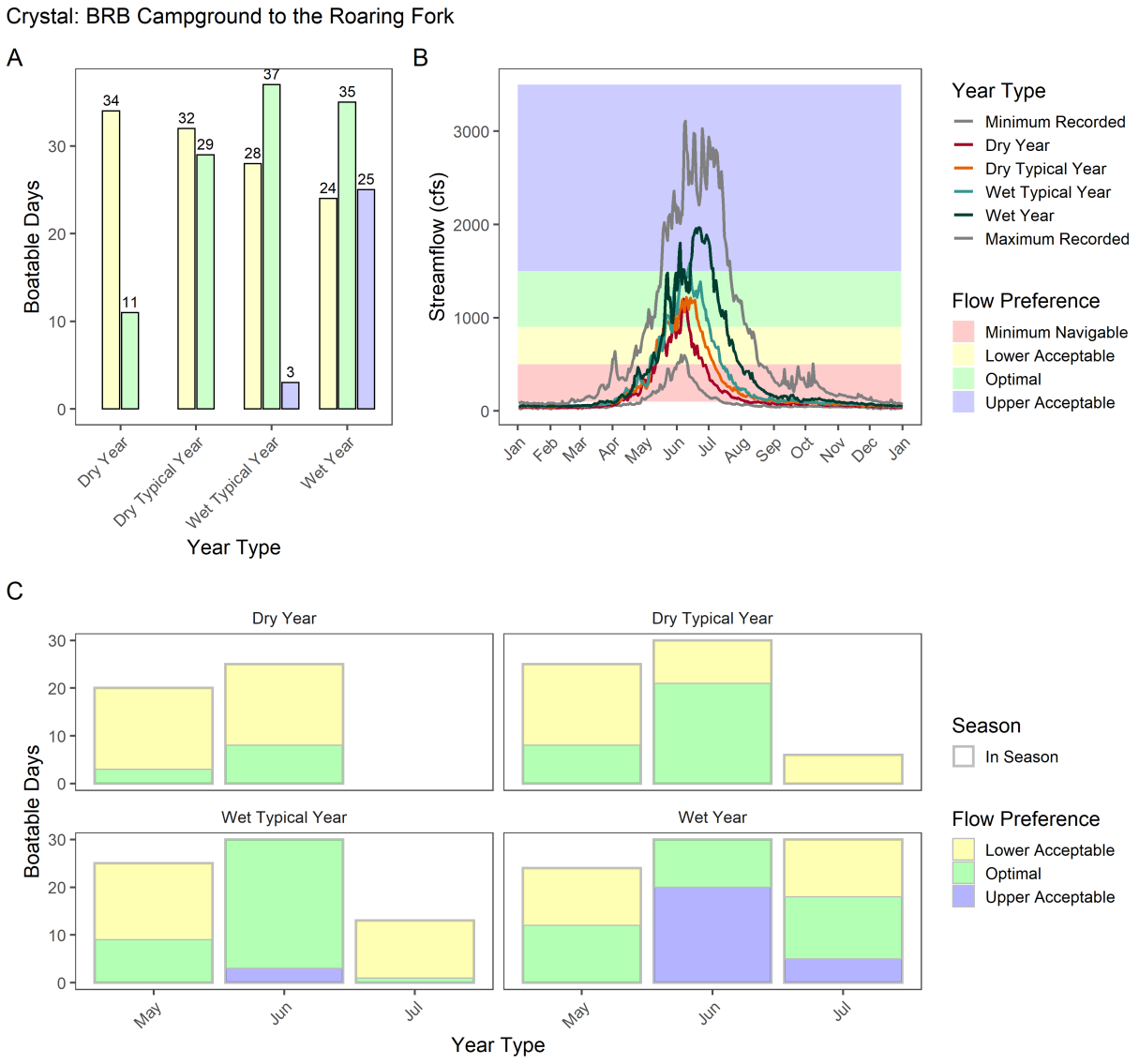


Figure 21: Boatable Days analysis results for the Crystal River: BRB Campground to Roaring Fork. (A) Annual Boatable Days totals summarized by hydrological year type. (B) Flow preference ranges mapped to representative streamflow time series for wet, wet typical, dry typical, and dry years. Minimum and maximum recorded daily streamflows also included for reference (C) Monthly Boatable Days totals summarized by hydrological year type.