Appendix S1

Estimating Carrying Capacity for Chinook Parr using Quantile Random Forest Models

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1 Choosing Habitat Covariates

One of the crucial steps in building this carrying capacity model was choosing which habitat covariates to include. Random forest models naturally incorporate interactions between correlated covariates, which is essential since nearly all habitat variables are considered correlated to one degree or another, however, we aimed to avoid overly redundant variables (i.e., variables that measure similar aspects of the habitat). Further, including too many covariates can result in overfitting of the model (e.g., including as many covariates as data points). Our goal was to select a group of covariates that captured as many different aspects of the stream habitat (e.g. substrate, flow, riparian condition, channel unit configuration, etc.) as possible, while still holding information about fish densities.

To prevent overfitting, we pared down the more than 100 metrics generated by the CHaMP protocol describing the quantity and quality of fish habitat for each survey site. Habitat metrics were first grouped into broad categories that included channel unit, complexity, cover, riparian areas, side channels, size, substrate, temperature, water quality, and woody debris. Habitat metrics measuring any large wood volume were scaled by the site length (in 100 m units). To assist in determining the habitat metrics to include in the QRF model, we used the Maximal Information-Based Nonparametric Exploration (MINE) class of statistics (Reshef et al. 2011) to determine those habitat characteristics (covariates) most highly associated with the log of observed parr densities. We calculated the maximal information coefficient (MIC), using the R package *minerva* (Filosi et al. 2019), to measure the strength of the linear or non-linear association between the natural log of fish density and each habitat metric (Reshef et al. 2011). MIC is a measure of correlation that incorporates potential non-linear associations, so for example if there is an expontential association the MIC value could be high, even when the standard correlation coefficient is low. We excluded categorical variables such as channel type (e.g. meandering, pool-riffle, plane-bed, etc.) because we assumed that other quantitative metrics would capture the differences between those qualitative categorical metrics.

Within each category, metrics were ranked according to their MIC value (Table S1 and Figure S1). The MIC value between each of the measured habitat characteristics and parr density was used to inform decisions on which habitat covariates to include in the QRF parr capacity model. We selected one or two variables amongst those with the highest MIC scores within each category, attempting to avoid covariates that were too highly correlated (Figure **??**), while focusing on covariates we thought could influence fish behavior. For example, cumulative drainage area, mean annual flow and observed discharge are all highly correlated, but fish really only experience the observed flow, so we chose to include that metric in our QRF model. We also tried to include covariates that can be directly influenced by restoration actions or have been shown to impact salmonid juvenile density. Finally, we attempted to avoid metrics with too many missing values, or too many all zero values, in the data set, as well as metrics that may have too much observer error (Rosgen et al. 2018).

2 References

Filosi, M., R. Visintainer, and D. Albanese. 2019. Minerva: Maximal information-based nonparametric exploration for variable analysis.

Reshef, D. N., Y. A. Reshef, H. K. Finucane, S. R. Grossman, G. McVean, P. J. Turnbaugh, E. S. Lander, M. Mitzenmacher, and P. C. Sabeti. 2011. Detecting novel associations in large data sets. Science 334:1518–1524.

Rosgen, D., A. Taillacq, B. Rosgen, and D. Geenen. 2018. A technical review of the Columbia Habitat Monitoring Program's protocol, data quality.

3 Tables

Table S1: MIC statistic for top metrics in each habitat category. Metrics selected for the QRF model are in bold.

Category	Name	Abbrv	MIC	perc_non0
ChannelUnit	Channel Unit Frequency	CU_Freq	0.241	0.979
ChannelUnit	Fast Turbulent Frequency	FstTurb_Freq	0.230	0.918
ChannelUnit	Fast NonTurbulent Frequency	FstNT_Freq	0.209	0.692
ChannelUnit	Slow Water Frequency	SlowWater_Freq	0.208	0.927
ChannelUnit	Fast Turbulent Percent	FstTurb_Pct	0.195	0.918
ChannelUnit	ChnlUnitTotal_Ct	ChnlUnitTotal_Ct	0.189	0.979
ChannelUnit	Channel Unit Count	CU_Ct	0.189	0.979
ChannelUnit	Fast Turbulent Count	FstTurb_Ct	0.178	0.918
ChannelUnit	Slow Water Percent	SlowWater_Pct	0.177	0.927
ChannelUnit	Fast NonTurbulent Percent	FstNT_Pct	0.169	0.692
Complexity	Wetted Width To Depth Ratio Avg	WetWDRat_Avg	0.247	0.997
Complexity	Bankfull Width To Depth Ratio Avg	BfWDRat_Avg	0.245	0.997
Complexity	Wetted Depth SD	DpthWet_SD	0.232	0.997
Complexity	Wetted Channel Braidedness	WetBraid	0.212	0.997
Complexity	Bankfull Channel Braidedness	BfBraid	0.211	0.997
Complexity	Wetted Channel Qualifying Island Count	Wet_QIsland_Ct	0.209	0.165
Complexity	Bankfull Width CV	BfWdth_CV	0.209	0.997
Complexity	Bankfull Width To Depth Ratio CV	BfWDRat_CV	0.202	0.997
Complexity	Detrended Elevation SD	DetrendElev_SD	0.196	0.997
Complexity	Bankfull Channel Qualifying Island Count	Bf_QIsland_Ct	0.193	0.220
Cover	Fish Cover: Total	FishCovTotal	0.225	0.970
Cover	Fish Cover: None	FishCovNone	0.224	0.979
Cover	Fish Cover: LW	FishCovLW	0.213	0.845
Cover	Fish Cover: Terrestrial Vegetation	FishCovTVeg	0.204	0.948
Cover	Percent Undercut by Length	UcutLgth_Pct	0.185	0.524
Cover	Percent Undercut by Area	UcutArea_Pct	0.184	0.524
Cover	Fish Cover: Aquatic Vegetation	FishCovAqVeg	0.166	0.369
Cover	Fish Cover: Artificial	FishCovArt	0.136	0.149
Riparian	Riparian Cover: Understory	RipCovUstory	0.206	1.000
Riparian	RipCovUstoryNone	RipCovUstoryNone	0.206	1.000
Riparian	Riparian Cover: No Canopy	RipCovCanNone	0.194	1.000
Riparian	Riparian Cover: Some Canopy	RipCovCanSome	0.194	0.905
Riparian	Riparian Cover: Big Tree	RipCovBigTree	0.184	0.817
Riparian	Riparian Cover: Ground	RipCovGrnd	0.182	1.000
Riparian	RipCovGrndNone	RipCovGrndNone	0.170	0.997
Riparian	Riparian Cover: Woody	RipCovWood	0.168	1.000
Riparian	Riparian Cover: Non-Woody	RipCovNonWood	0.166	1.000
Riparian	Riparian Cover: Coniferous	RipCovConif	0.164	0.808
SideChannel	Bankfull Side Channel Width	BfSCWdth	0.223	0.204
SideChannel	Wetted Side Channel Width	WetSCWdth	0.213	0.168
SideChannel	Wetted Side Channel Percent By Area	WetSC_Pct	0.209	0.180
SideChannel	SCSm_Freq	SCSm_Freq	0.153	0.079
SideChannel	SCSm_Ct	SCSm_Ct	0.153	0.079
SideChannel	SC_Area_Pct	SC_Area_Pct	0.153	0.079
Size	Mean Annual Flow	MeanU	0.346	0.524
Size	Wetted Width Integrated	WetWdth_Int	0.332	0.997
Size	Bankfull Width Integrated	BfWdthInt	0.324	0.997
Size	Wetted Width Avg	WetWdth_Avg	0.324	0.997

Category	Name	Abbrv	MIC	perc_non0
Size	Drainage Area (Flowline)	CUMDRAINAG	0.302	0.659
Size	Bankfull Width Avg	BfWdth_Avg	0.298	0.997
Size	DpthThlwg_Avg	DpthThlwg_Avg	0.280	0.997
Size	Discharge	Q	0.259	0.963
Size	Bankfull Depth Avg	DpthBf_Avg	0.245	0.982
Size	Bankfull Depth Max	DpthBf_Max	0.240	0.982
Substrate	Substrate $<$ 6mm	SubLT6	0.237	0.945
Substrate	Substrate $<$ 2mm	SubLT2	0.227	0.918
Substrate	Substrate: D16	SubD16	0.219	0.988
Substrate	Substrate: Embeddedness Avg	SubEmbed_Avg	0.204	0.683
Substrate	Substrate: D50	SubD50	0.197	0.988
Substrate	Substrate Est: Sand and Fines	SubEstSandFines	0.190	0.970
Substrate	Substrate Est: Cobbles	SubEstCbl	0.185	0.973
Substrate	Substrate: D84	SubD84	0.185	0.988
Substrate	Substrate Est: Boulders	SubEstBldr	0.183	0.851
Substrate	Substrate: Embeddedness SD	SubEmbed_SD	0.181	0.680
Temperature	Avg. August Temperature	avg_aug_temp	0.272	1.000
Temperature	Elev_M	Elev_M	0.262	0.637
Temperature	August Temperature	aug_temp	0.188	0.845
Temperature	Solar Access: Summer Avg	SolarSummr_Avg	0.186	0.930
WaterQuality	Conductivity	Cond	0.254	0.973
WaterQuality	Alkalinity	Alk	0.225	0.973
WaterQuality	Drift Biomass	DriftBioMass	0.000	0.616
Wood	Large Wood Volume: Bankfull Slow Water	LWVol_BfSlow	0.213	0.768
Wood	Large Wood Volume: Wetted Slow Water	LWVol_WetSlow	0.207	0.710
Wood	Large Wood Frequency: Wetted	LWFreq_Wet	0.199	0.875
Wood	Large Wood Volume: Bankfull	LWVol_Bf	0.189	0.915
Wood	Large Wood Volume: Wetted Fast Turbulent	LWVol_WetFstTurb	0.187	0.726
Wood	Large Wood Frequency: Bankfull	LWFreq_Bf	0.178	0.915
Wood	Large Wood Volume: Bankfull Fast NonTurbulent	LWVol_BfFstNT	0.175	0.479
Wood	Large Wood Volume: Wetted	LWVol_Wet	0.166	0.875
Wood	Large Wood Volume: Wetted Fast NonTurbulent	LWVol_WetFstNT	0.159	0.405

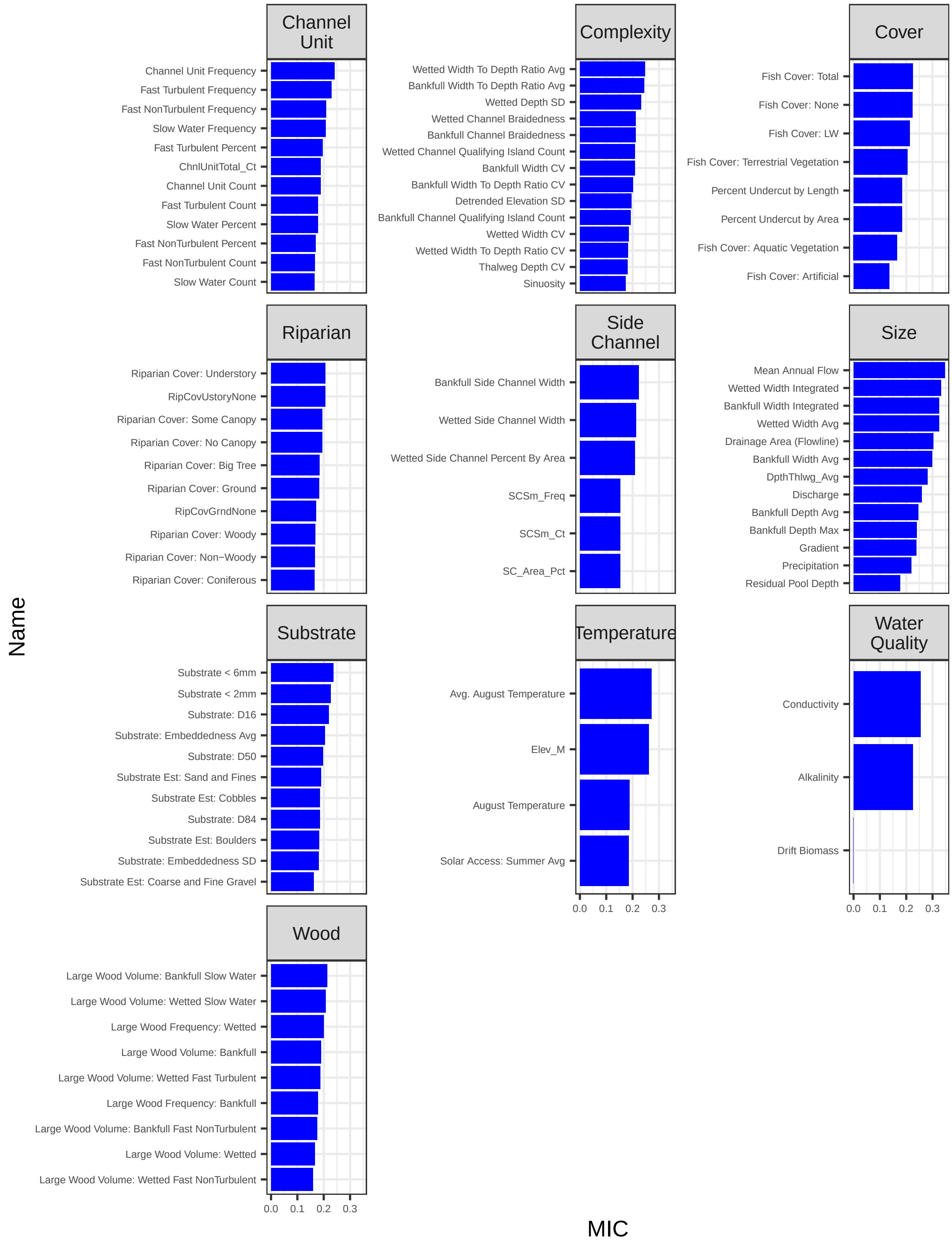


Figure S1: Barplots of MIC statistics, faceted by habitat category.

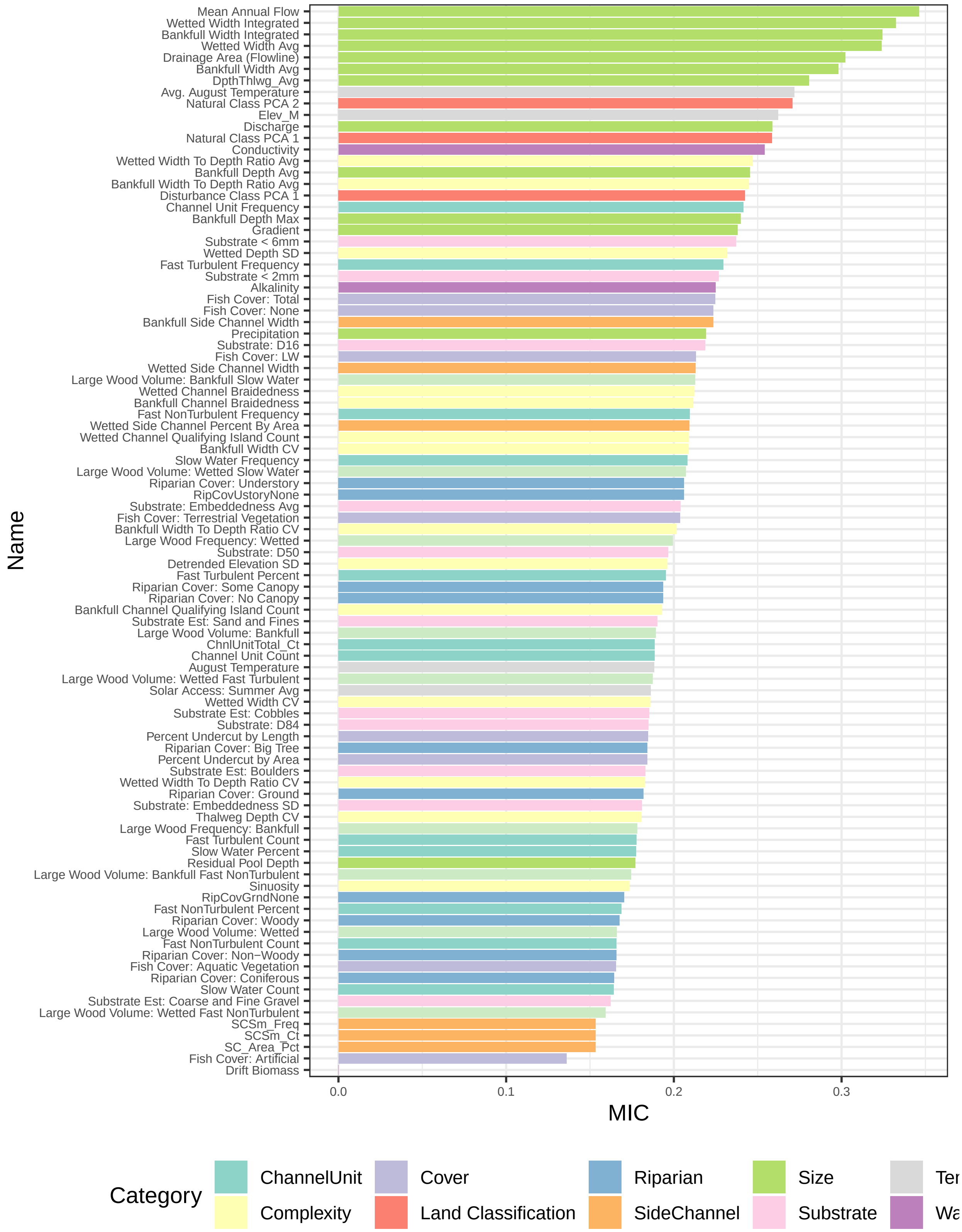
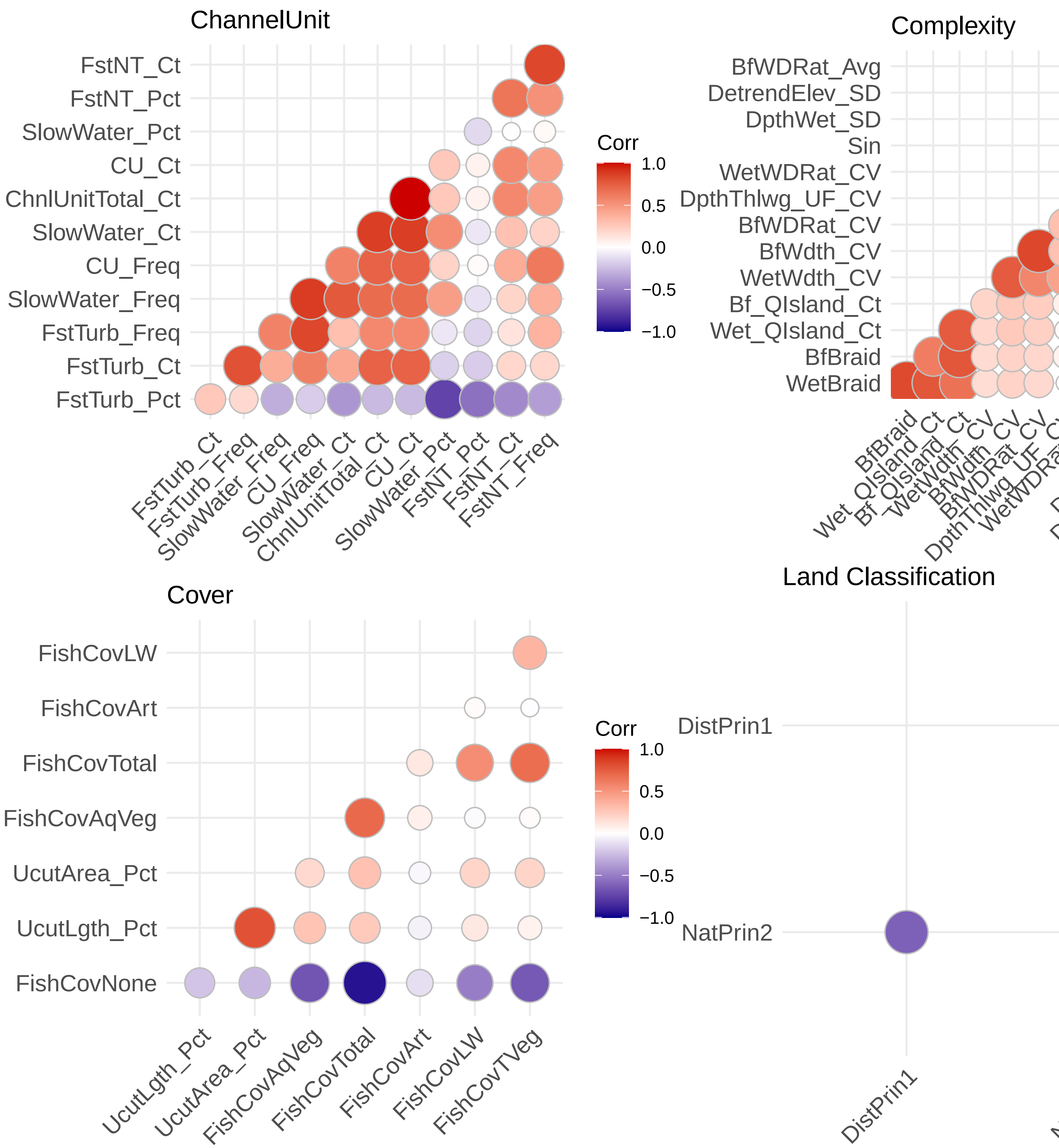


Figure S2: Barplot of MIC statistics, colored by habitat category.

4 Figures



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FstNT_Pct
SlowWater_Pct
CU_Ct
ChnlUnitTotal_Ct
SlowWater_Ct
CU_Freq
SlowWater_Freq
FstTurb_Freq
FstTurb_Ct
FstTurb_Pct
FstTurb_Ct
FstTurb_Freq
SlowWater_Freq
CU_Freq
SlowWater_Ct
ChnlUnitTotal_Ct
CU_Ct
SlowWater_Pct
FstNT_Pct
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FstNT_Freq
Corr
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0.0
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Complexity
BfWDRat_Avg
DetrendElev_SD
DpthWet_SD
Sin
WetWDRat_CV
DpthThlwg_UF_CV
BfWDRat_CV
BfWdth_CV
WetWdth_CV
Bf_QIsland_Ct
Wet_QIsland_Ct
BfBraid
WetBraid
BfBraid
Wet_QIsland_Ct
Bf_QIsland_Ct
WetWdth_CV
BfWdth_CV
BfWDRat_CV
DpthThlwg_UF_CV
Cover
FishCovLW
FishCovArt
FishCovTotal
FishCovAqVeg
UcutArea_Pct
UcutLgth_Pct
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UcutArea_Pct
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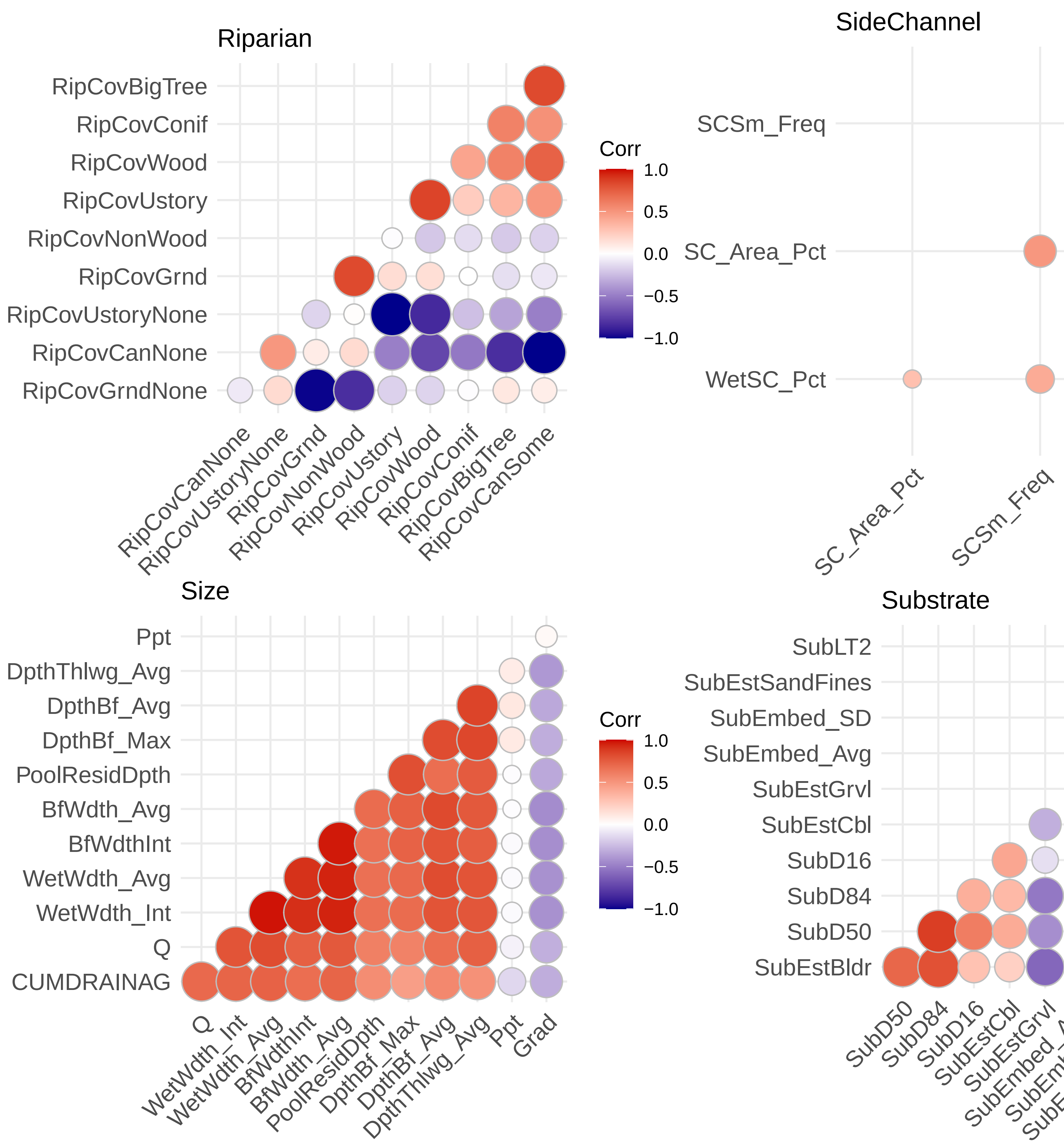
NatPrin2
DistPrin1



Riparian
RipCovBigTree
RipCovConif
RipCovWood
RipCovUstory
RipCovNonWood
RipCovGrnd
RipCovUstoryNone
RipCovCanNone
RipCovGrndNone
RipCovCanNone
RipCovUstoryNone
RipCovGrnd
RipCovNonWood
RipCovUstory
RipCovWood
RipCovConif
RipCovBigTree
RipCovCanSome
Corr
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SideChannel
SCSm_Freq
SC_Area_Pct
WetSC_Pct
SC_Area_Pct
SCSm_Freq
Size
Ppt
DpthThlwg_Avg
DpthBf_Avg
DpthBf_Max
PoolResidDpth
BfWdth_Avg
BfWdthInt
WetWdth_Avg
WetWdth_Int
Q
CUMDRAINAG
Q
WetWdth_Int
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BfWdthInt
BfWdth_Avg
PoolResidDpth
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DpthBf_Avg
DpthThlwg_Avg
Ppt
Grad
Corr
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Substrate
SubLT2
SubEstSandFines
SubEmbed_SD
SubEmbed_Avg
SubEstGrvl
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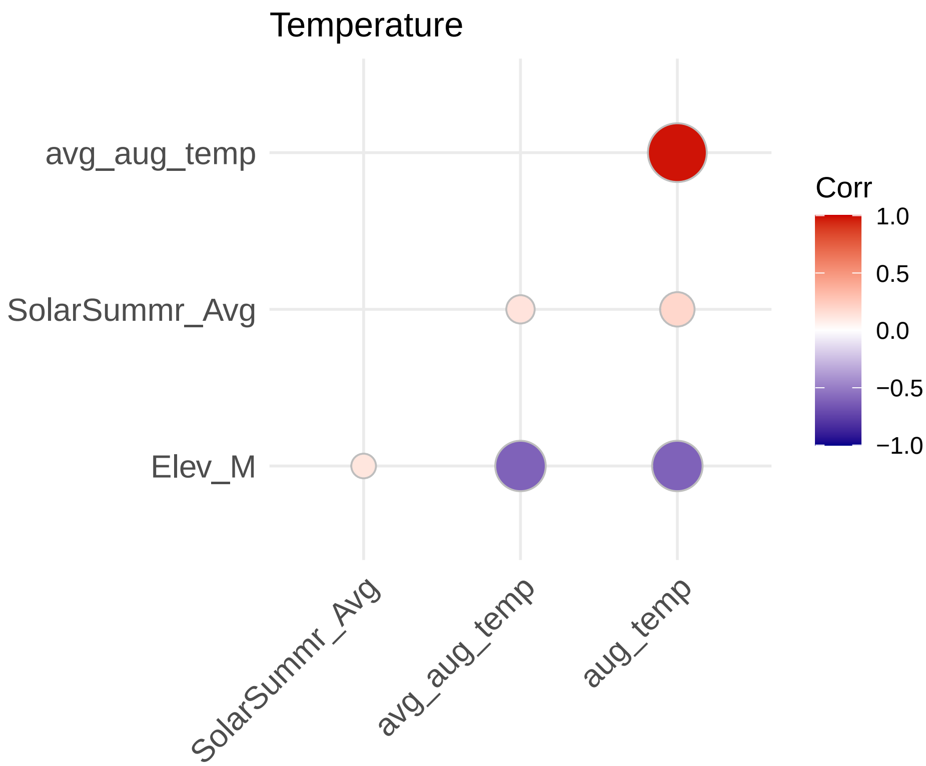
SubEstGrvl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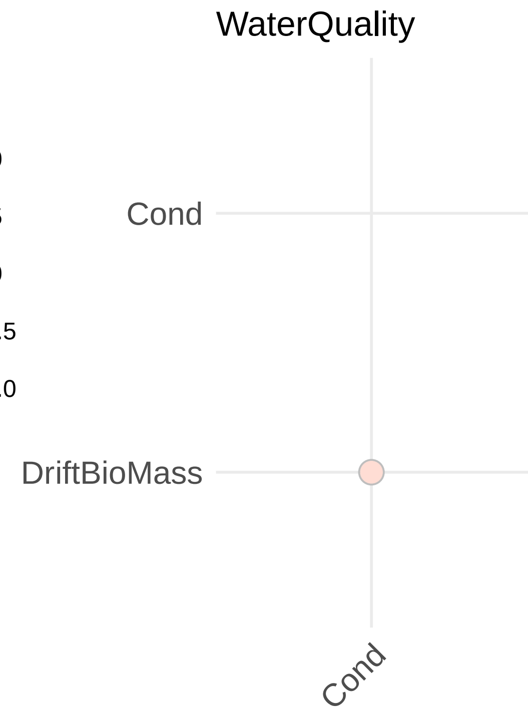
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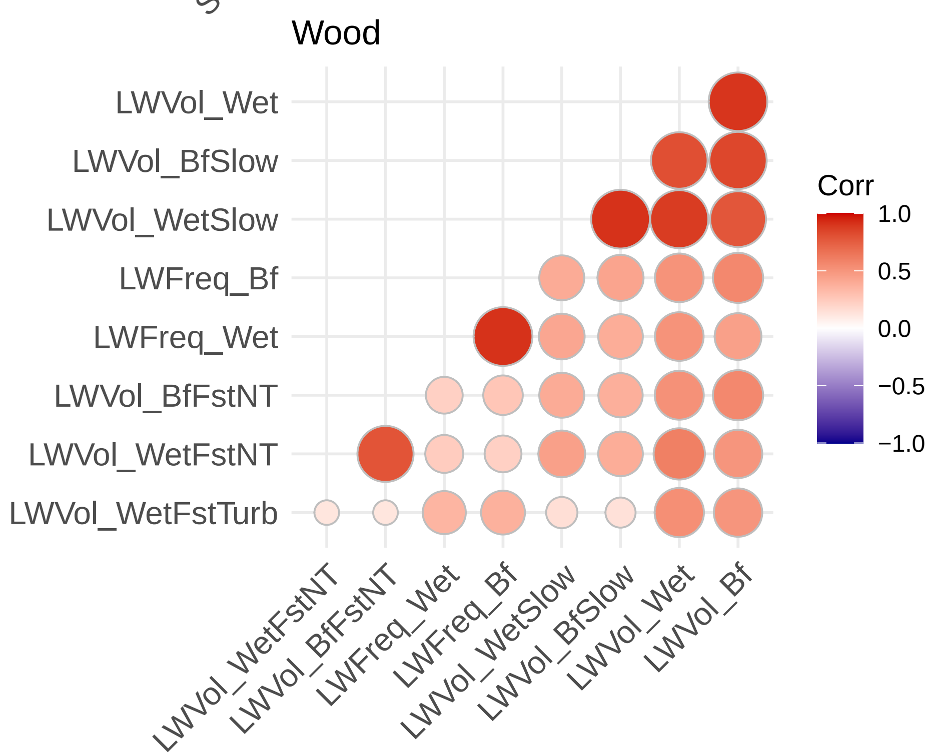
Cond
DriftBioMass
Cond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LWVol_WetFstNT
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LWVol_WetFstNT
LWVol_BfFstNT
LWFreq_Wet
LWFreq_Bf
LWVol_WetSlow
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LWVol_Bf
Corr
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0.0
−0.5
−1.0

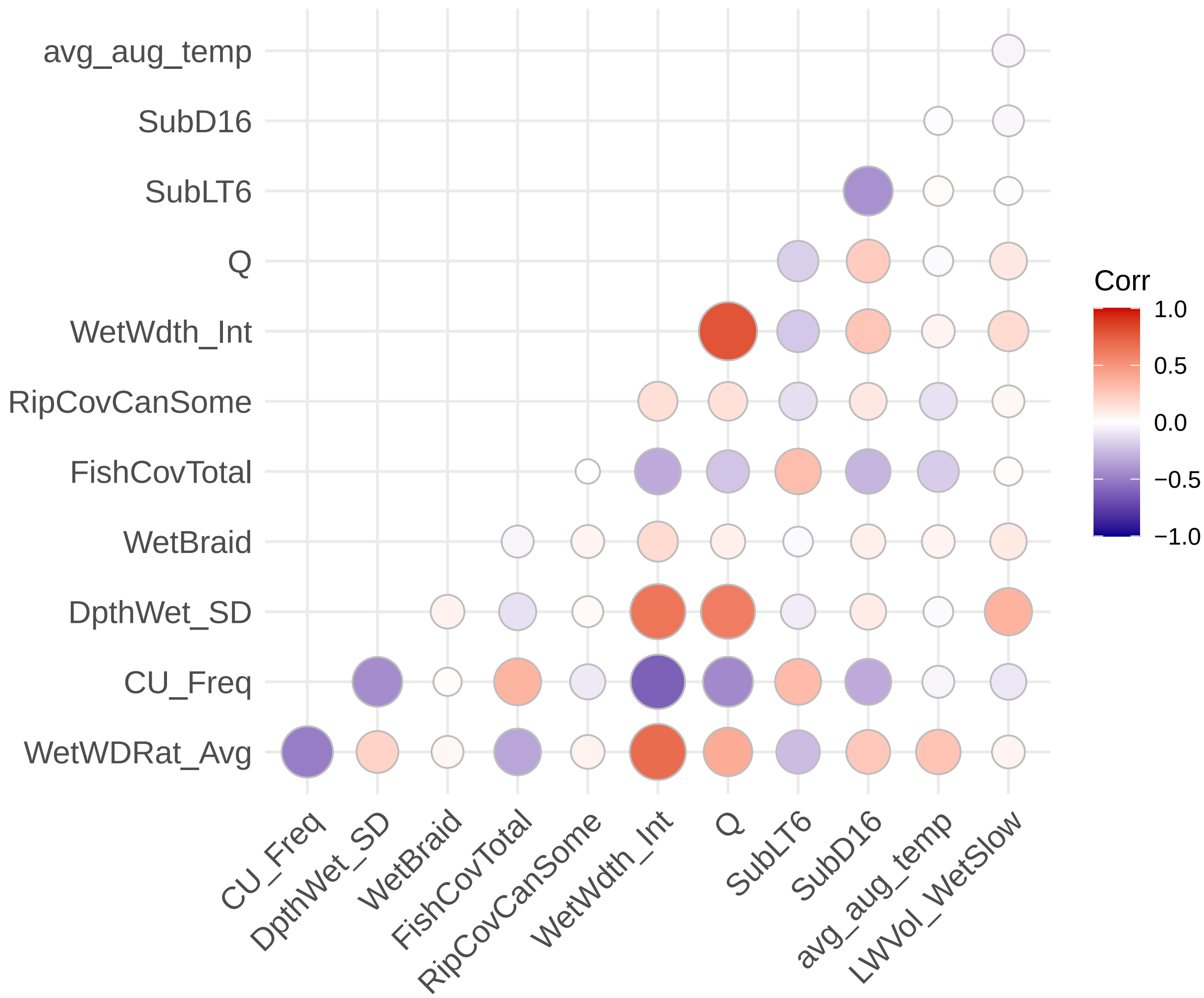

Figure S3: Correlation plot of habitat metrics used in QRF model.

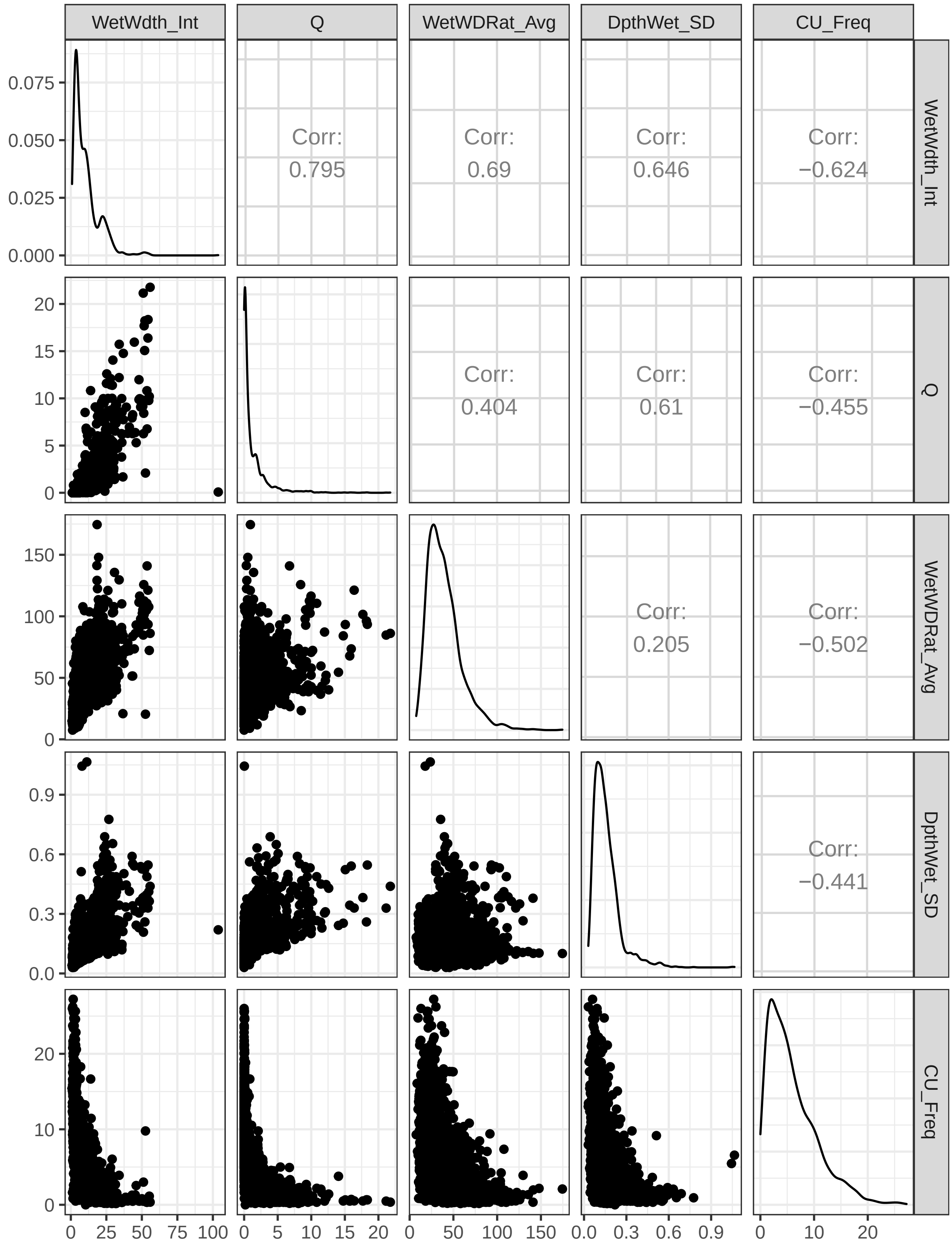

Figure S4: Pairs plot of habitat metrics used in QRF model with a correlation coefficient greater than 0.5.

4.0.1 Colophon

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#>  tibble         * 3.0.1      2020-04-20 [1] CRAN (R 3.6.2)
#>  tidyr          * 1.0.3      2020-05-07 [1] CRAN (R 3.6.2)
#>  tidyselect       1.0.0      2020-01-27 [1] CRAN (R 3.6.0)
#>  tidyverse      * 1.3.0      2019-11-21 [1] CRAN (R 3.6.0)
#>  usethis          1.5.1      2019-07-04 [1] CRAN (R 3.6.0)
#>  vctrs            0.2.4      2020-03-10 [1] CRAN (R 3.6.0)
#>  viridisLite      0.3.0      2018-02-01 [2] CRAN (R 3.6.0)
#>  webshot          0.5.2      2019-11-22 [1] CRAN (R 3.6.0)
#>  withr            2.2.0      2020-04-20 [1] CRAN (R 3.6.2)
#>  xfun             0.12       2020-01-13 [1] CRAN (R 3.6.0)
#>  xml2             1.2.2      2019-08-09 [2] CRAN (R 3.6.0)
#>  yaml             2.2.0      2018-07-25 [2] CRAN (R 3.6.0)
#>
```

```
#> [1] /Users/seek/Library/R/3.6/library
#> [2] /Library/Frameworks/R.framework/Versions/3.6/Resources/library
```

The current Git commit details are:

```
#> Local:    master /Users/seek/Documents/GitProjects/MyProjects/QRFpaper
#> Remote:   master @ origin (git@github.com:KevinSee/QRFpaper.git)
#> Head:     [8e70457] 2020-06-10: Merge branch 'master' of github.com:KevinSee/QRFpaper
```