Appendix A. Supplementary information

Kuemmerlen et al., 2018. "Ecological assessment of river networks: from reach to catchment scale" https://doi.org/10.1016/j.scitotenv.2018.09.019

A1: Translation of original assessment modules to continuous value function

Table A1: Original assessment with five color-coded quality classes for the example of orthophosphate ($PO4^{3-}$) according to the nutrient module of the Swiss modular concept (Liechti, 2010) and its translation to a continuous value scale assuming an equal width of each class.

Assessment class	Phosphate $PO4^{3-}$ [mgP/L]	value scale	degree of fulfillment of the objective
high	0 - <0.02	1 – 0.8	100% – 80%
good	0.02 - <0.04	<0.8 – 0.6	<80% – 60%
moderate	0.04 - <0.06	<0.6 – 0.4	<60% – 40%
poor	0.06 - <0.08	<0.4 – 0.2	<40% – 20%
bad	>= 0.08	<0.2 – 0	<20% – 0%

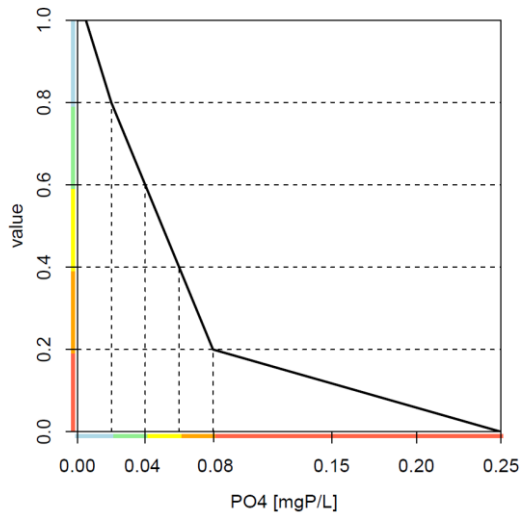


Fig. A1: Translation of the phosphate assessment in mgP/L to the continuous value scale based on class boundaries given by the original assessment and linear interpolation between class boundaries.

A2: Objectives hierarchy for nutrient assessment

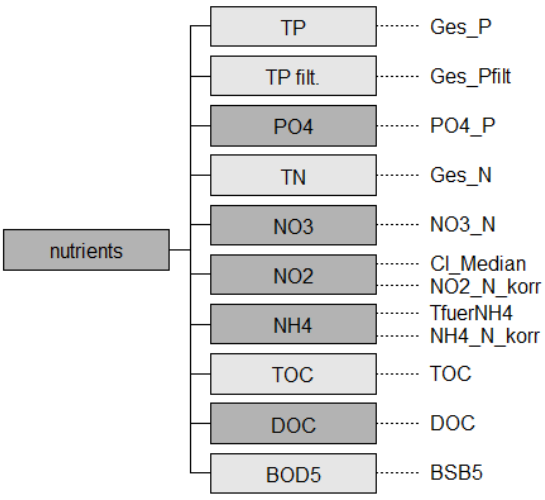


Fig. A2: Objectives hierarchy for the aggregation of different nutrients to attain the nutrient evaluation for a given reach. Dark gray represents mandatory parameters; light gray represents optional parameters.

A3: Nutrient assessment model

Nutrient valuation data at observation sites were used to estimate coefficients of a logistic regression model for extrapolation of nutrient valuations to all reaches in the catchment. This resulted in the following extrapolation formula

$$v_{\text{nutrients}} = \frac{1}{1 + \exp(-1.22 + 4.72 \cdot f_{ww} + 0.00458\ \text{km}^2 \cdot d_{\text{cow}} + 0.0219 \cdot f_{\text{agri}})}$$

where $v_{\text{nutrients}}$ is the degree of fulfillment of the objective of reaching a "natural nutrient state", f_{ww} is the fraction of waste water in mean river discharge, d_{cow} is the density of cattle in the upstream subcatchment in units of "cow equivalents" per km^2, and f_{agri} is the fraction of crop land including orchards and wineyards also in the upstream subcatchment (FOEN, 2014; FSO, 2008; swisstopo, 2010). Note that the value of $v_{\text{nutrients}}$ (degree of fulfillment of the objective "natural nutrient state") decreases with increasing values of all influence factors f_{ww}, d_{cow} and f_{agri}.

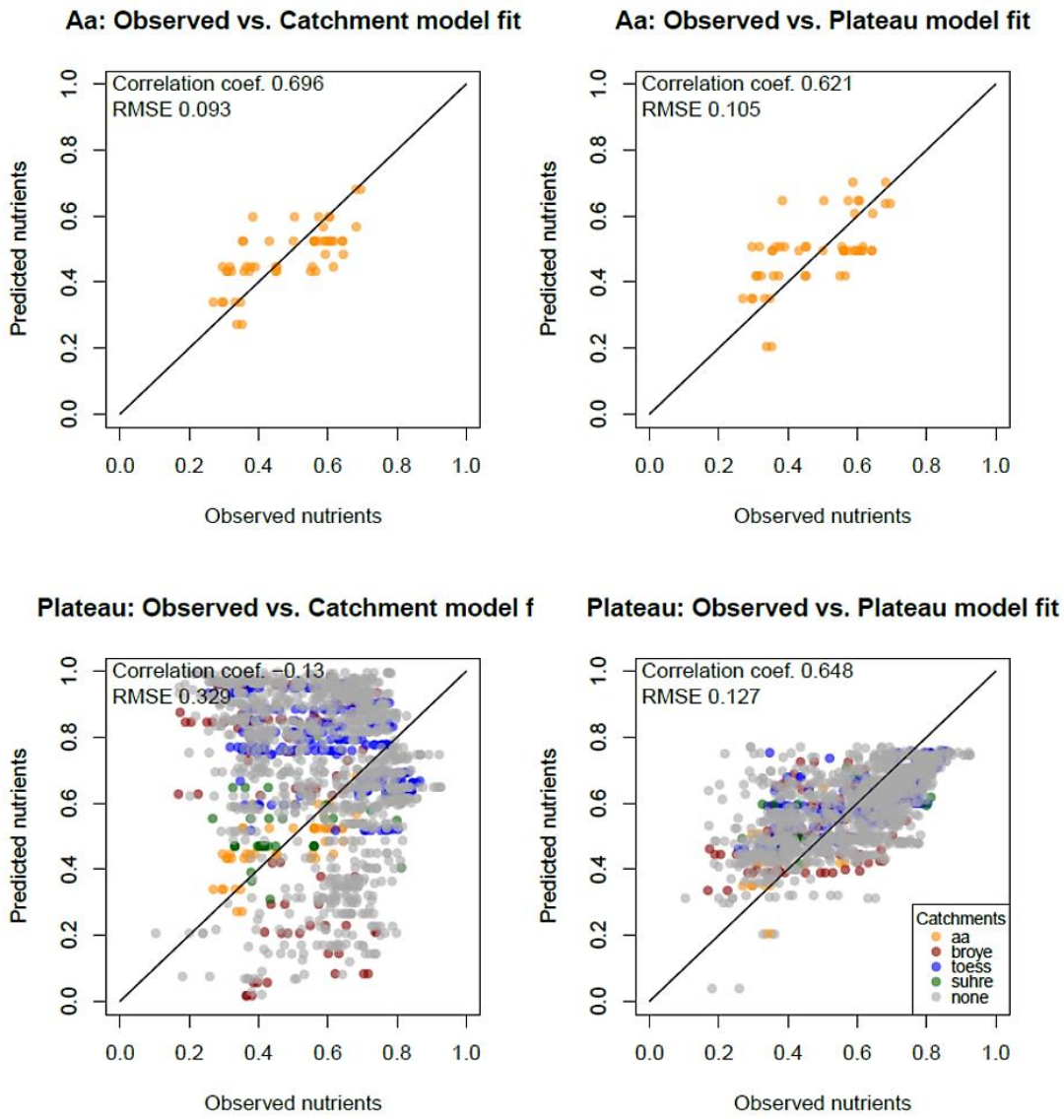


Fig. A3: Exemplary aggregated nutrient state prediction for the Mönchaltdorfer Aa catchment. Panes show comparisons of observed vs. fitted data, top left: catchment data vs. catchment calibrated model; top right: catchment data vs. Swiss plateau calibrated model; bottom left: Swiss plateau data vs. catchment calibrated model; bottom right: Swiss plateau data vs. Swiss plateau calibrated model

A4: Calculation of the insecticide landuse index UIAR

As a rough proxy to assess the micropollutant state we use a landuse index $UIAR$ that quantifies the proportion of the different crops and urban area in the catchment weighted by an estimation of their contribution of insecticides

$$UIAR = f_{\text{urban}} u + \sum_i f_{\text{crop } i} n_i$$

where f_{urban} is the proportion of urban area in the upstream subcatchment, $u = 0.6$ is a factor that quantifies the relative contribution of insecticides from urban areas (Vermeiren *et al.,* submitted), $f_{\text{crop } i}$ is the proportion of crop i in the catchment and n_i is the average number of insecticide treatments of this crop per year with

$n_{\text{orchards}} = 3.10, n_{\text{vegetables}} = 2.66, n_{\text{rapeseed}} = 1.82,\ n_{\text{potatoes}} = 0.44, n_{\text{legumes}} = 0.38,$ $n_{\text{vineyards}} = 0.37,\ n_{\text{beets}} = 0.07, n_{\text{grains}} = 0.03,\ n_{\text{corn}} = 0.01$ (FOEN, 2014; FSO, 2008; Spycher et al., 2015; swisstopo, 2010).

A5: Correlation of biotic indices with catchment scale assessment at monitoring sites

Table A2: Statistical test results on the relationship between one of two biotic indices (IBCH or Fish Assessment) and catchment scale assessments of five objectives and their different alternatives, for subcatchments delineated upstream of 193 biotic monitoring sites in the Toess, Mönchaltdorfer Aa, Suhre and Broye catchments. Selected alternatives for each criterion shown in bold font.

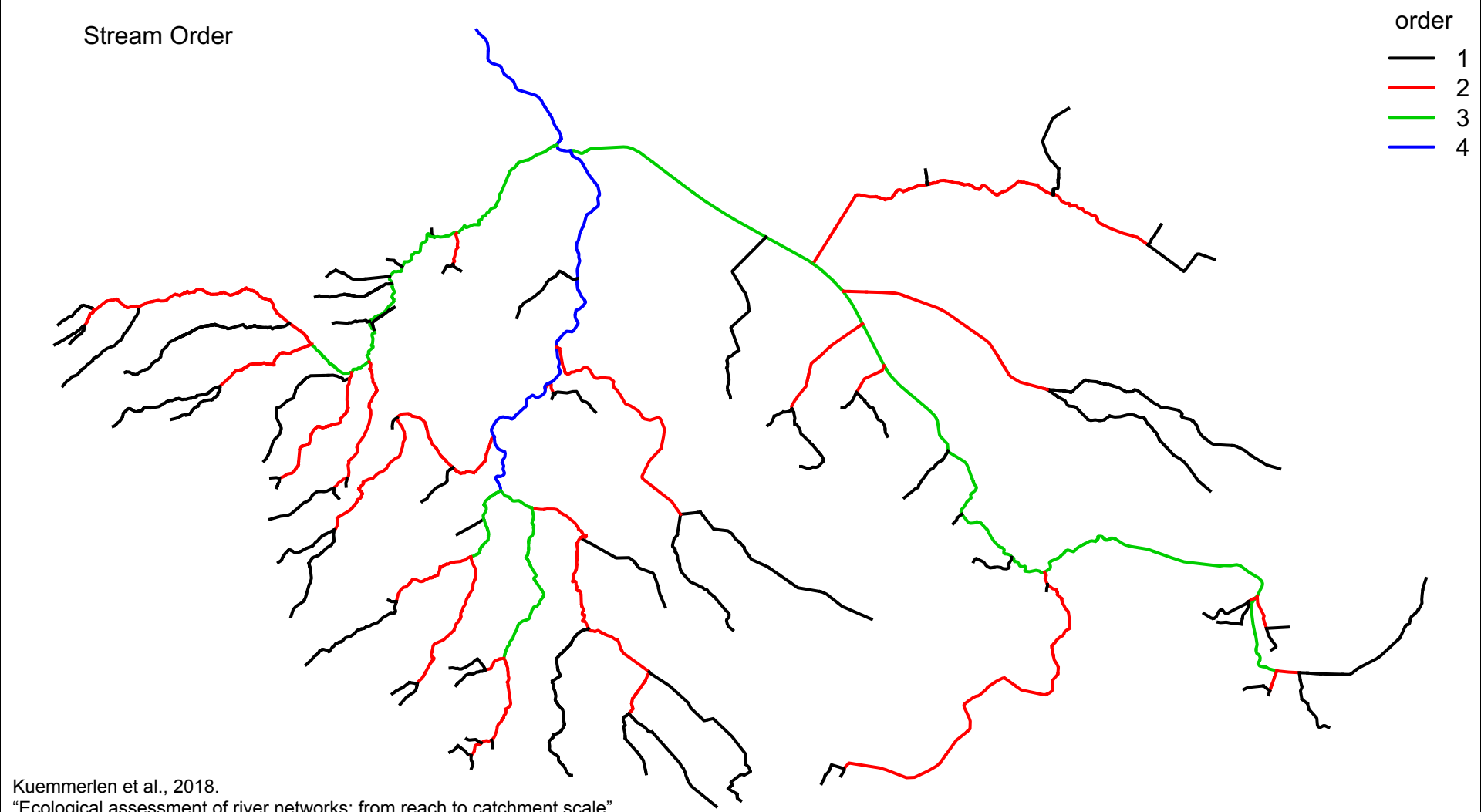
Biotic index	Objective	Sub-Objective	Version	n	r	R^2	p-value	Slope	Intercept
Mean Fish Stream Assessment	Near-natural fish migration potential	Many reachable headwaters: all fish	Ecological state	23	0.21	0.01	0.332	4.18	1.58
		Many reachable headwaters: all fish	Culverts	23	-0.09	0.00	0.679	-0.15	1.66
		Many reachable headwaters: trout	Large barriers	23	0.42	0.06	0.061	0.50	1.54
		Many reachable headwaters: trout	Large barriers & ecological state	23	0.20	0.01	0.373	2.88	1.64
		Many reachable headwaters: trout	Large barriers & culverts	23	0.44	0.08	0.048	0.75	1.52
		Many reachable headwaters: other fish	Small barriers	23	-0.18	0.03	0.459	-1.47	1.72
		Many reachable headwaters: other fish	Small barriers & ecological state	23	0.20	0.01	0.396	2.69	1.66
		Many reachable headwaters: other fish	Small barriers & culverts	23	0.06	0.00	0.801	-0.57	1.69
		Many reachable headwaters: all fish	Ecological state	23	-0.06	0.03	0.777	-4.80	1.63
		Many reachable headwaters: all fish	Culverts	23	-0.05	0.00	0.835	0.14	1.52
		Many reachable headwaters: trout	Large barriers	23	0.14	0.03	0.535	0.33	1.49
		Many reachable headwaters: trout	Large barriers & ecological state	23	-0.06	0.03	0.777	-4.92	1.63
		Many reachable headwaters: trout	Large barriers & culverts	23	0.27	0.06	0.219	0.53	1.46
		Many reachable headwaters: other fish	Small barriers	23	-0.04	0.00	0.862	-0.24	1.63
		Many reachable headwaters: other fish	Small barriers & ecological state	23	-0.06	0.03	0.777	-4.84	1.63
		Many reachable headwaters: other fish	Small barriers & culverts	23	0.07	0.00	0.744	-0.16	1.62
Mean IBCH (Stream Macroinvertebrates)	**Good mean ecological state of river reaches**	**Good mean state of reaches**	-	**193**	**0.55**	**0.28**	**0.000**	**10.32**	**6.52**
		Many reaches in good state	-	**193**	**0.53**	**0.29**	**0.000**	**4.45**	**10.36**
	Resilience supporting habitats	**Resilience supporting habitats: all fish**	**Ecological state**	**193**	**0.50**	**0.20**	**0.000**	**3.47**	**11.30**
		Resilience supporting habitats: all fish	**Culverts**	**193**	**0.19**	**0.05**	**0.008**	**3.01**	**10.47**
		Resilience supporting habitats: trout	**Large barriers**	**193**	**-0.22**	**0.09**	**0.002**	**-3.29**	**15.03**
		Resilience supporting habitats: trout	**Large barriers & ecological state**	**193**	**0.45**	**0.09**	**0.000**	**3.28**	**11.90**
		Resilience supporting habitats: trout	Large barriers & culverts	193	-0.09	0.03	0.236	-1.91	14.01
		Resilience supporting habitats: other fish	Small barriers	193	-0.10	0.04	0.163	-2.03	14.08
		Resilience supporting habitats: other fish	**Small barriers & ecological state**	**193**	**0.44**	**0.07**	**0.000**	**3.09**	**12.03**
		Resilience supporting habitats: other fish	Small barriers & culverts	193	-0.03	0.01	0.693	-1.23	13.57
	Low network fragmentation	**Low network fragmentation: all fish**	**Ecological state**	**193**	**0.51**	**0.25**	**0.000**	**4.45**	**10.03**
		Low network fragmentation: all fish	Culverts	193	-0.13	0.00	0.063	6.91	6.09
		Low network fragmentation: trout	**Large barriers**	**193**	**-0.22**	**0.09**	**0.002**	**-3.29**	**15.03**
		Low network fragmentation: trout	**Large barriers & ecological state**	**193**	**0.32**	**0.03**	**0.000**	**1.85**	**12.22**
		Low network fragmentation: trout	**Large barriers & culverts**	**193**	**-0.21**	**0.09**	**0.003**	**-3.26**	**14.99**
		Low network fragmentation: other fish	Small barriers	193	-0.10	0.04	0.163	-2.03	14.08
		Low network fragmentation: other fish	**Small barriers & ecological state**	**193**	**0.37**	**0.05**	**0.000**	**2.63**	**12.05**
		Low network fragmentation: other fish	Small barriers & culverts	193	-0.08	0.03	0.272	-1.81	13.94
	Near-natural habitat diversity	-	-	**193**	**0.50**	**0.27**	**0.000**	**4.76**	**10.14**

A6: Correlation among spatial criteria

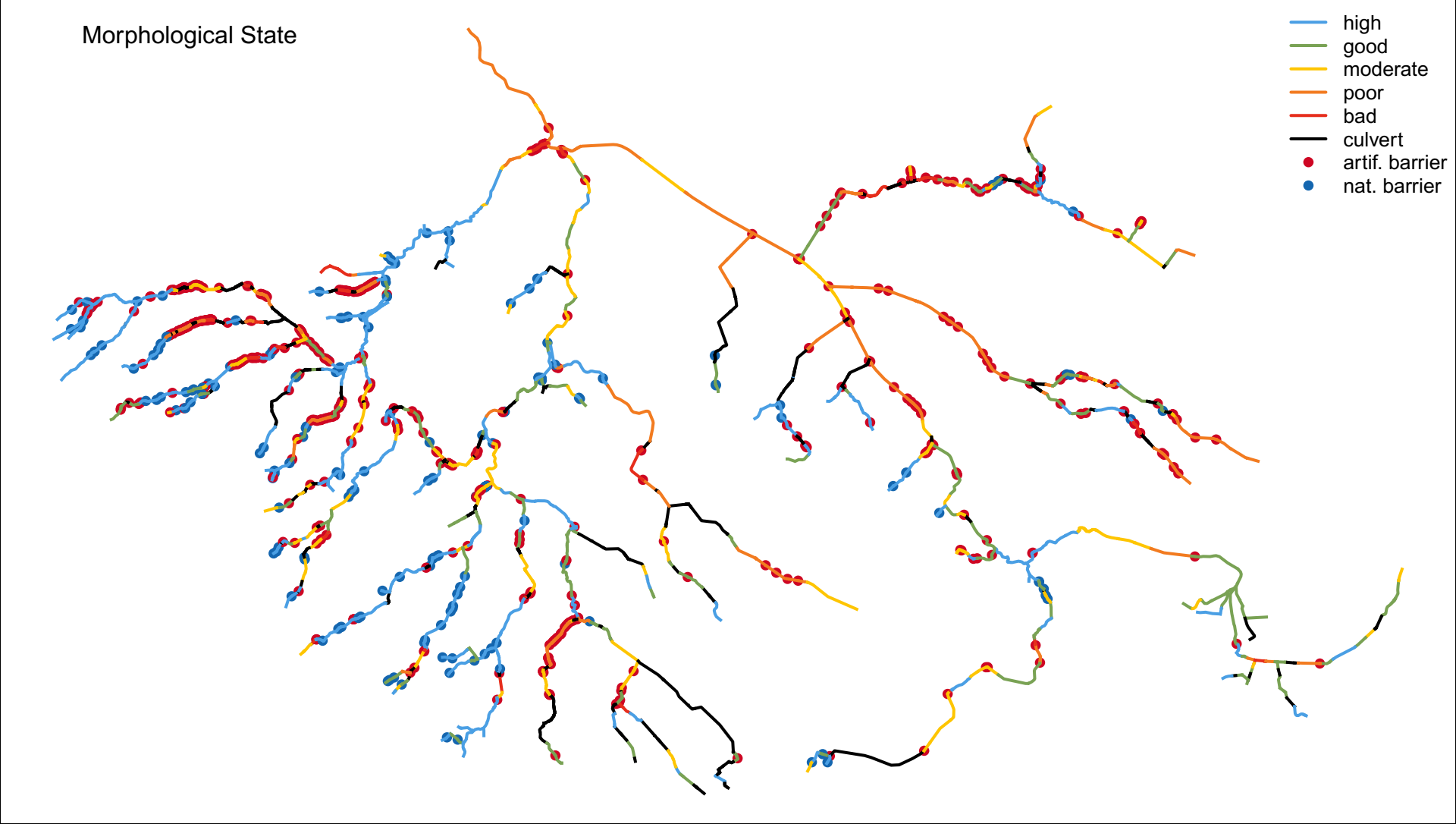
Table A3. Correlation coefficients among recommended versions of the spatial criteria. The lower left half (gray shaded) shows correlations from 182 subcatchments based on biotic monitoring sites, while the upper right half shows correlations from 42 manually selected subcatchments; significant correlation coefficients ($p < 0.05$) are highlighted in bold.

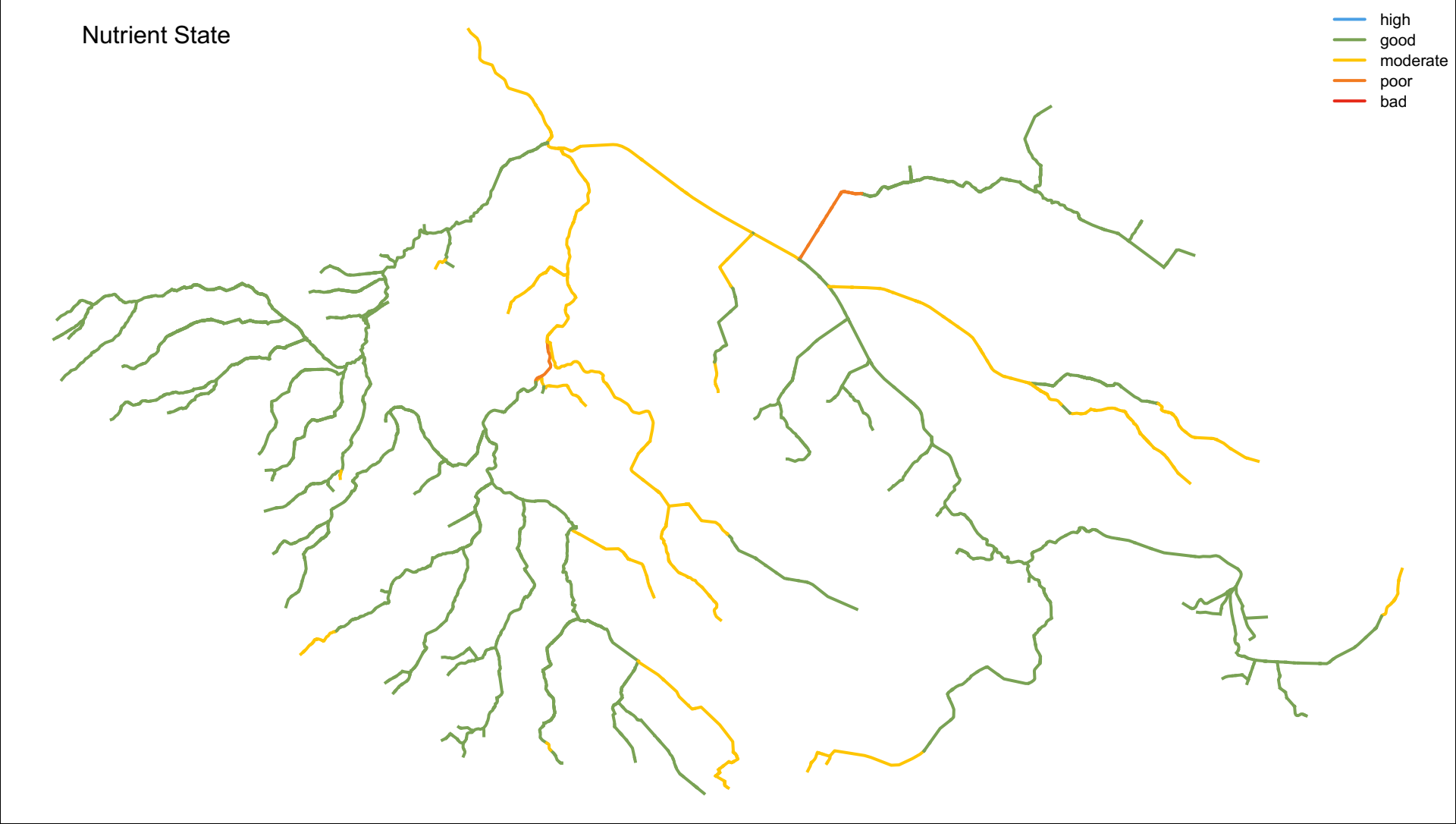
	Good mean state of reaches	Many reaches in good state	Many reachable headwaters: trout	Many reachable headwaters: other fish	Many reachable upstream habitats: trout	Many reachable upstream habitats: other fish	Resilience supporting habitats: ecological state	Resilience supporting habitats: trout	Resilience supporting habitats: other fish	Low network fragmentation: ecological state	Low network fragmentation: trout	Low network fragmentation: other fish	Near-natural habitat diversity
Good mean state of reaches	-	**0.906**	0.045	0.067	0.051	0.099	**0.859**	**0.752**	**0.733**	**0.830**	**0.531**	**0.548**	**0.847**
Many reaches in good state	**0.891**	-	0.042	0.050	0.041	0.105	**0.916**	**0.778**	**0.760**	**0.916**	**0.595**	**0.619**	**0.950**
Many reachable headwaters: trout	-0.230	-0.217	-	**0.781**	**0.737**	**0.525**	**0.188**	**0.229**	**0.200**	**0.148**	**0.246**	0.146	0.082
Many reachable headwaters: other fish	-0.064	-0.039	**0.474**	-	**0.567**	**0.726**	**0.173**	**0.206**	**0.185**	0.107	**0.254**	**0.184**	0.072
Many reachable upstream habitats: trout	0.034	0.035	**0.901**	**0.343**	-	**0.758**	**0.146**	**0.182**	**0.157**	0.097	**0.225**	**0.165**	0.036
Many reachable upstream habitats: other fish	-0.093	-0.025	**0.351**	**0.550**	**0.381**	-	**0.170**	**0.210**	**0.182**	0.124	**0.247**	**0.207**	0.106
Resilience supporting habitats: ecological state	**0.897**	**0.904**	-0.182	-0.090	0.104	-0.032	-	**0.859**	**0.824**	**0.910**	**0.673**	**0.665**	**0.899**
Resilience supporting habitats: trout	**0.881**	**0.800**	-0.079	-0.113	0.110	-0.036	**0.883**	-	**0.975**	**0.813**	**0.860**	**0.857**	**0.766**
Resilience supporting habitats: other fish	**0.854**	**0.768**	0.013	-0.086	0.181	-0.134	**0.840**	**0.936**	-	**0.781**	**0.837**	**0.883**	**0.743**
Low network fragmentation: ecological state	**0.883**	**0.920**	-0.205	-0.142	0.052	-0.003	**0.913**	**0.832**	**0.803**	-	**0.715**	**0.640**	**0.898**
Low network fragmentation: trout	**0.678**	**0.578**	-0.120	-0.073	0.045	0.008	**0.685**	**0.891**	**0.836**	**0.684**	-	**0.899**	**0.581**
Low network fragmentation: other fish	**0.707**	**0.586**	-0.071	-0.031	0.089	-0.111	**0.683**	**0.850**	**0.889**	**0.668**	**0.940**	-	**0.590**
Near-natural habitat diversity	**0.721**	**0.854**	-0.248	-0.225	-0.001	-0.148	**0.789**	**0.623**	**0.609**	**0.827**	**0.388**	**0.413**	-

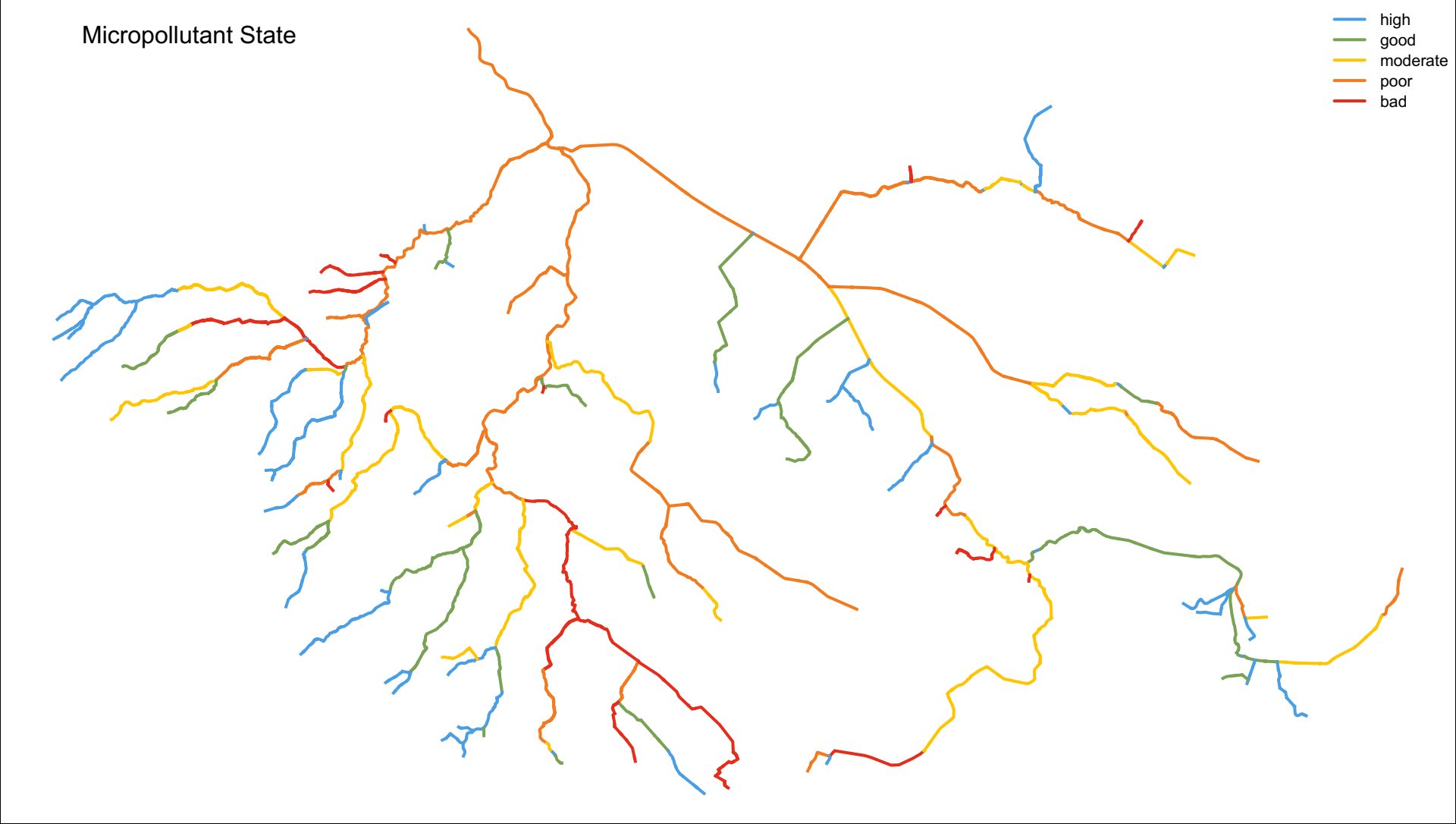
A5 to A8: Visualizations of reach scale assessments and spatial criteria for all four catchments (see separate pdfs).

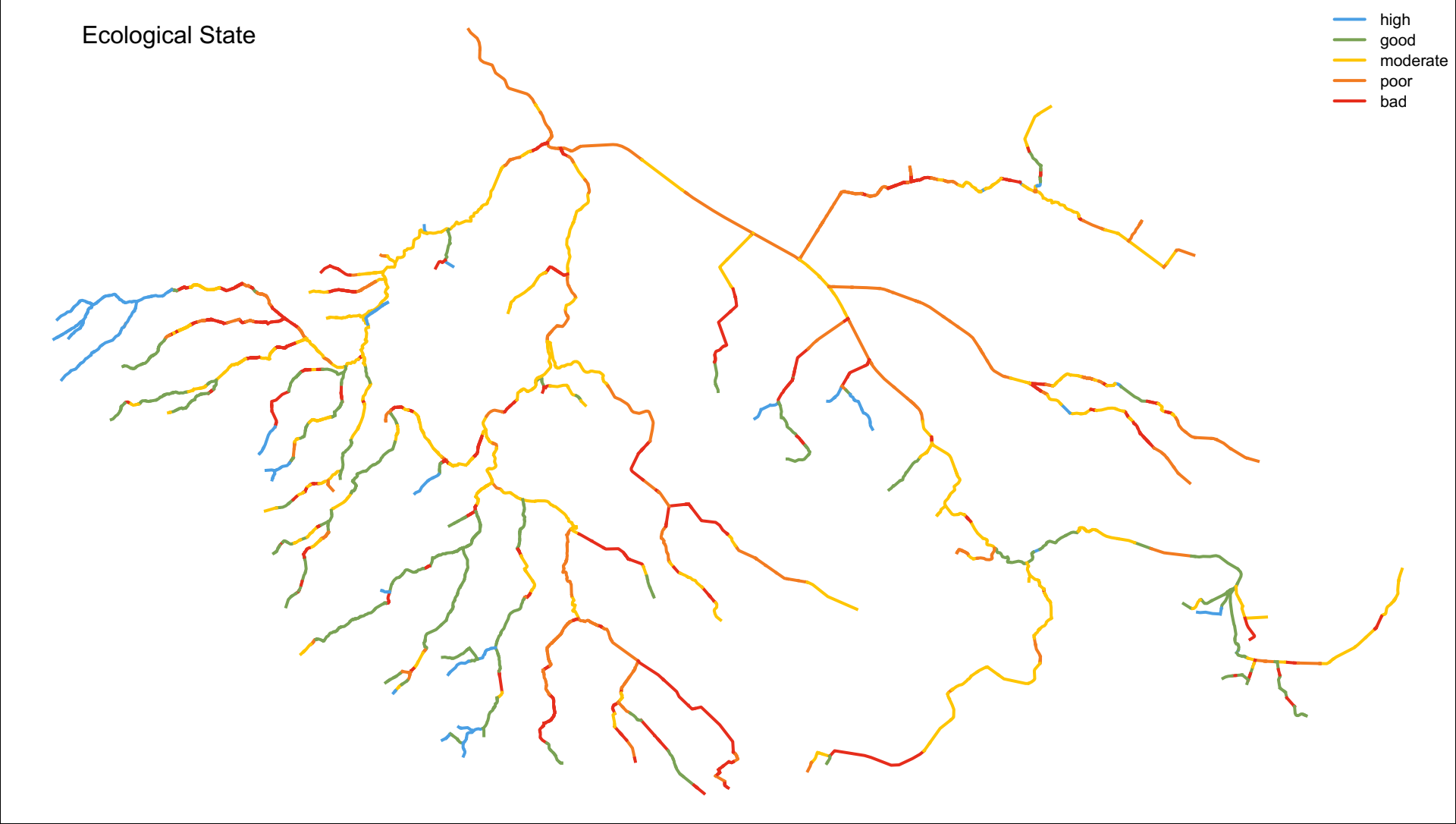


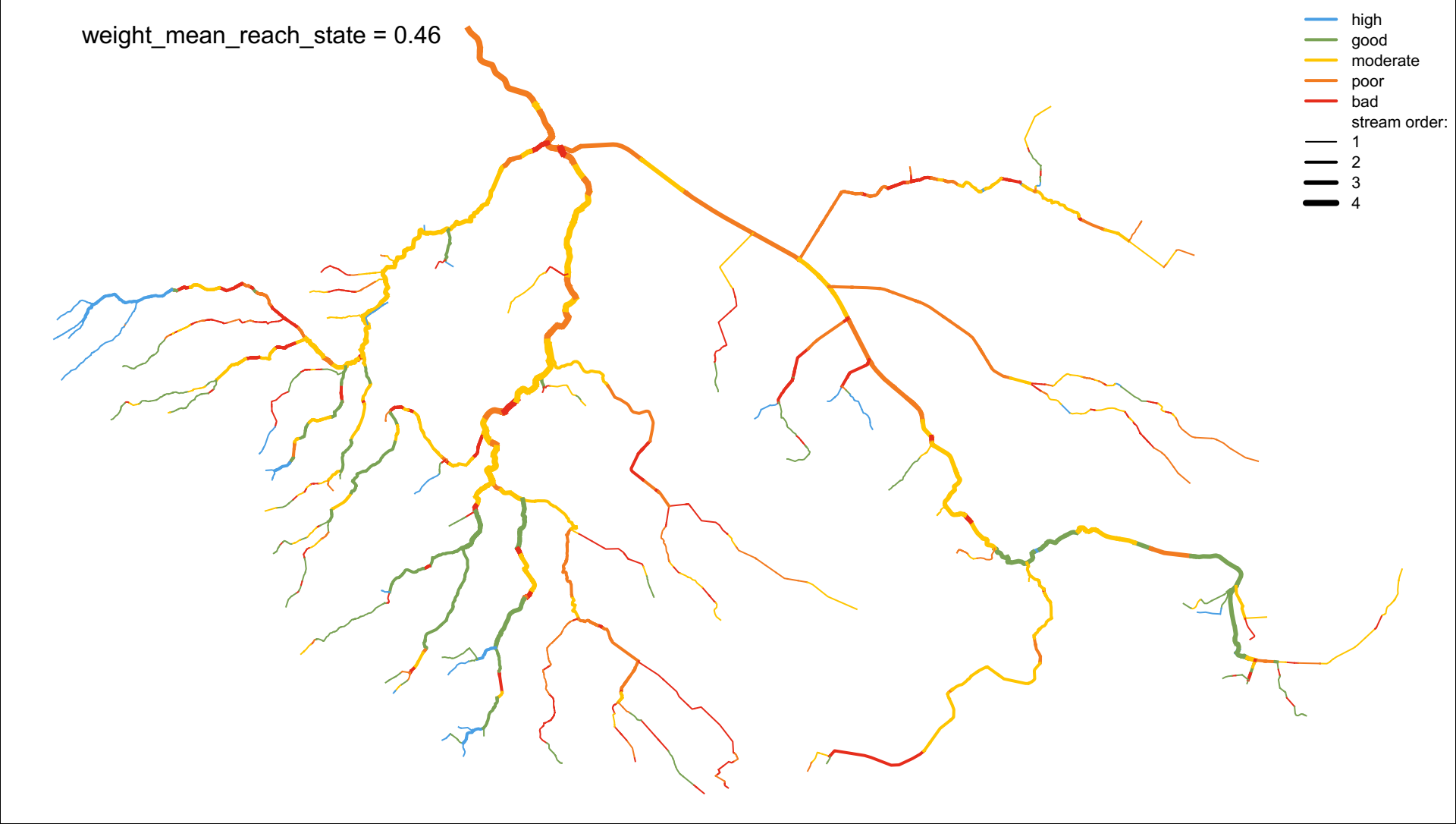
Kuemmerlen et al., 2018.
“Ecological assessment of river networks: from reach to catchment scale”

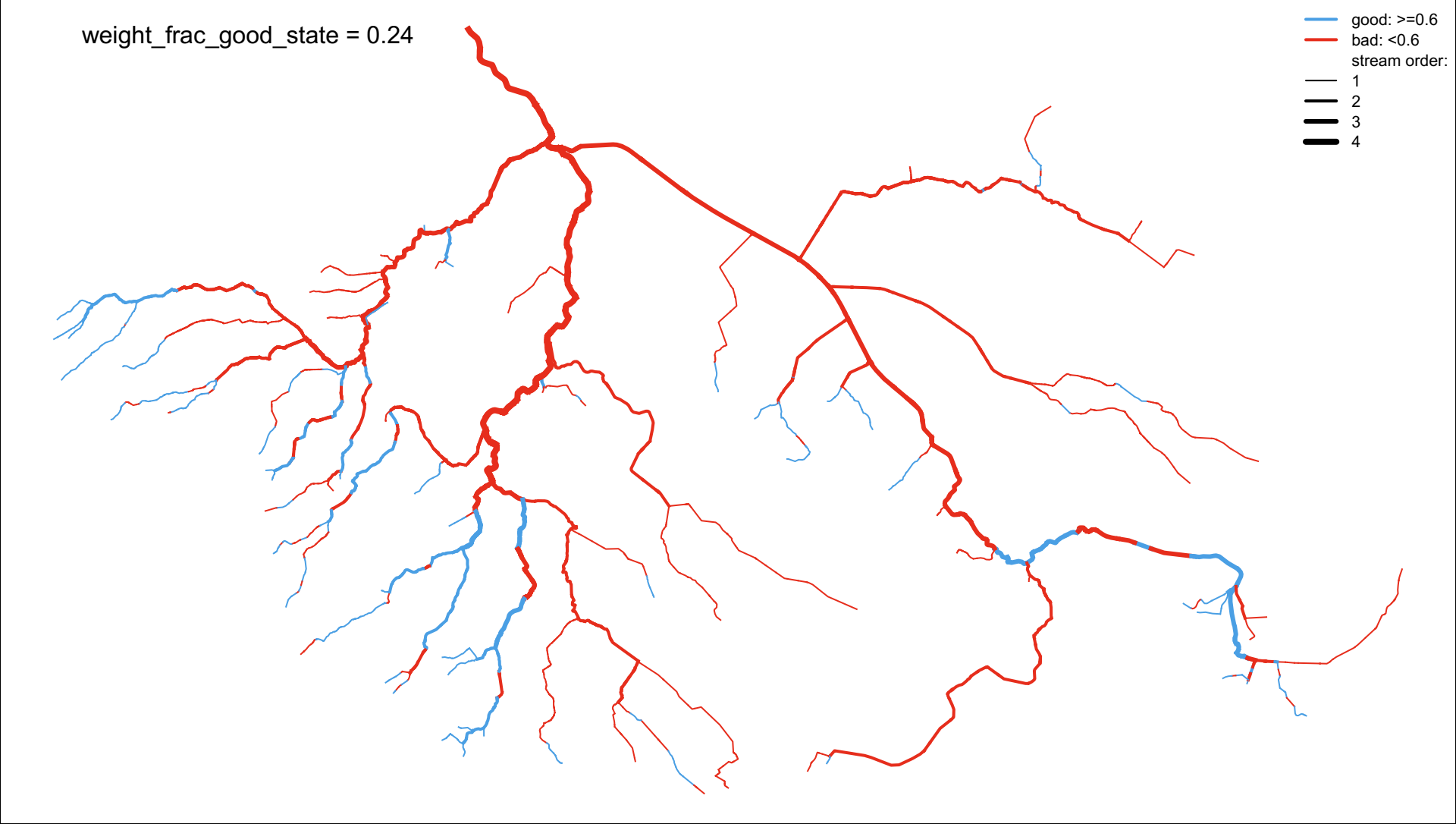

Morphological State
high
good
moderate
poor
bad
culvert
artif. barrier
nat. barrier

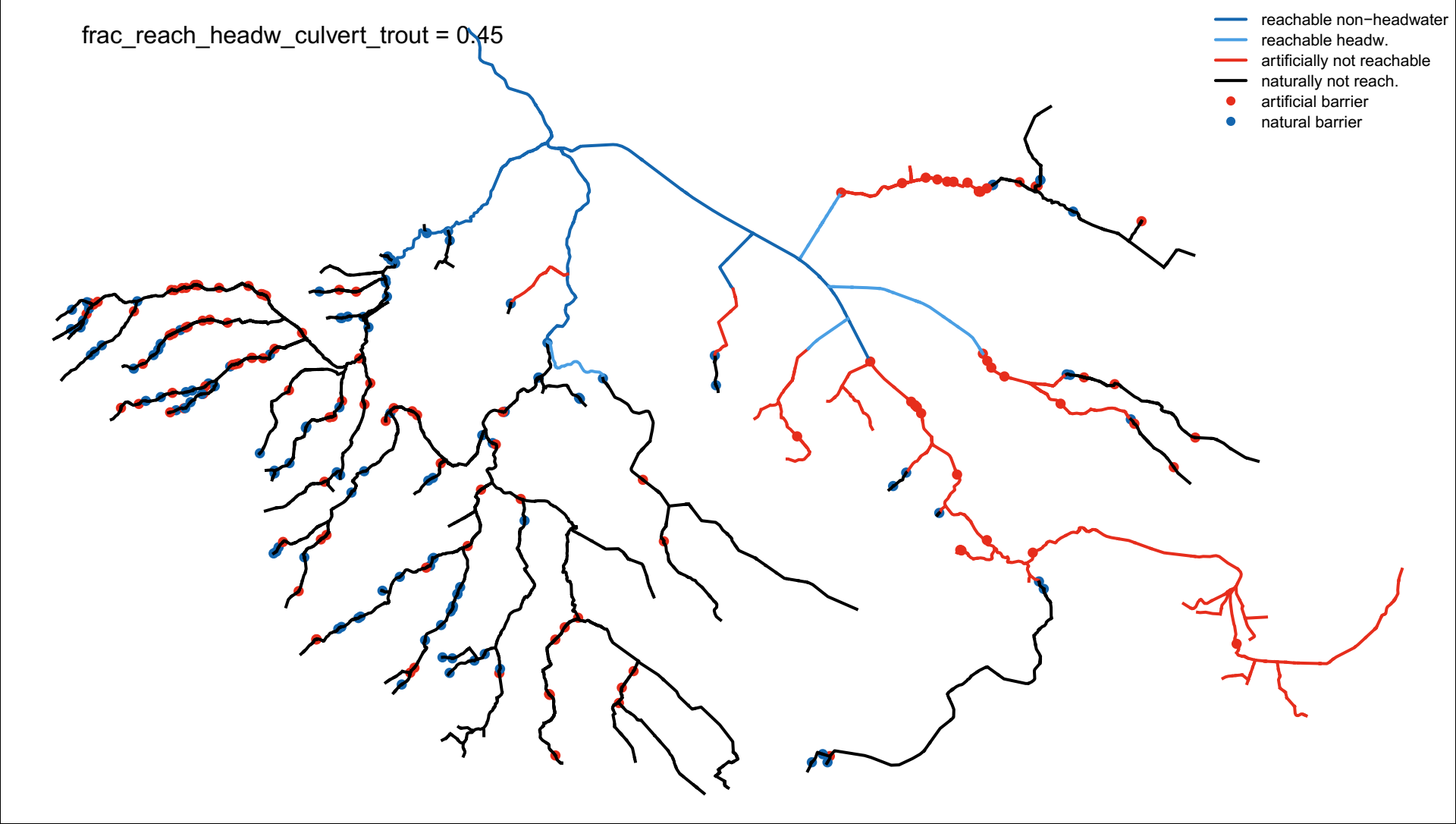

Nutrient State
high
good
moderate
poor
bad

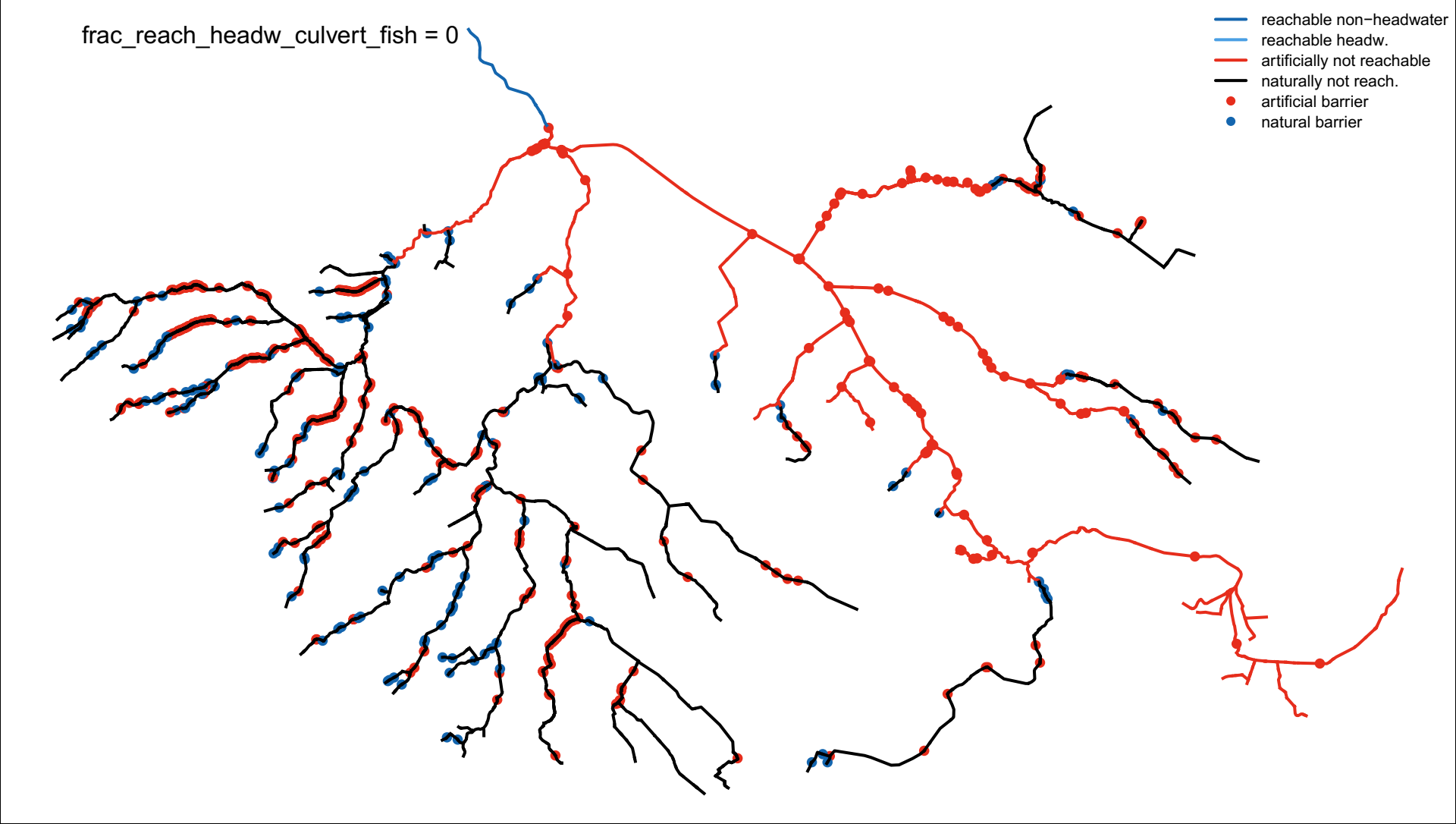

Micropollutant State
high
good
moderate
poor
bad

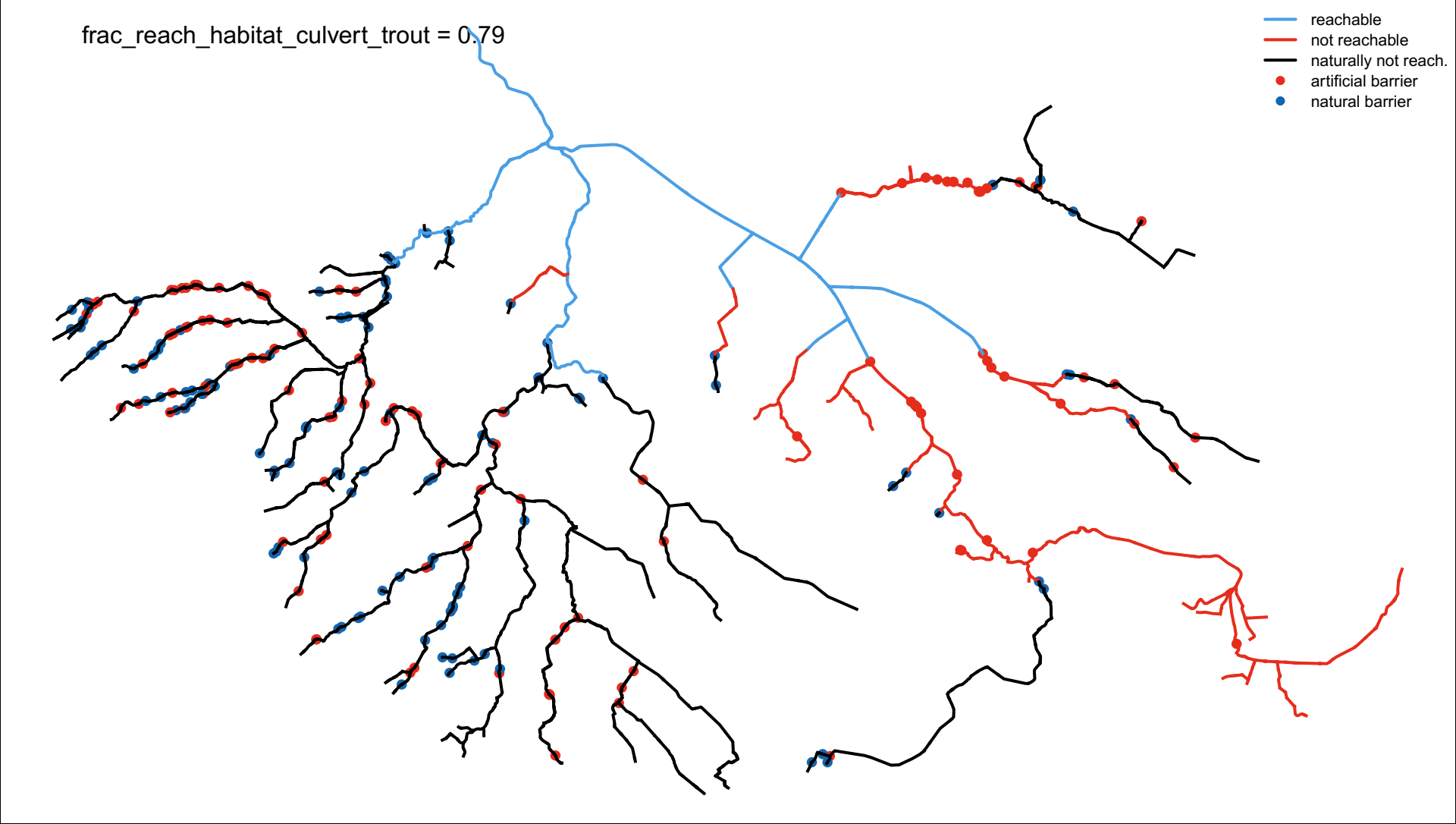

Ecological State
high
good
moderate
poor
bad

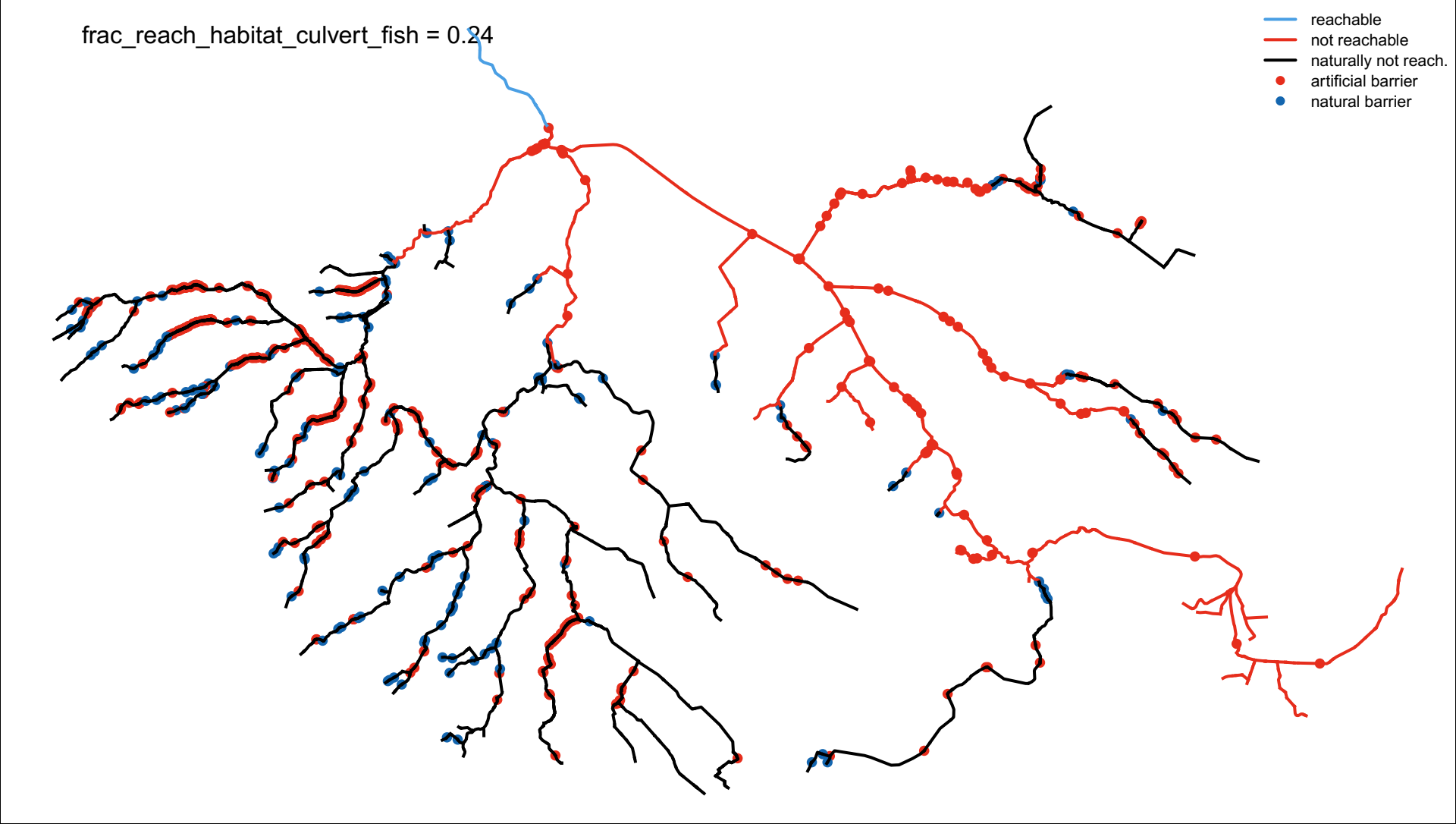

weight_mean_reach_state = 0.46
high
good
moderate
poor
bad
stream order:
1
2
3
4

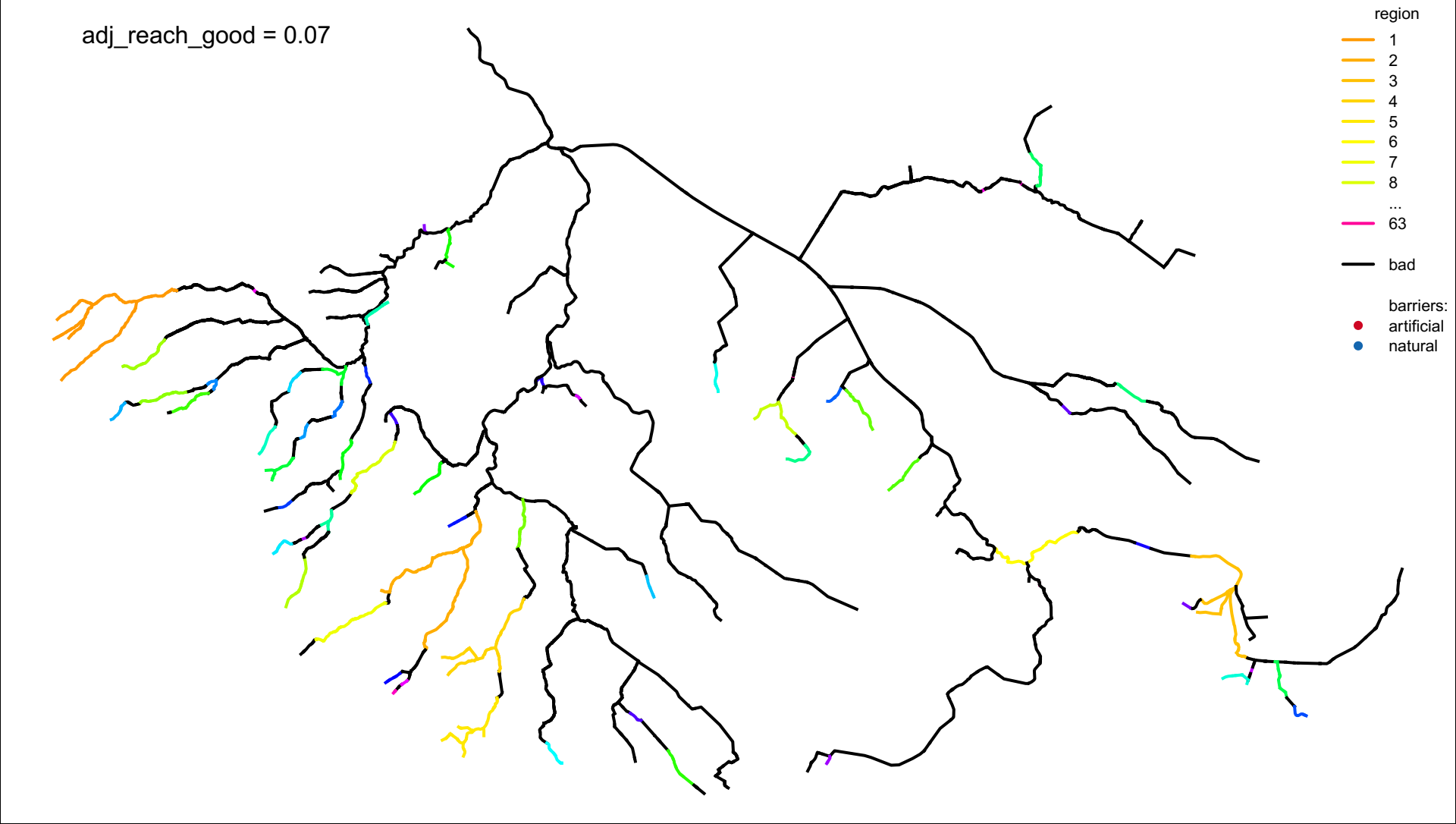

weight_frac_good_state = 0.24
good: >=0.6
bad: <0.6
stream order:
1
2
3
4

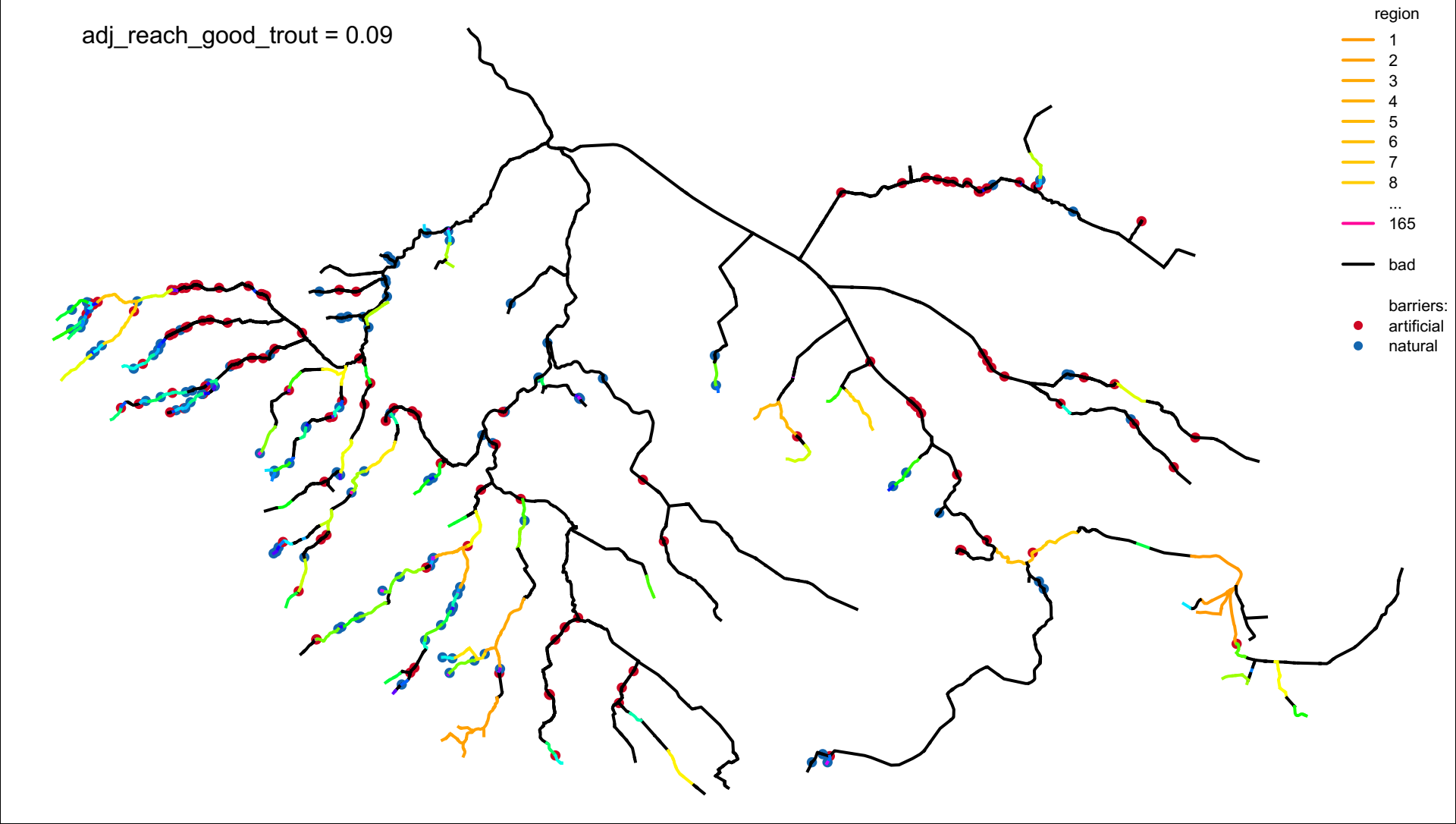

frac_reach_headw_culvert_trout = 0.45
reachable non−headwater
reachable headw.
artificially not reachable
naturally not reach.
artificial barrier
natural barrier

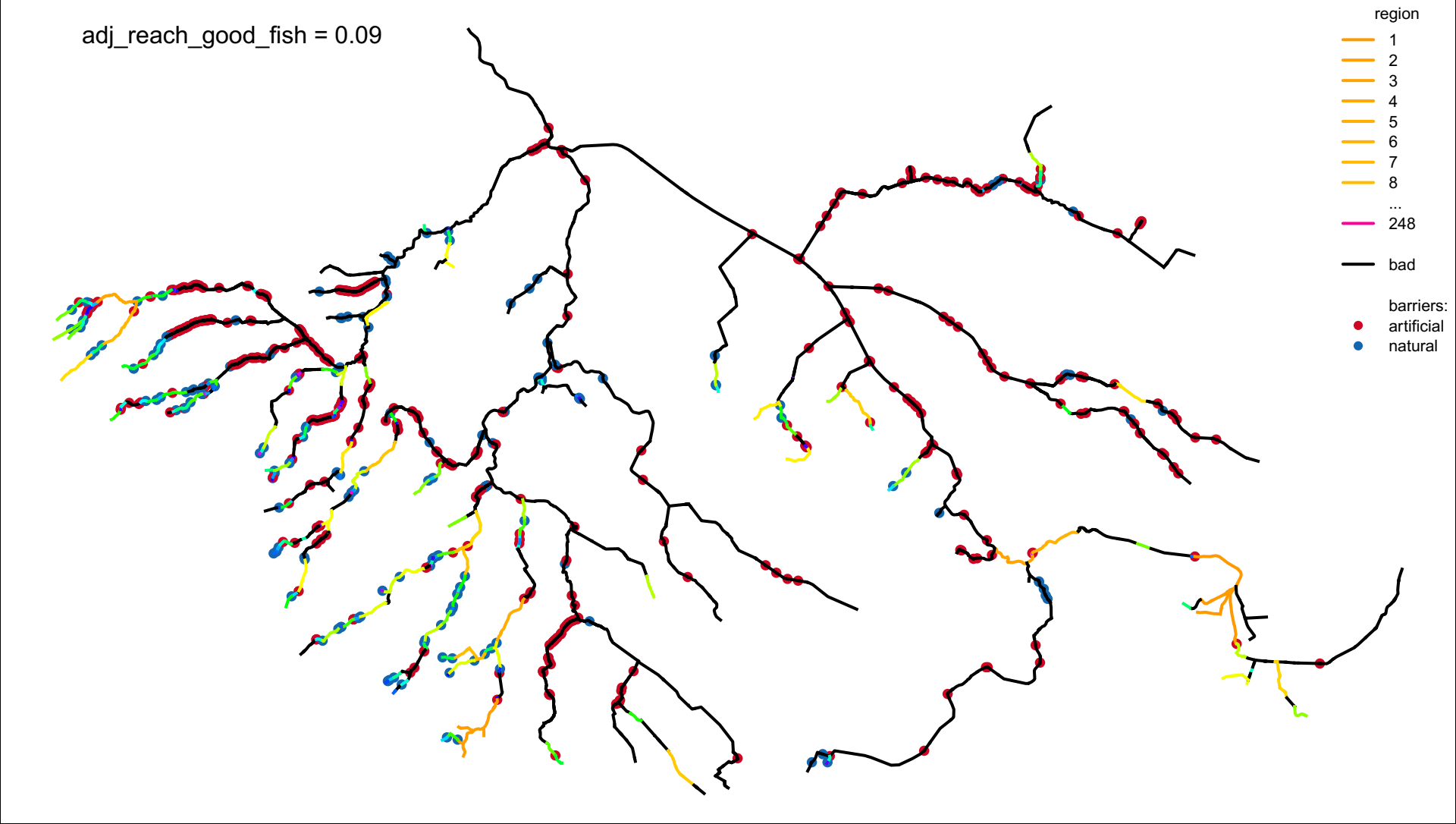

frac_reach_headw_culvert_fish = 0
reachable non−headwater
reachable headw.
artificially not reachable
naturally not reach.
artificial barrier
natural barrier

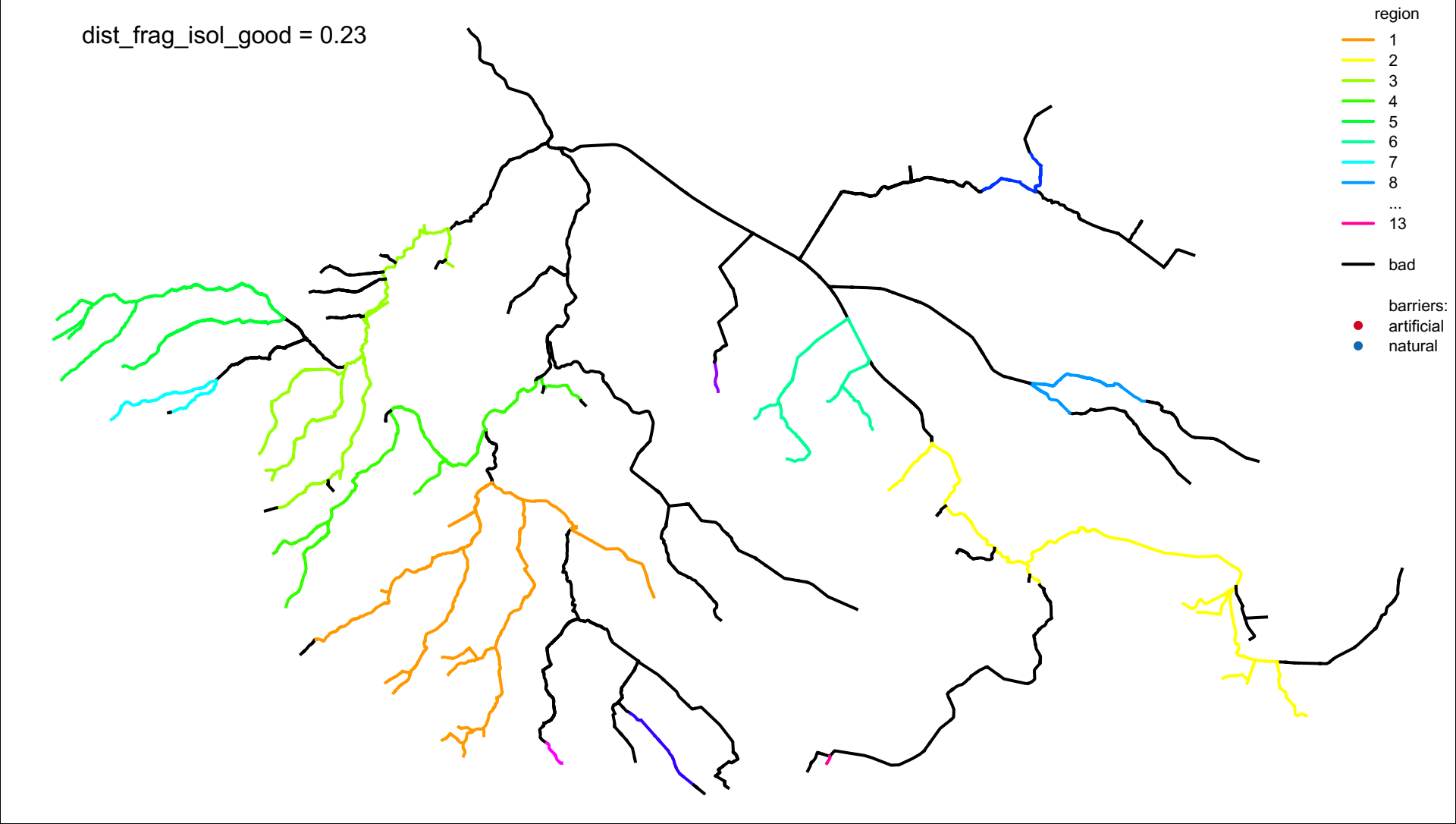

frac_reach_habitat_culvert_trout = 0.79
reachable
not reachable
naturally not reach.
artificial barrier
natural barrier

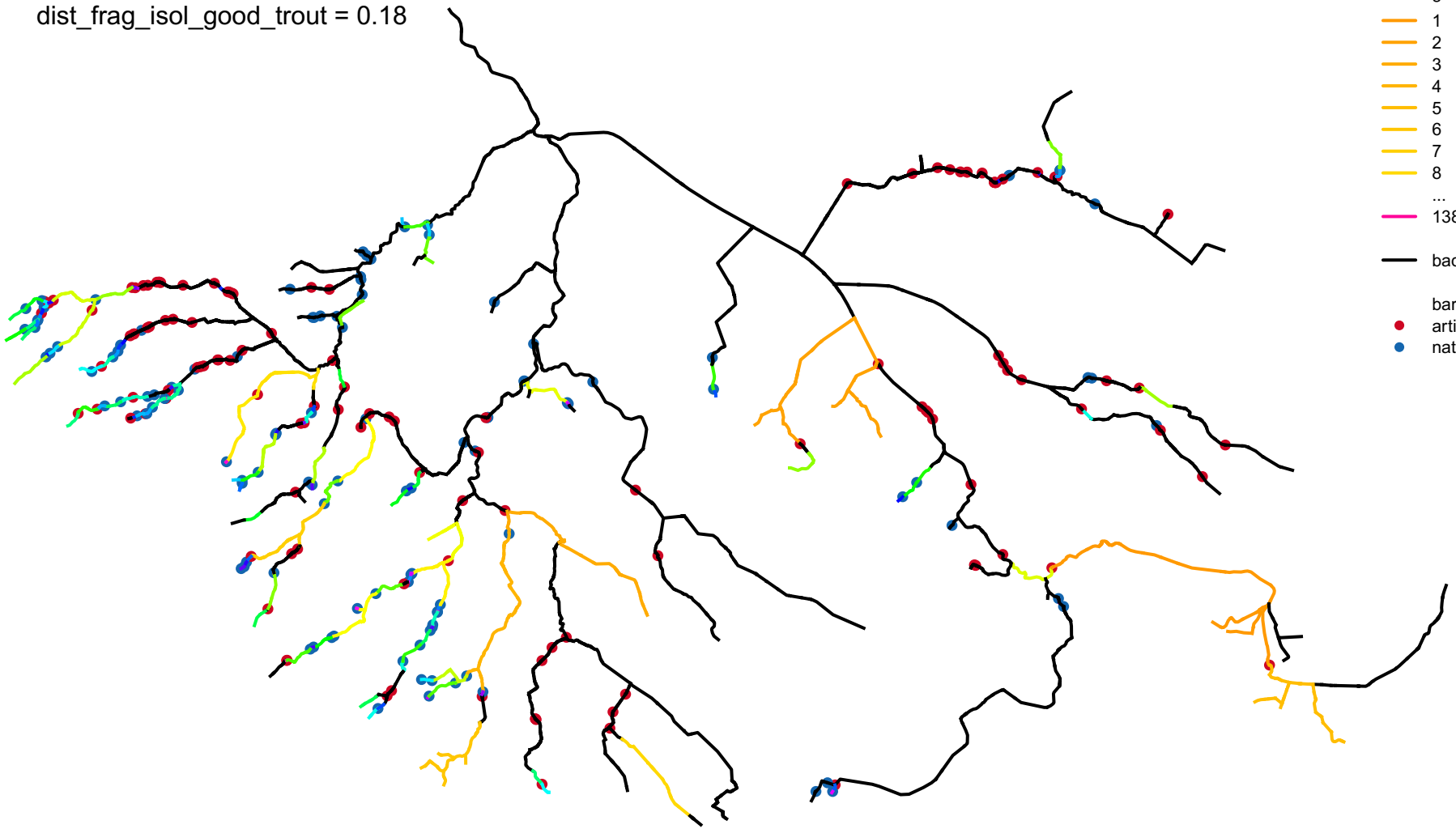

frac_reach_habitat_culvert_fish = 0.24
reachable
not reachable
naturally not reach.
artificial barrier
natural barrier

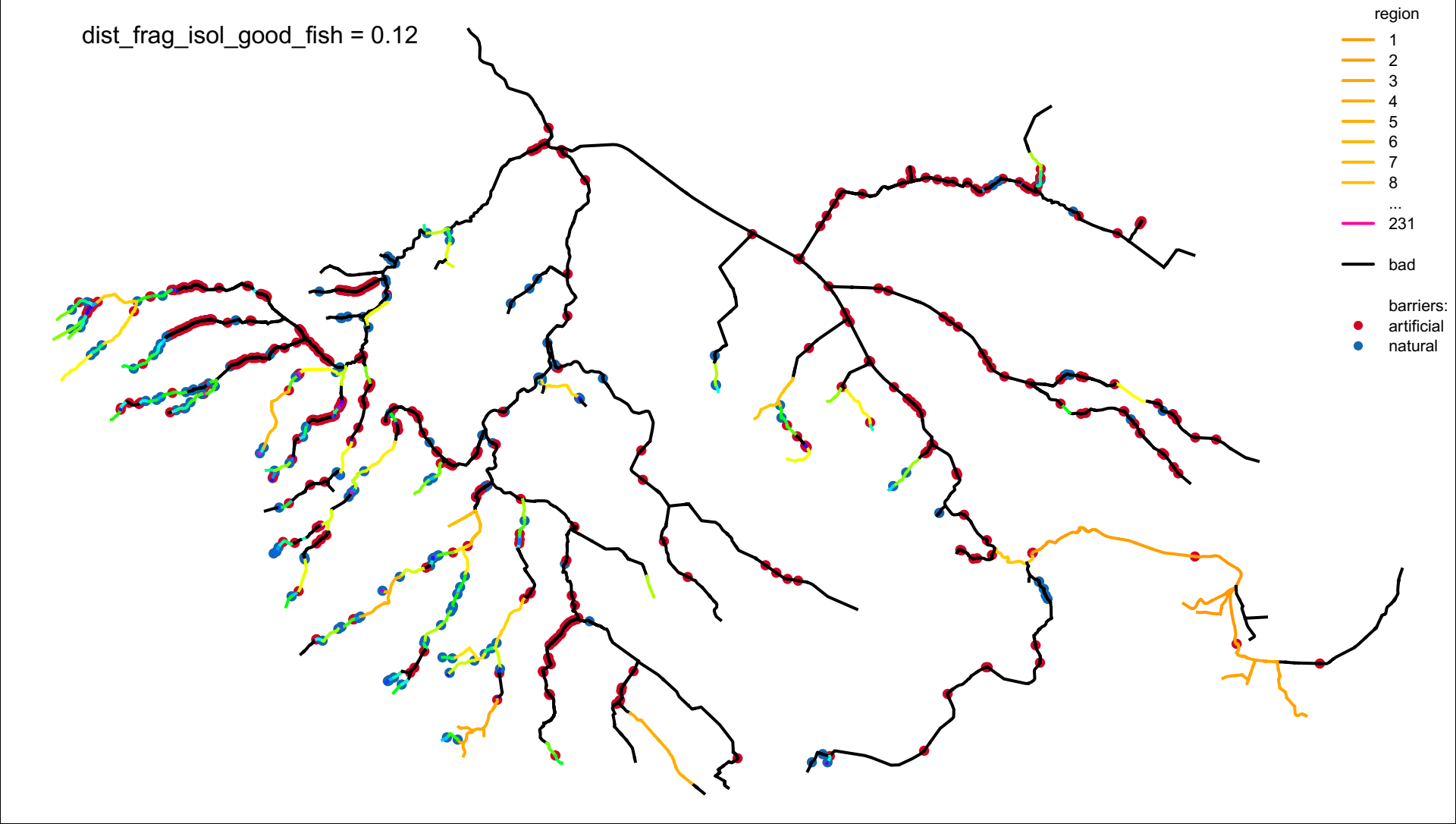

adj_reach_good = 0.07
region
1
2
3
4
5
6
7
8
...
63
bad
barriers:
artificial
natural

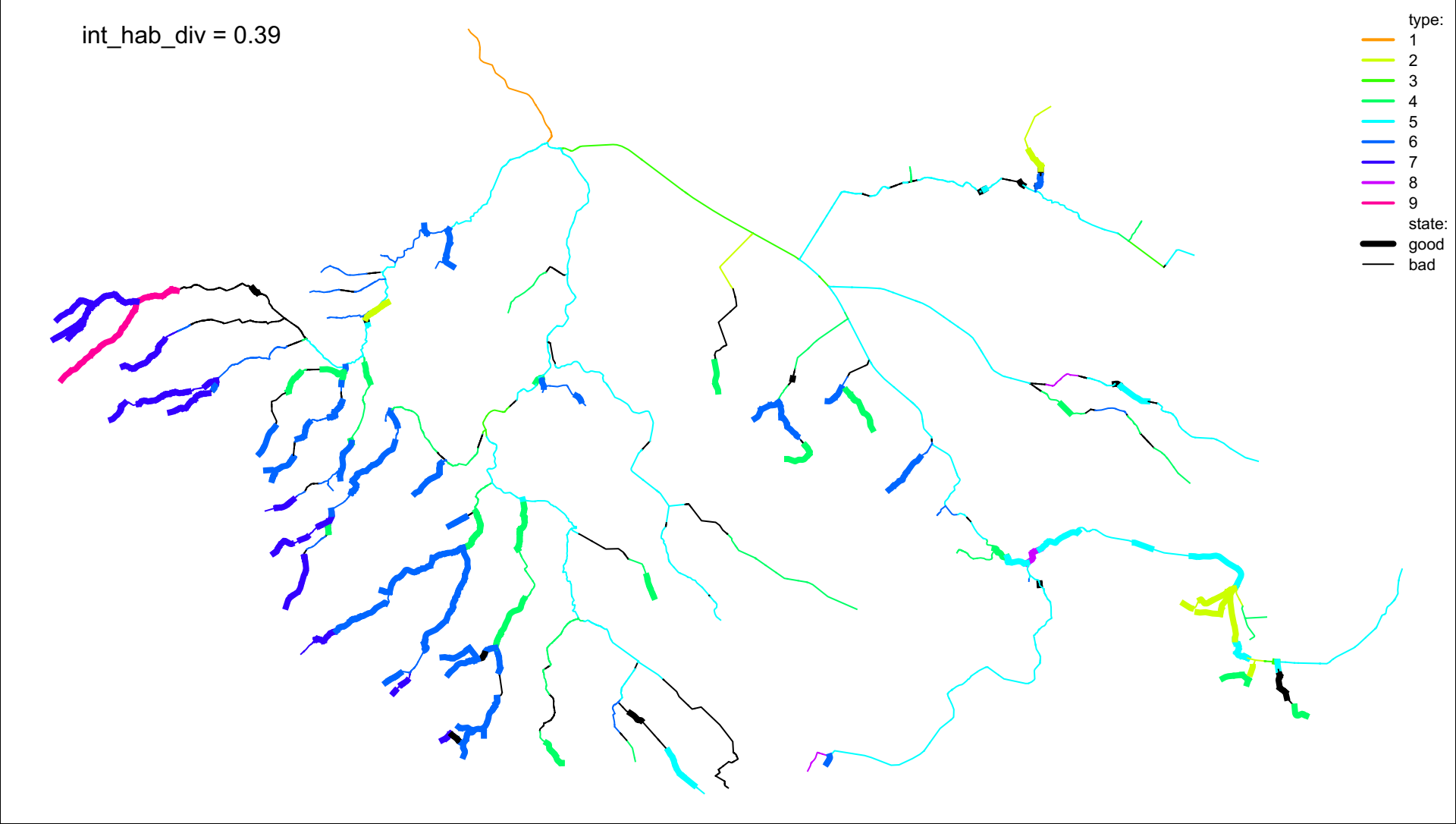

adj_reach_good_trout = 0.09
region
1
2
3
4
5
6
7
8
...
165
bad
barriers:
artificial
natural


adj_reach_good_fish = 0.09
region
1
2
3
4
5
6
7
8
...
248
bad
barriers:
artificial
natural


dist_frag_isol_good = 0.23
region
1
2
3
4
5
6
7
8
...
13
bad
barriers:
artificial
natural

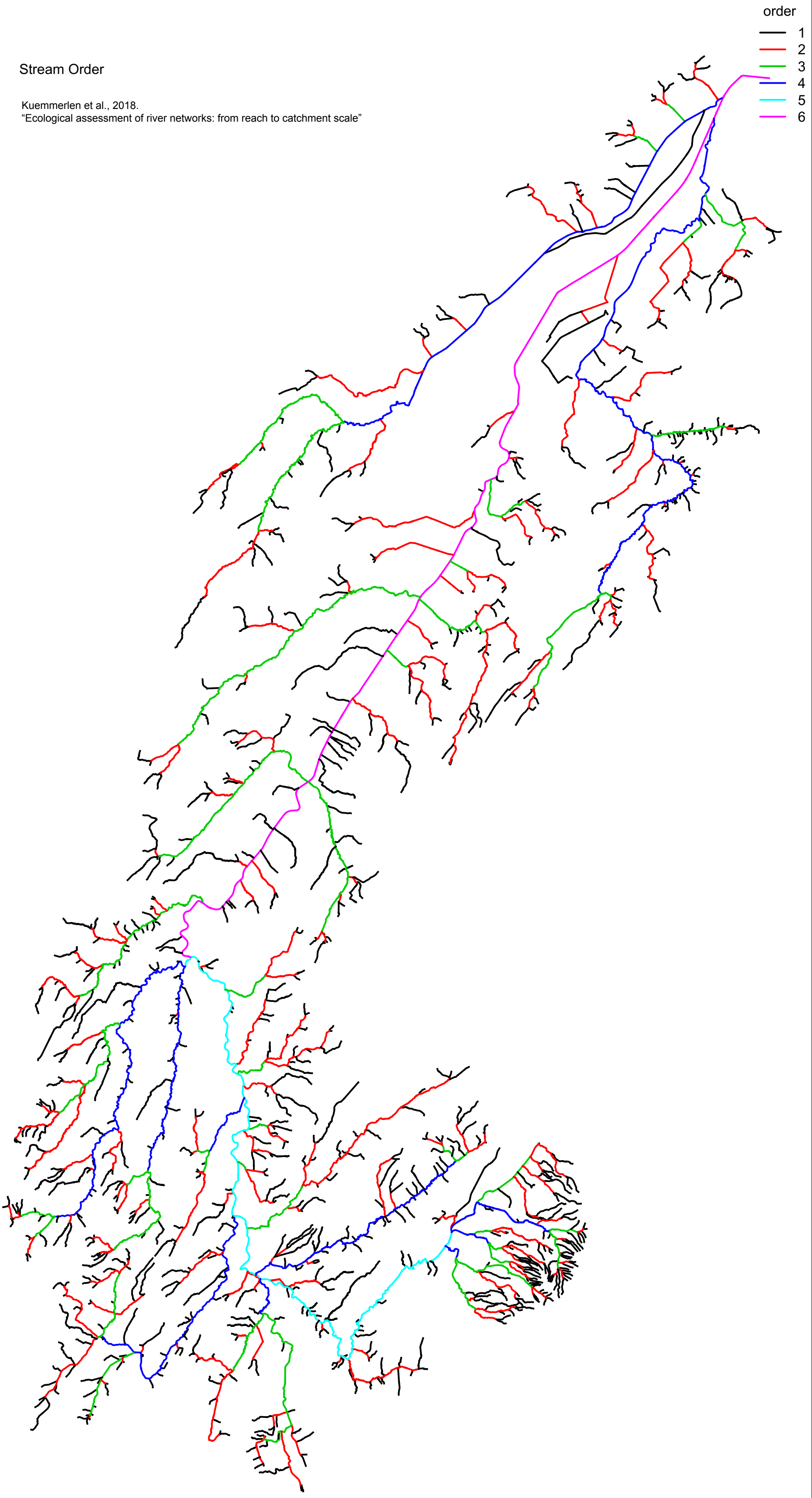

dist_frag_isol_good_trout = 0.18
region
1
2
3
4
5
6
7
8
...
138
bad
barriers:
artificial
natural


dist_frag_isol_good_fish = 0.12
region
1
2
3
4
5
6
7
8
...
231
bad
barriers:
artificial
natural

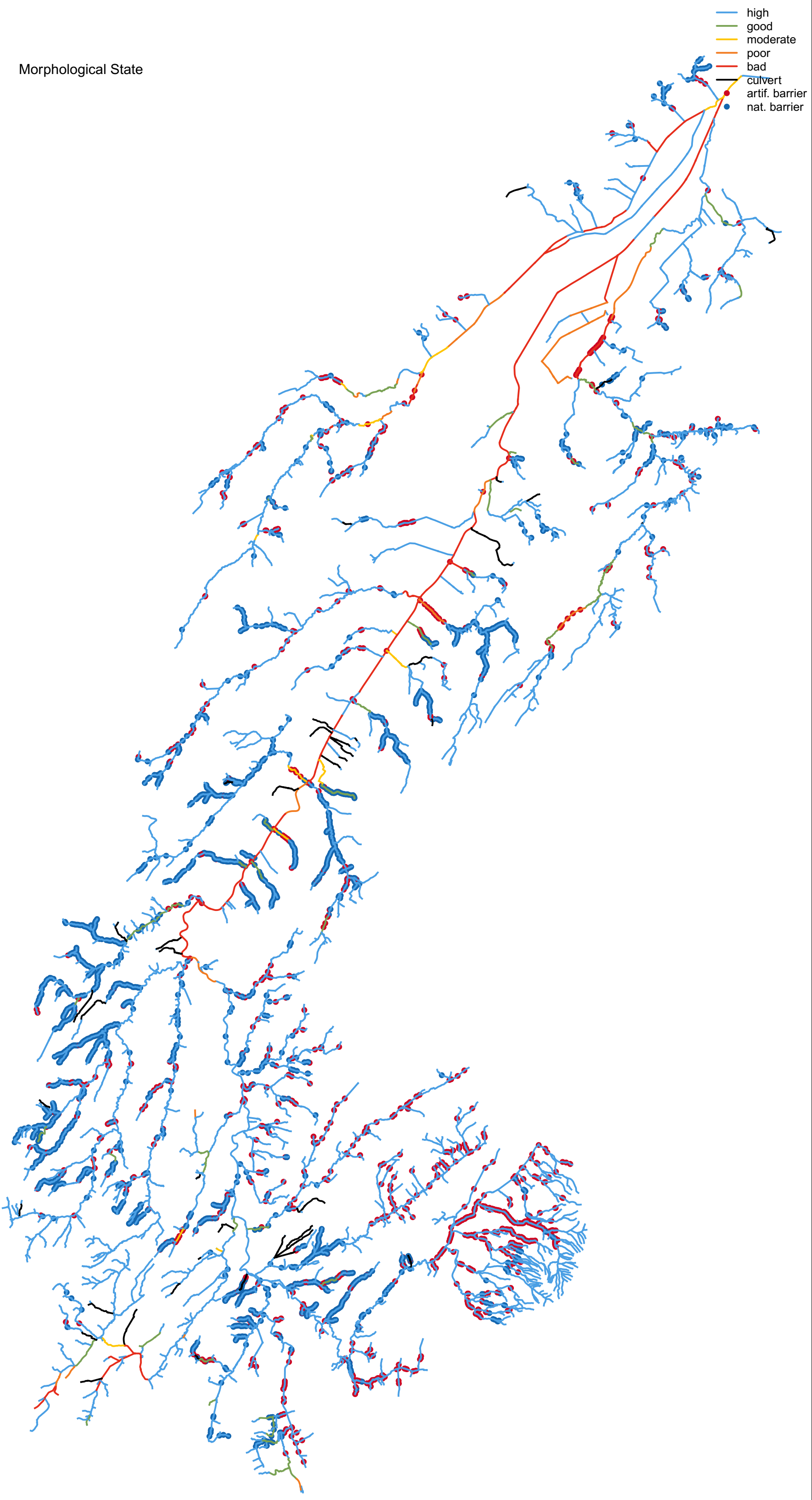

int_hab_div = 0.39
type:
1
2
3
4
5
6
7
8
9
state:
good
bad

Stream Order

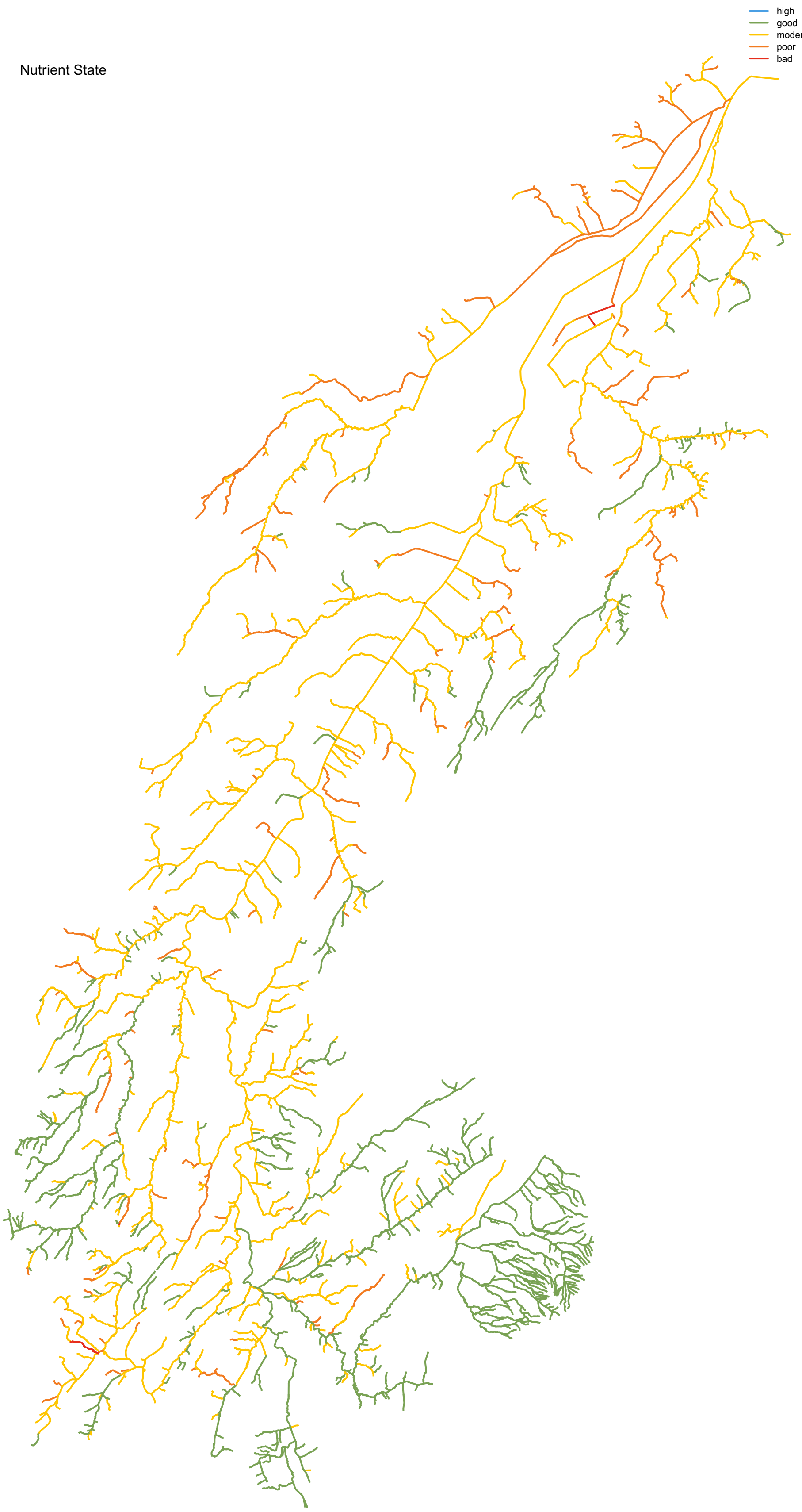
Kuemmerlen et al., 2018.
“Ecological assessment of river networks: from reach to catchment scale”



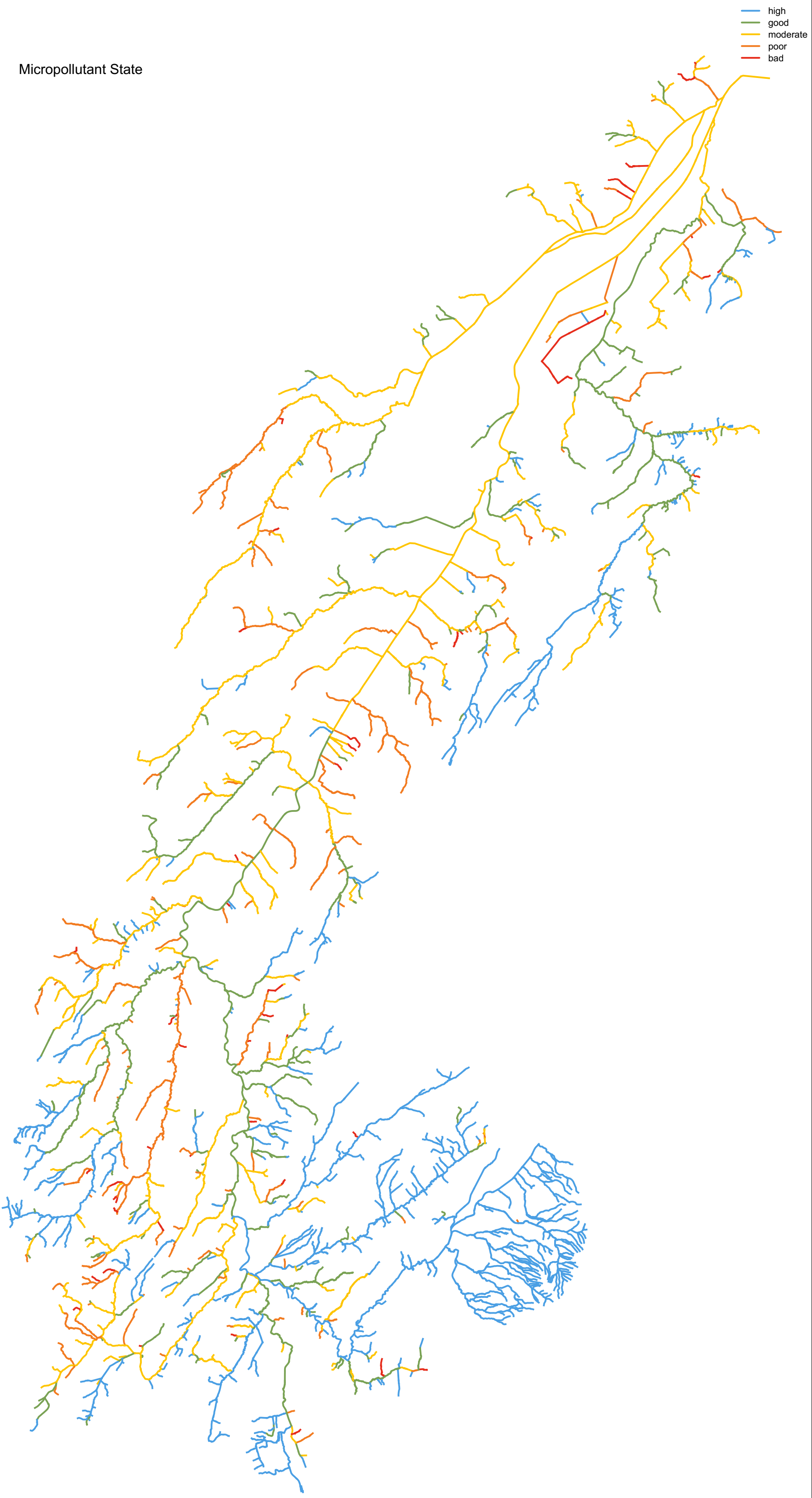
Morphological State



Nutrient State

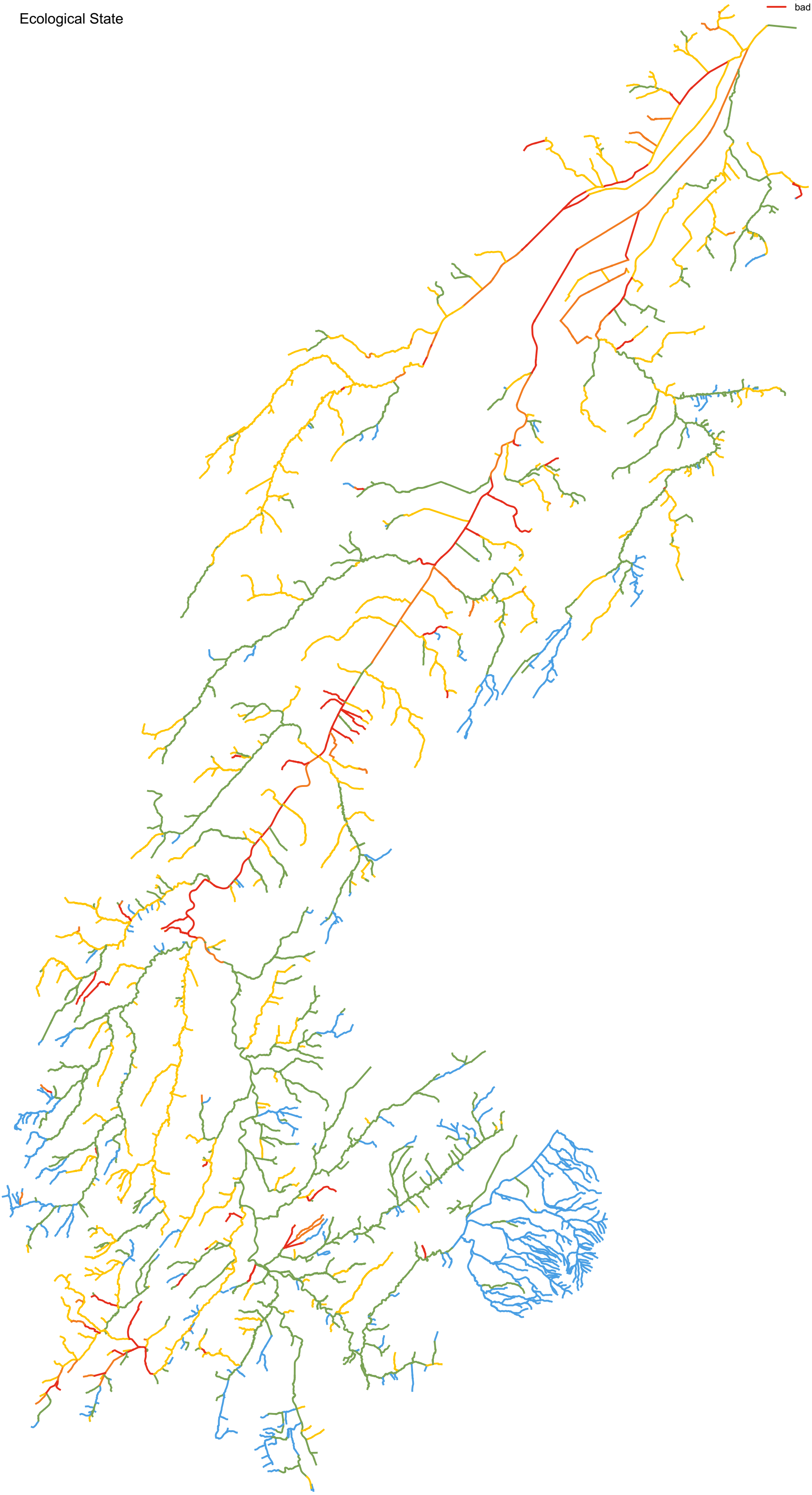


Micropollutant State

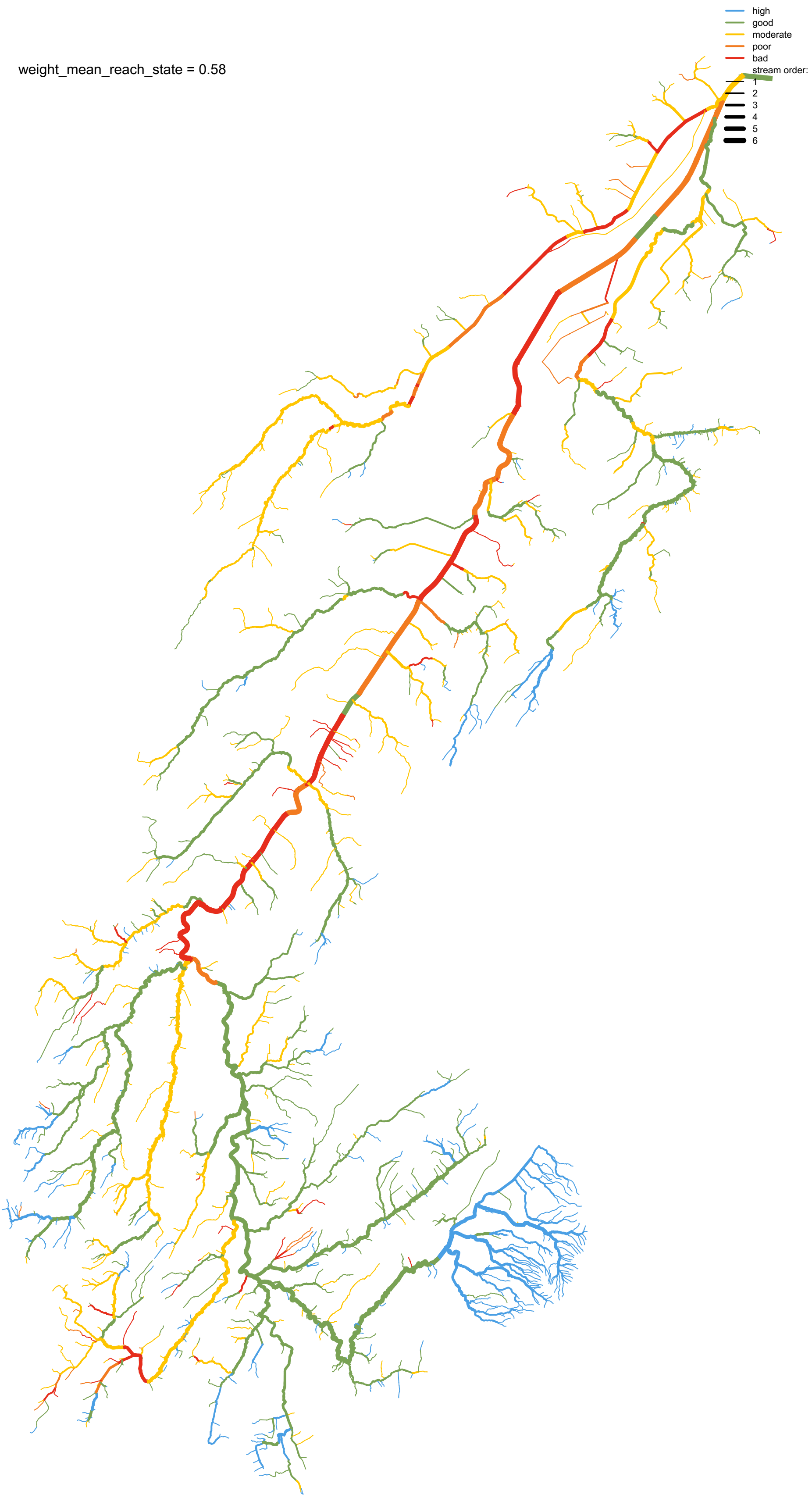


Ecological State

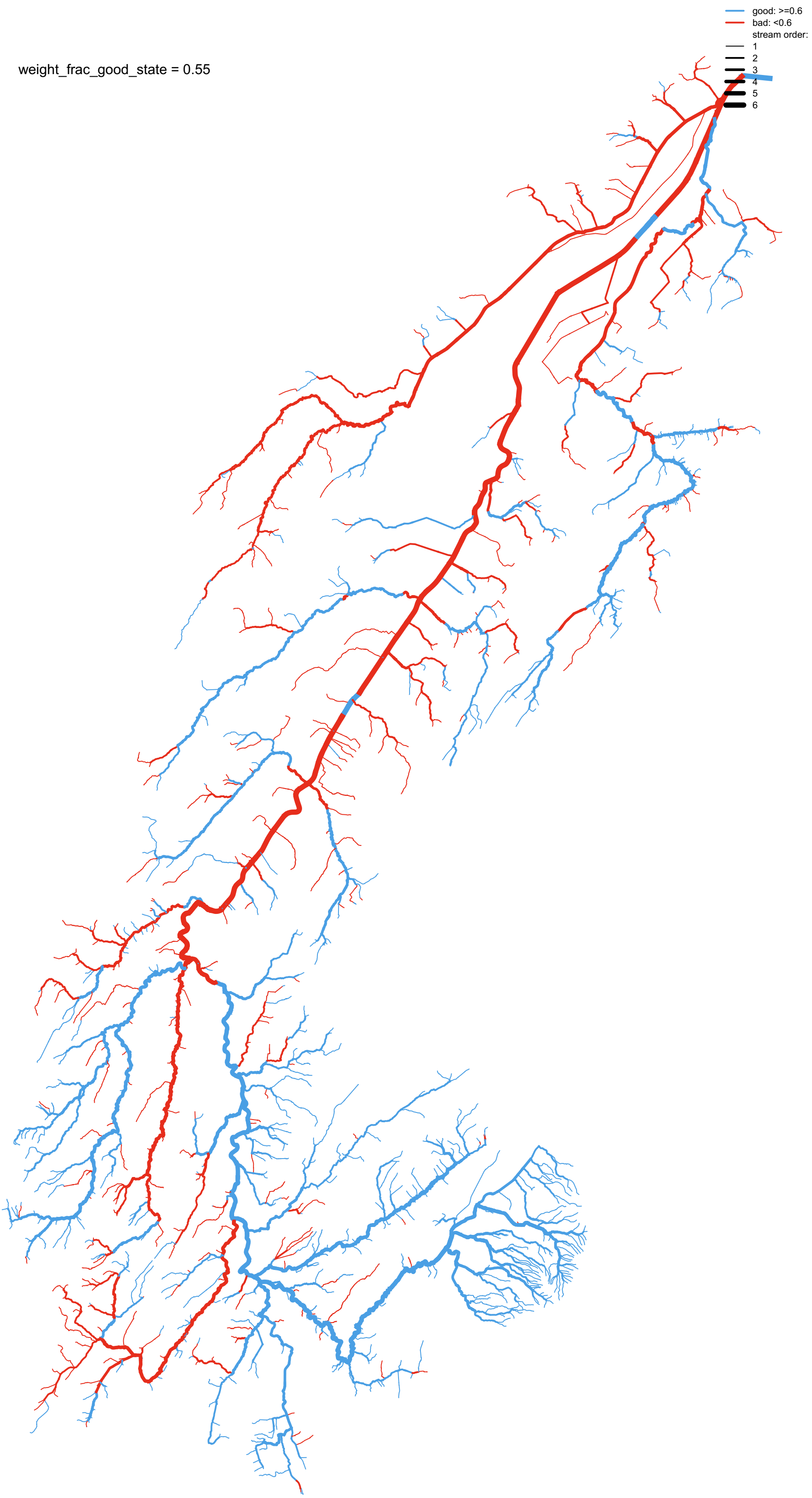
high
good
moderate
poor
bad



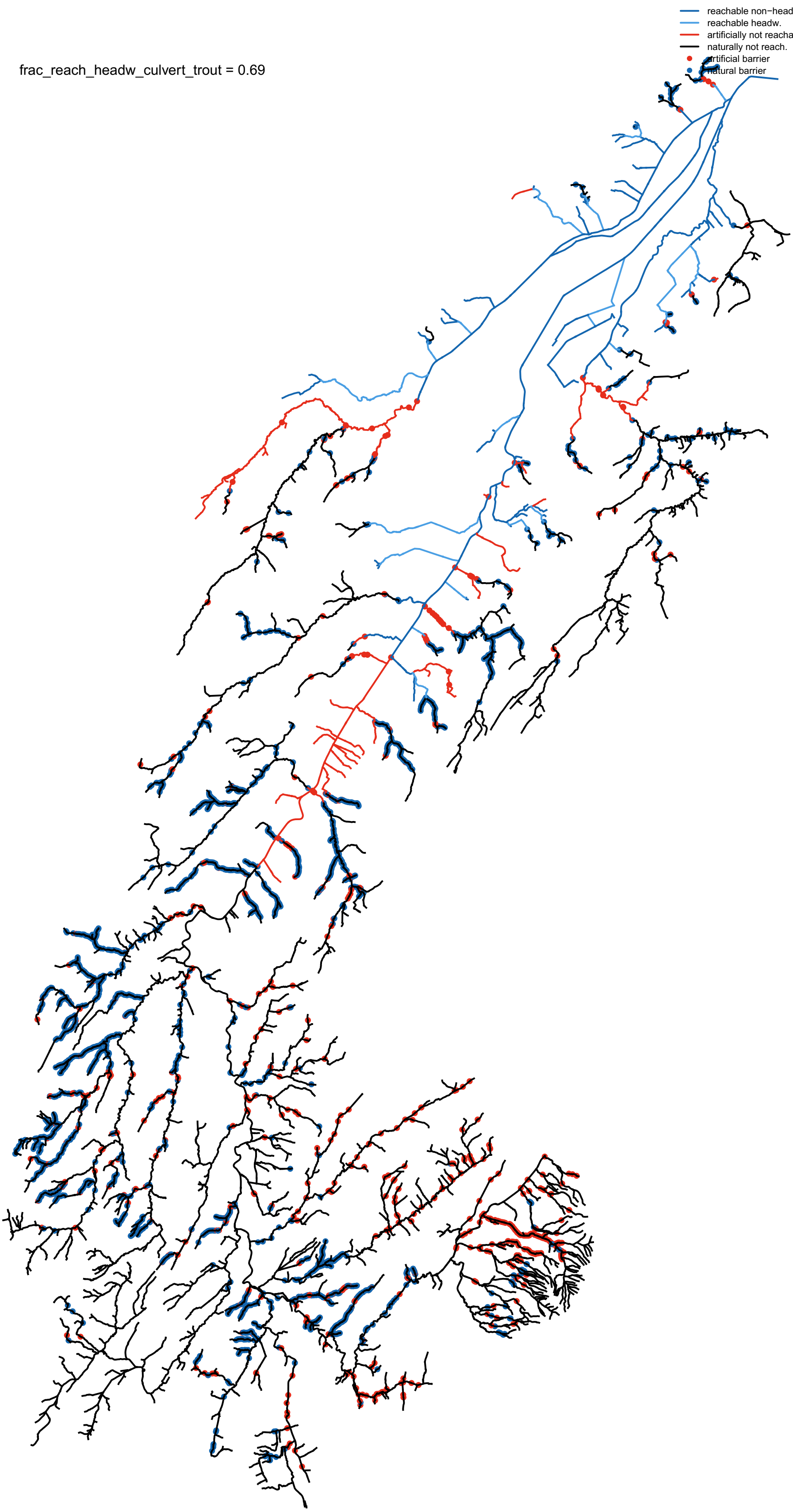
weight_mean_reach_state = 0.58



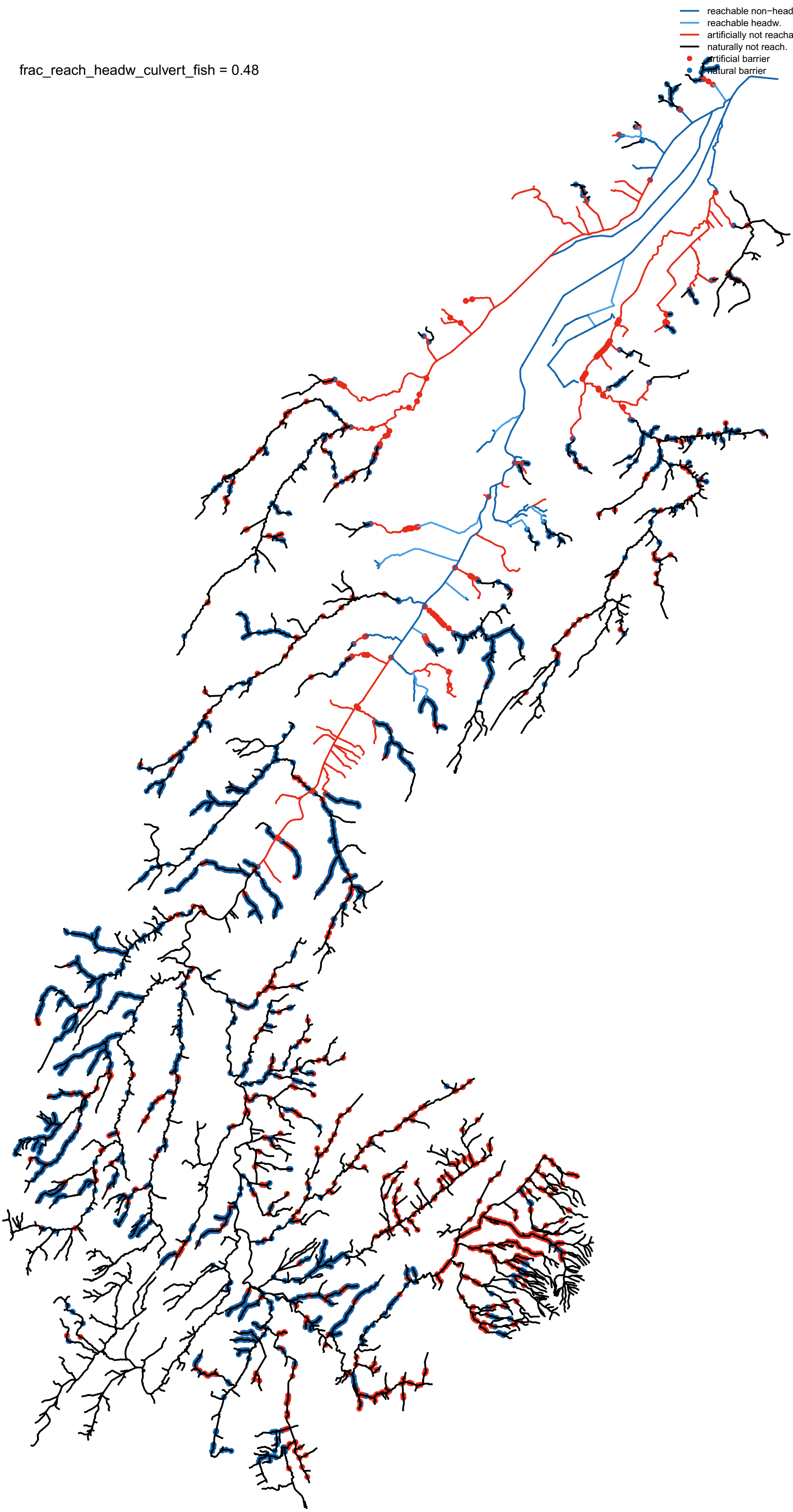
weight_frac_good_state = 0.55



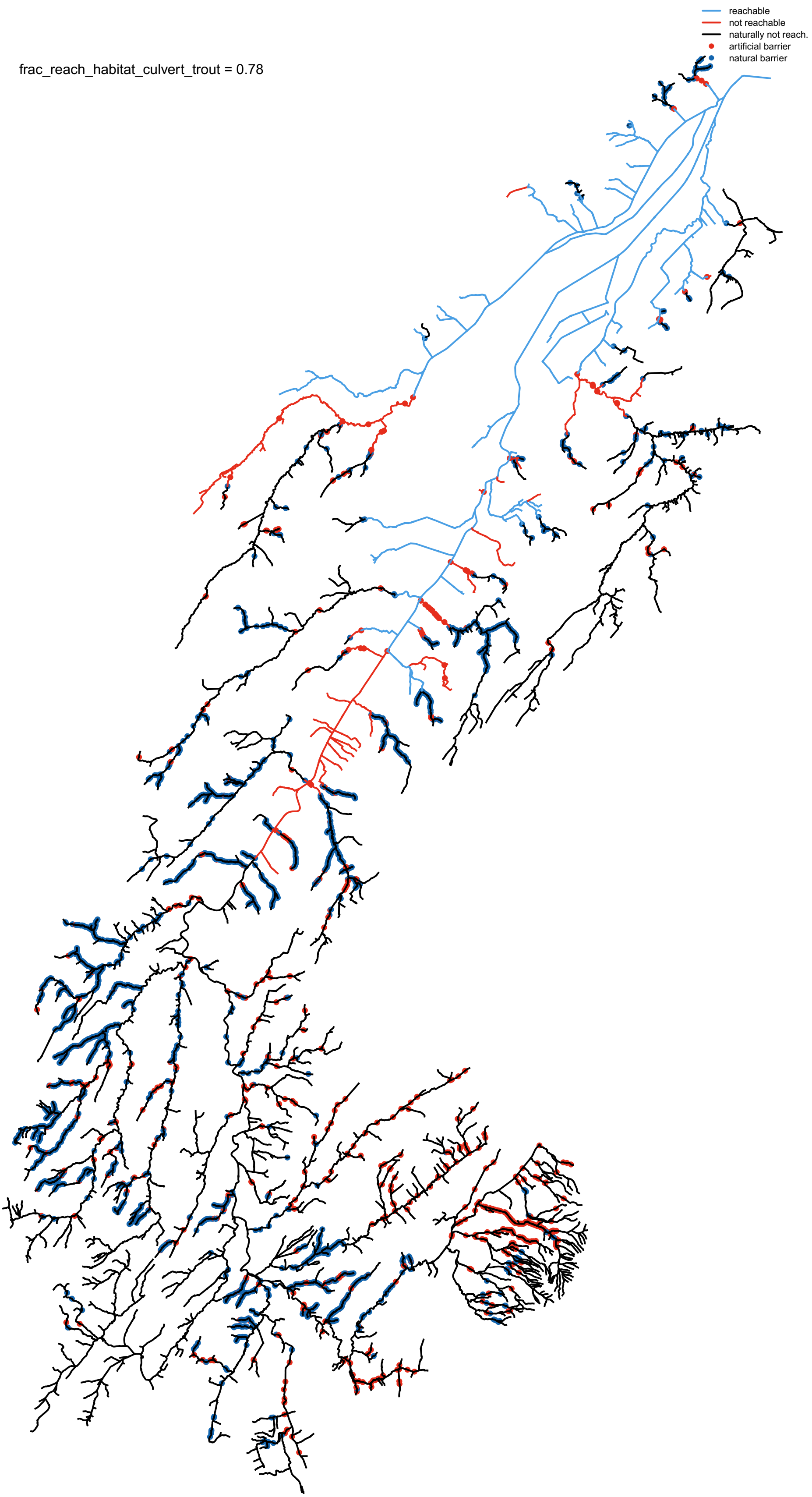
frac_reach_headw_culvert_trout = 0.69



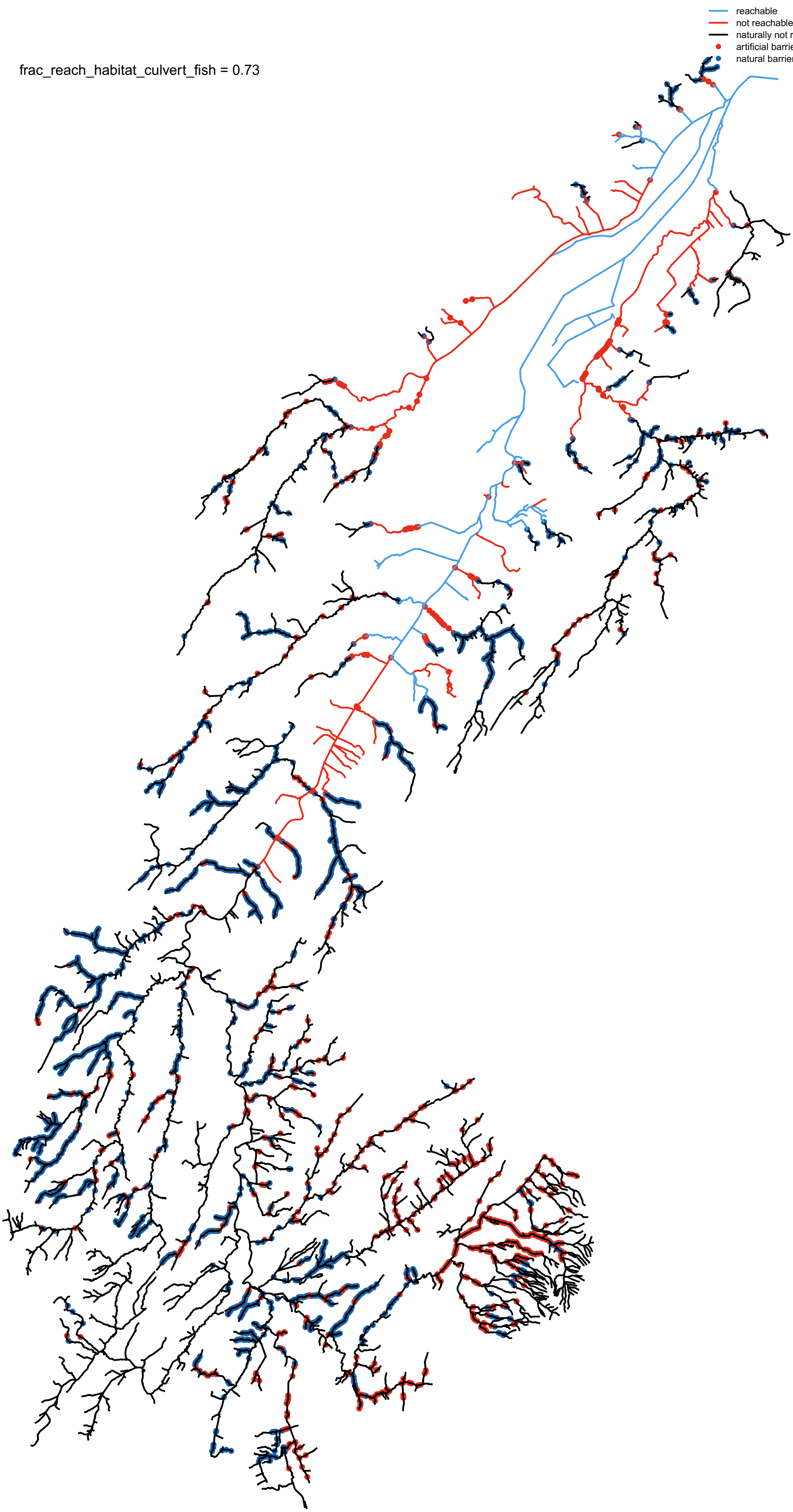
frac_reach_headw_culvert_fish = 0.48



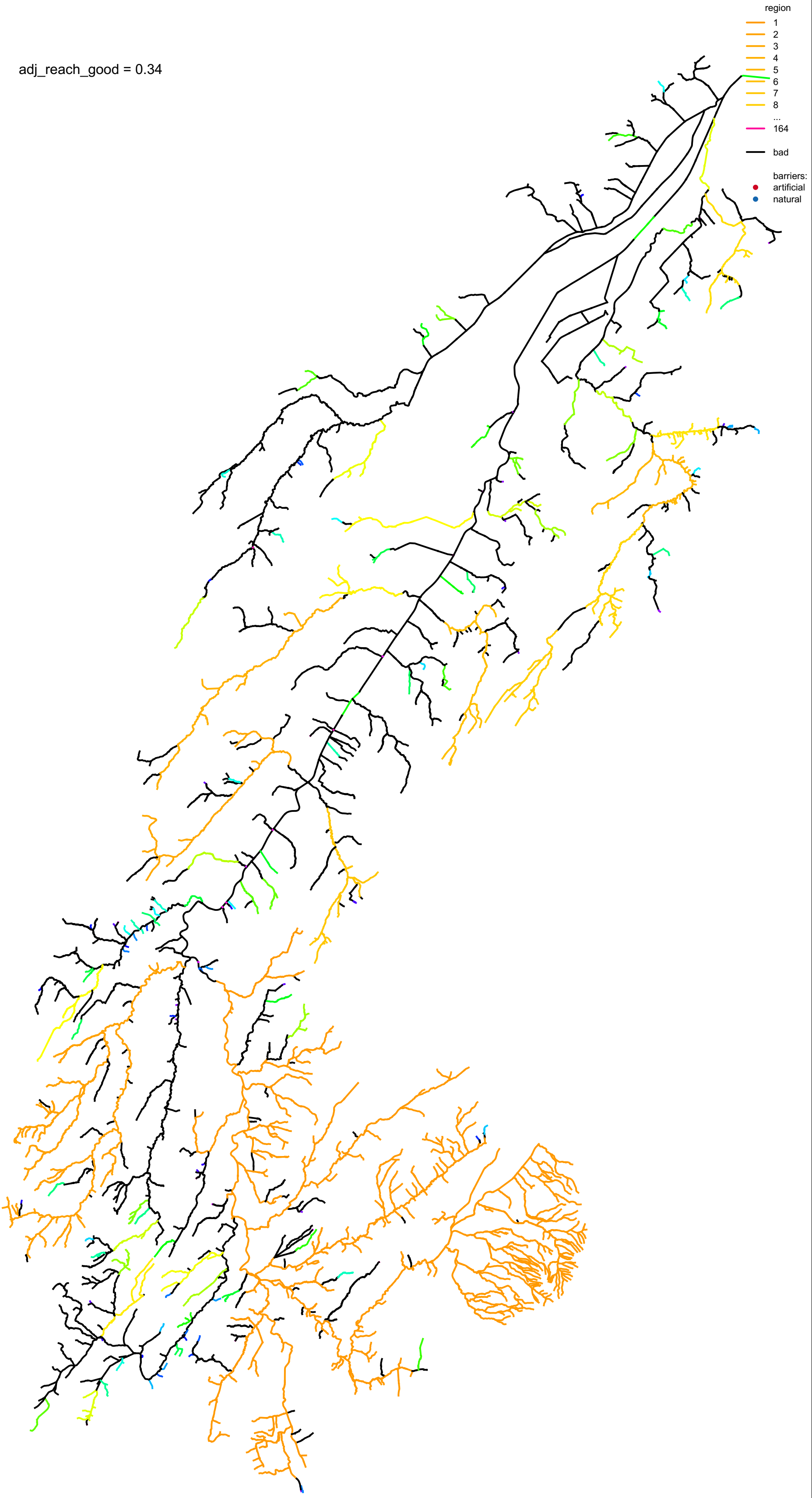
frac_reach_habitat_culvert_trout = 0.78



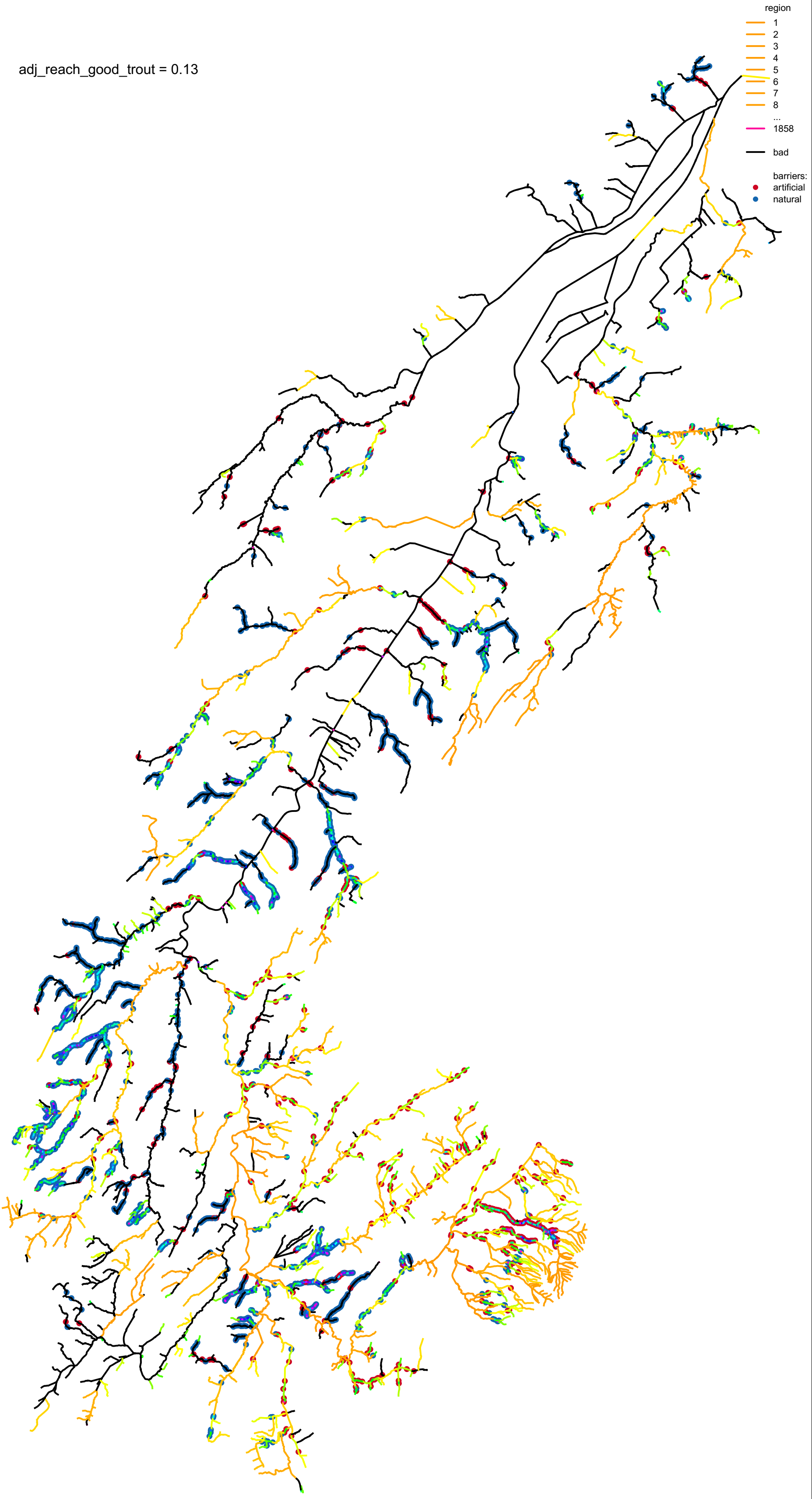
frac_reach_habitat_culvert_fish = 0.73



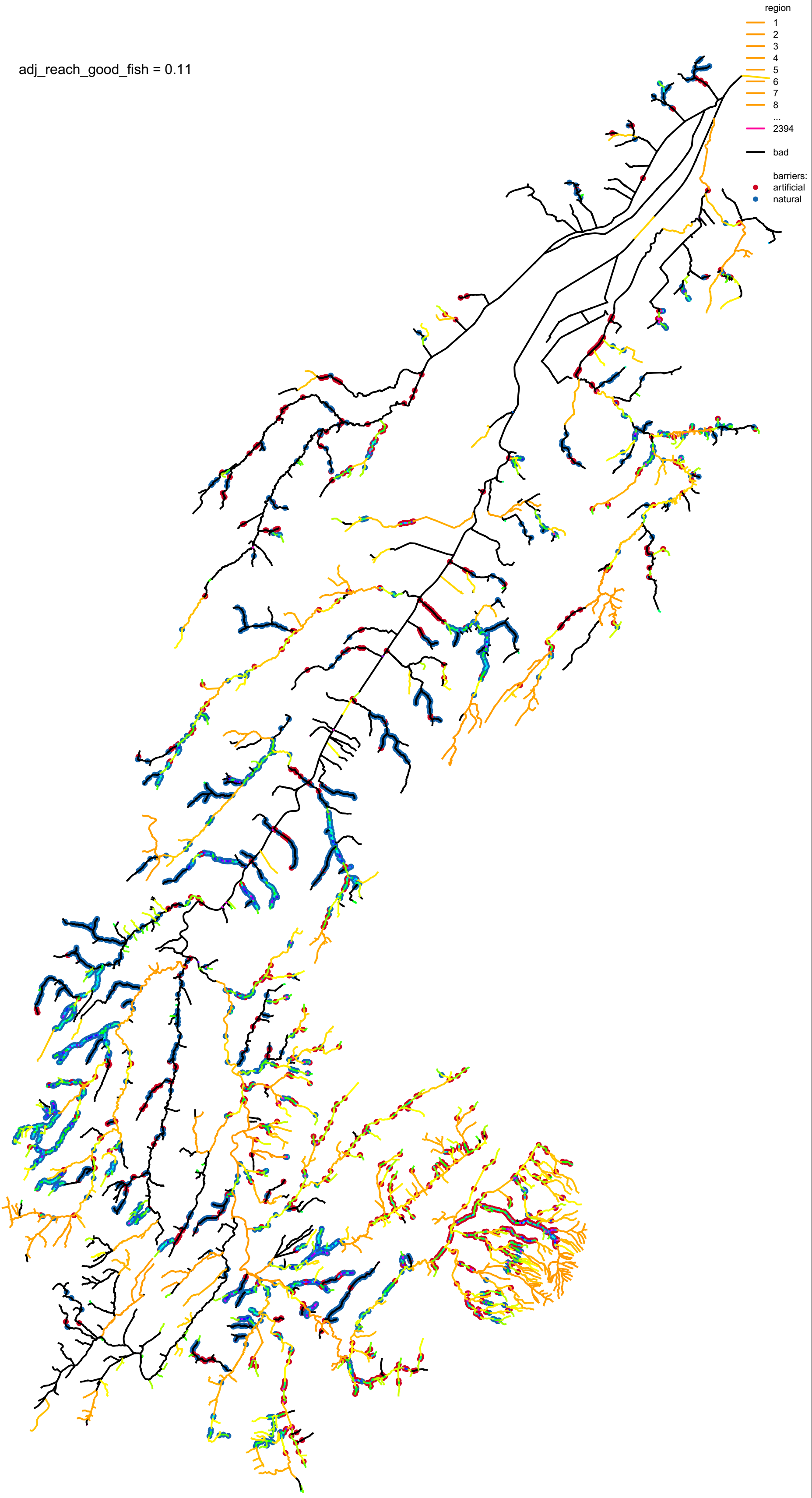
adj_reach_good = 0.34



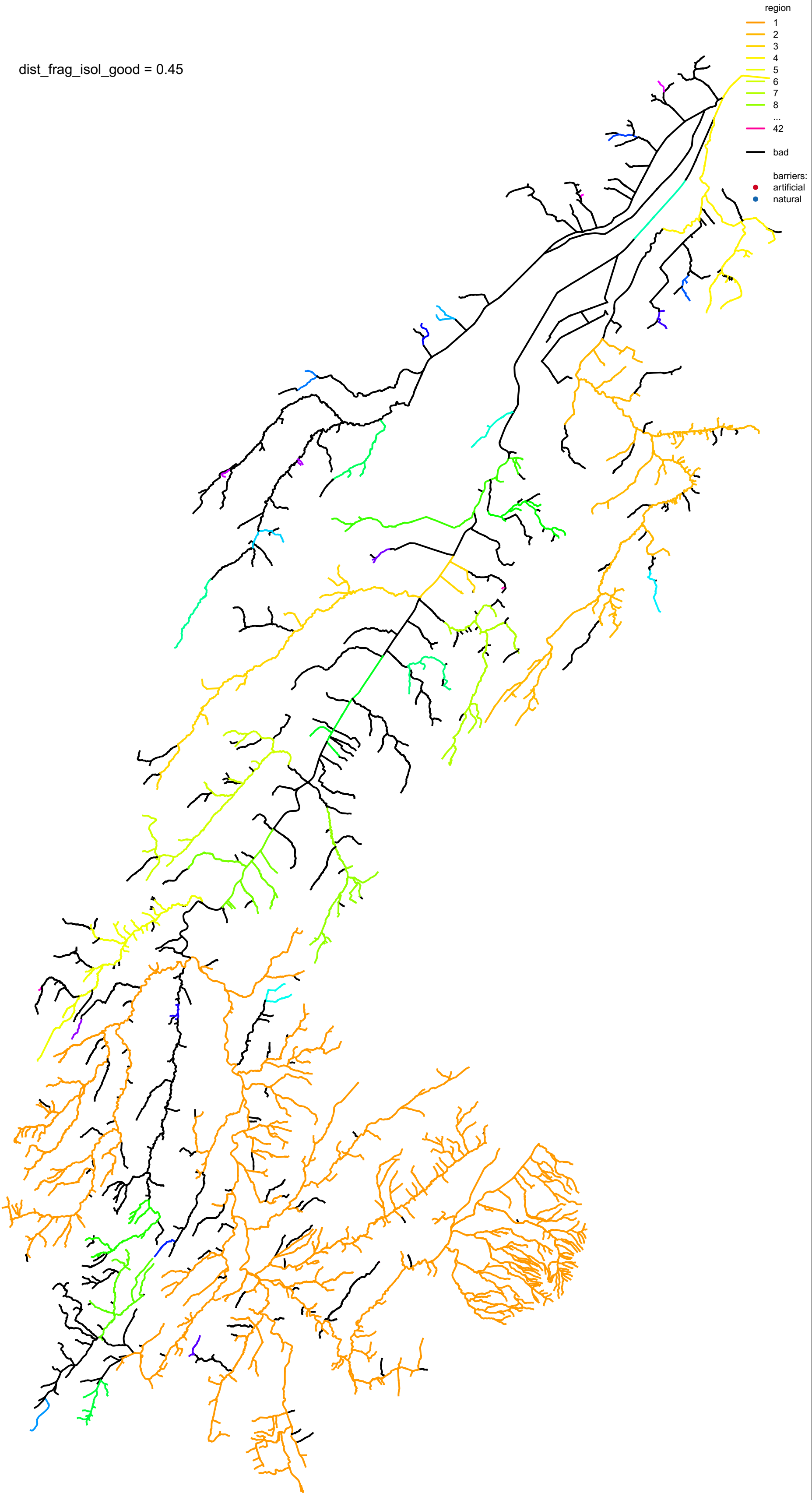
adj_reach_good_trout = 0.13



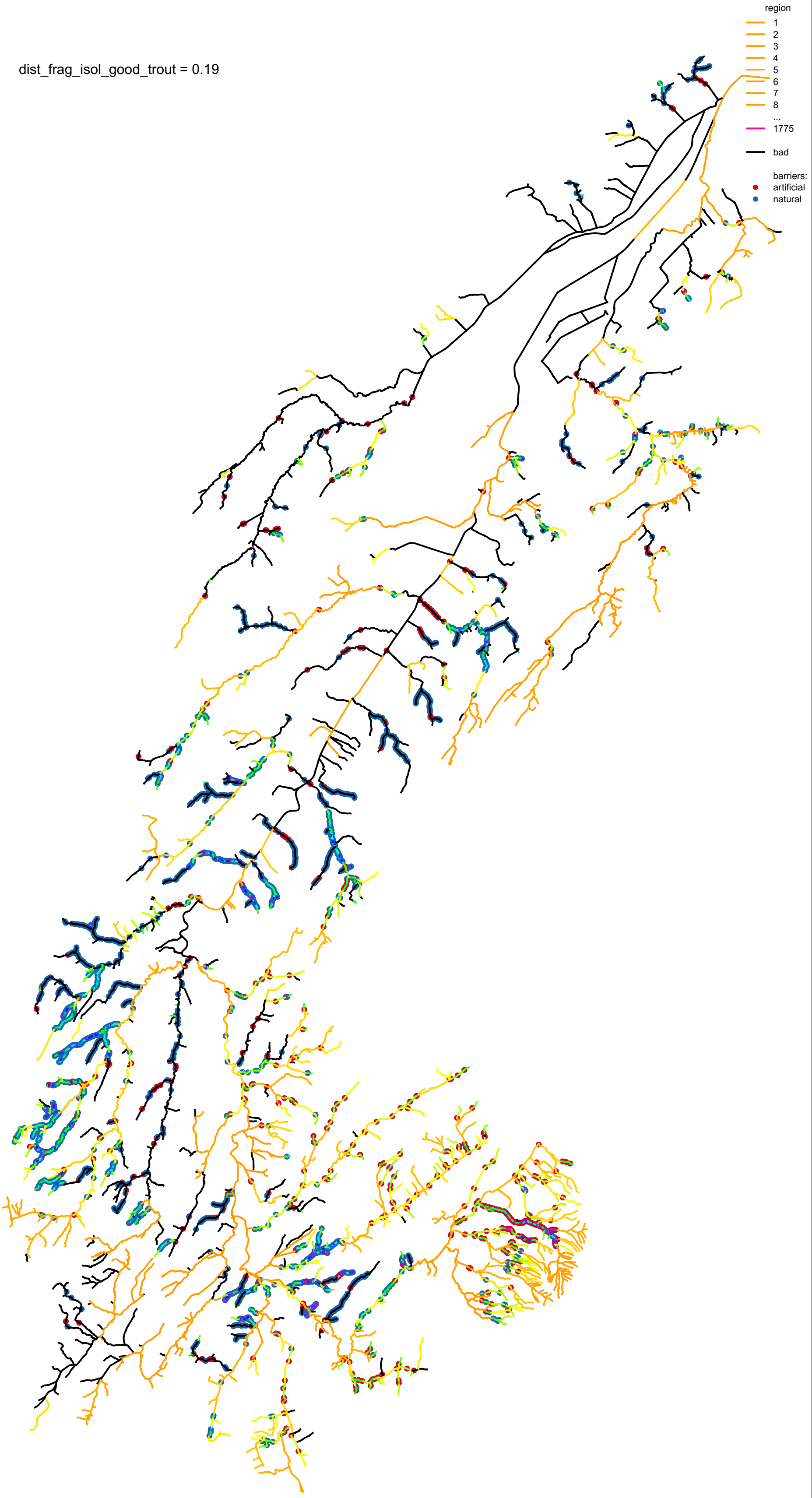
adj_reach_good_fish = 0.11



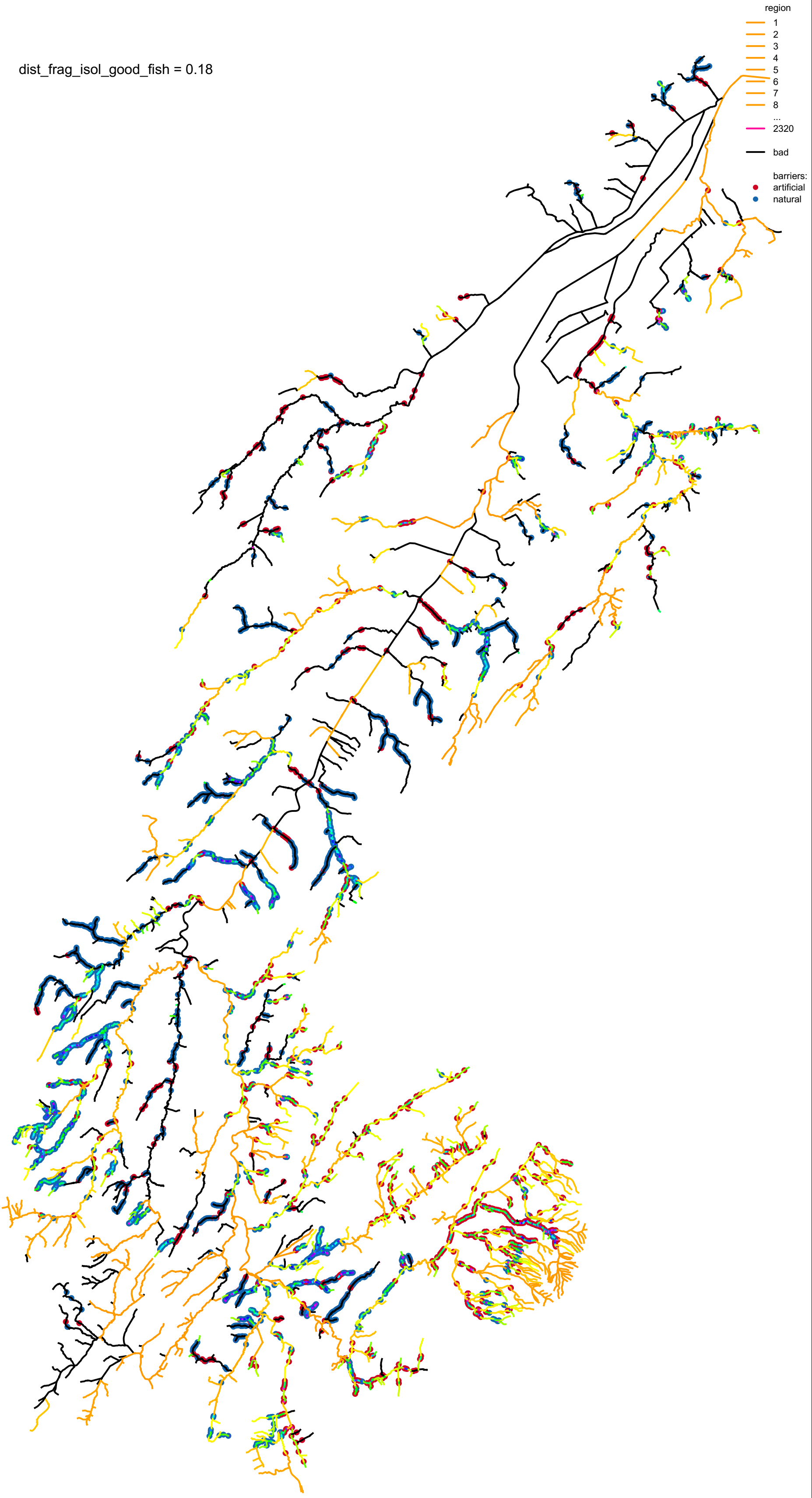
dist_frag_isol_good = 0.45



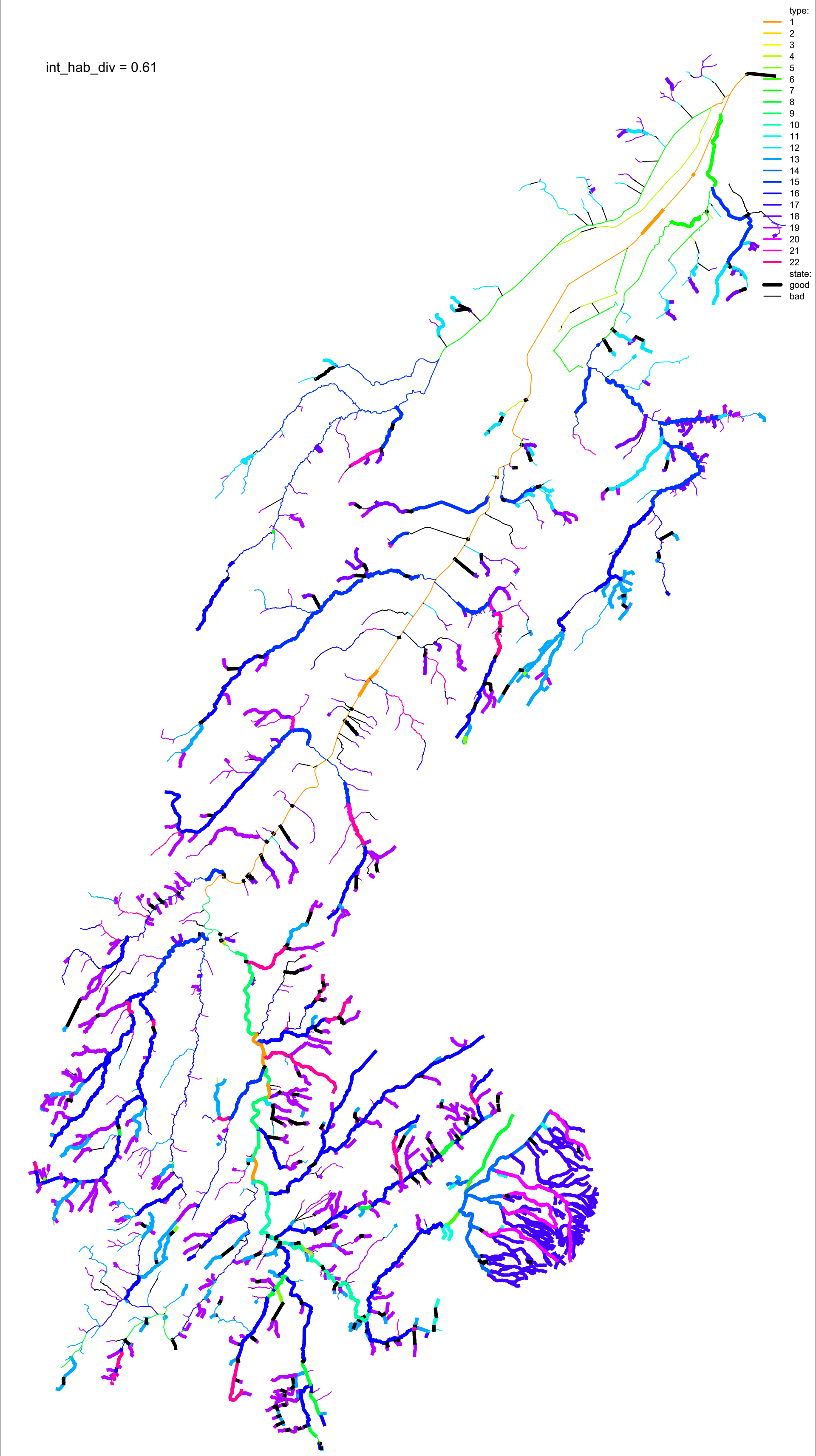
dist_frag_isol_good_trout = 0.19



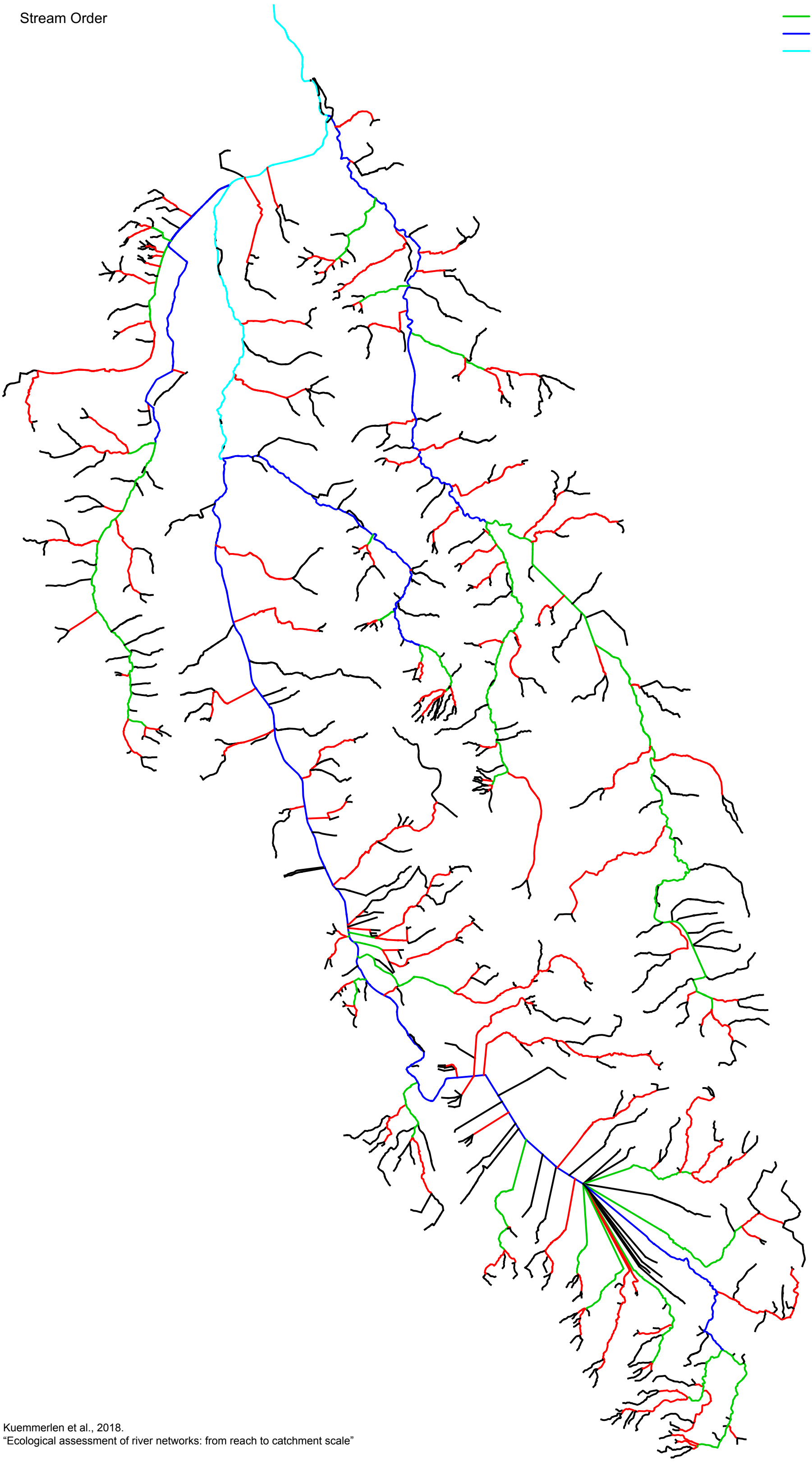
dist_frag_isol_good_fish = 0.18



int_hab_div = 0.61



Stream Order



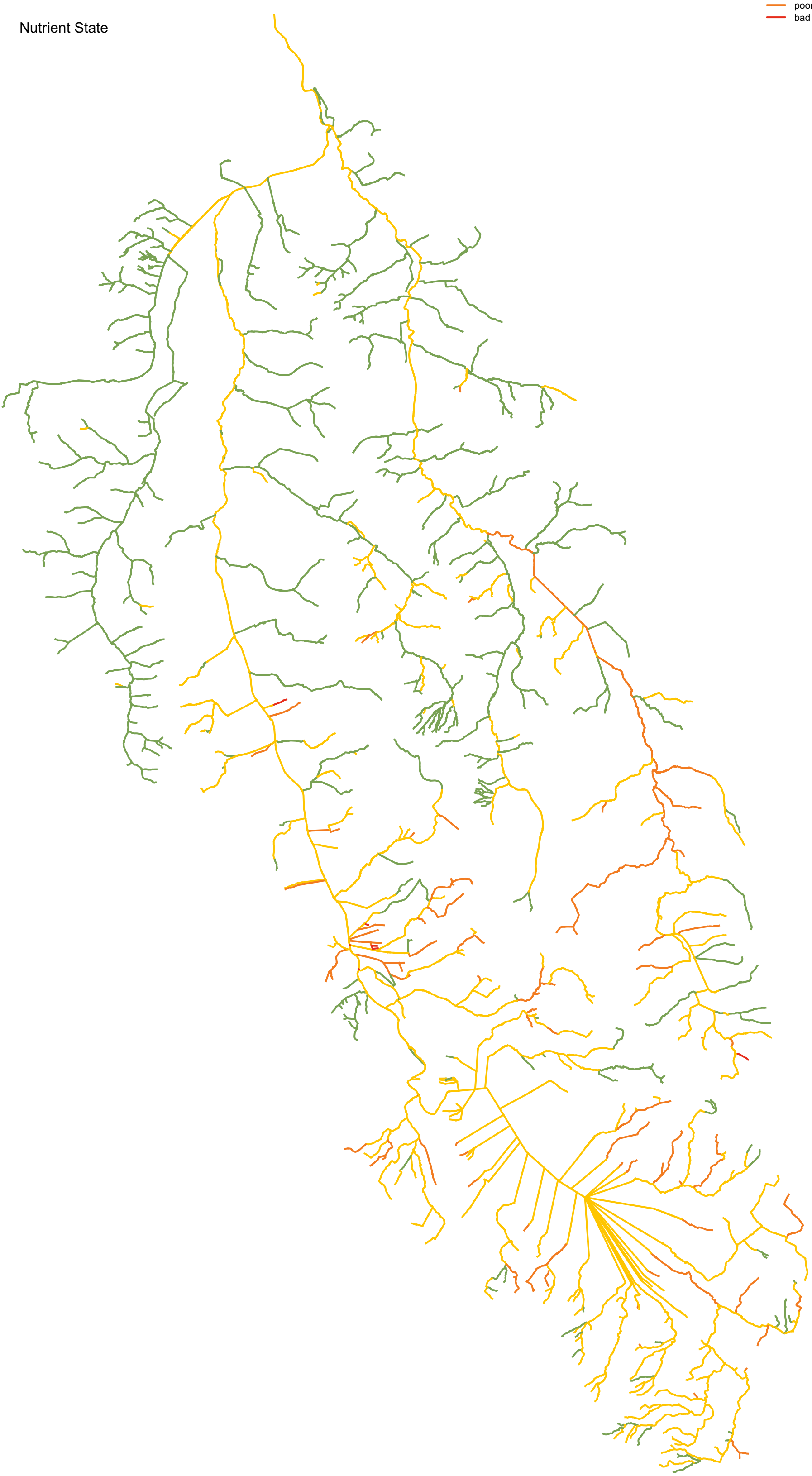
Kuemmerlen et al., 2018.
“Ecological assessment of river networks: from reach to catchment scale”

Morphological State

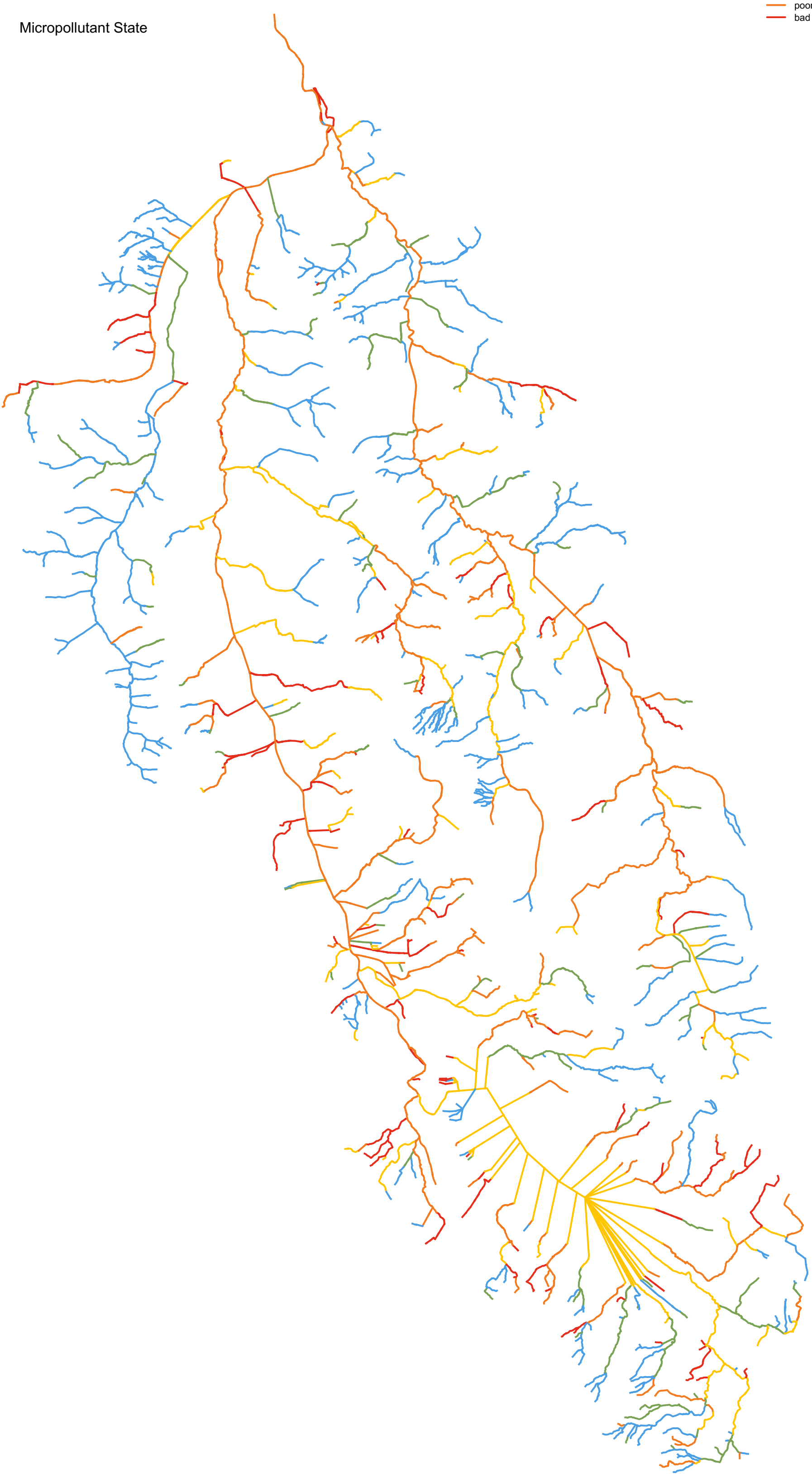
high
good
moderate
poor
bad
culvert
artif. barrier
nat. barrier

Nutrient State

high
good
moderate
poor
bad

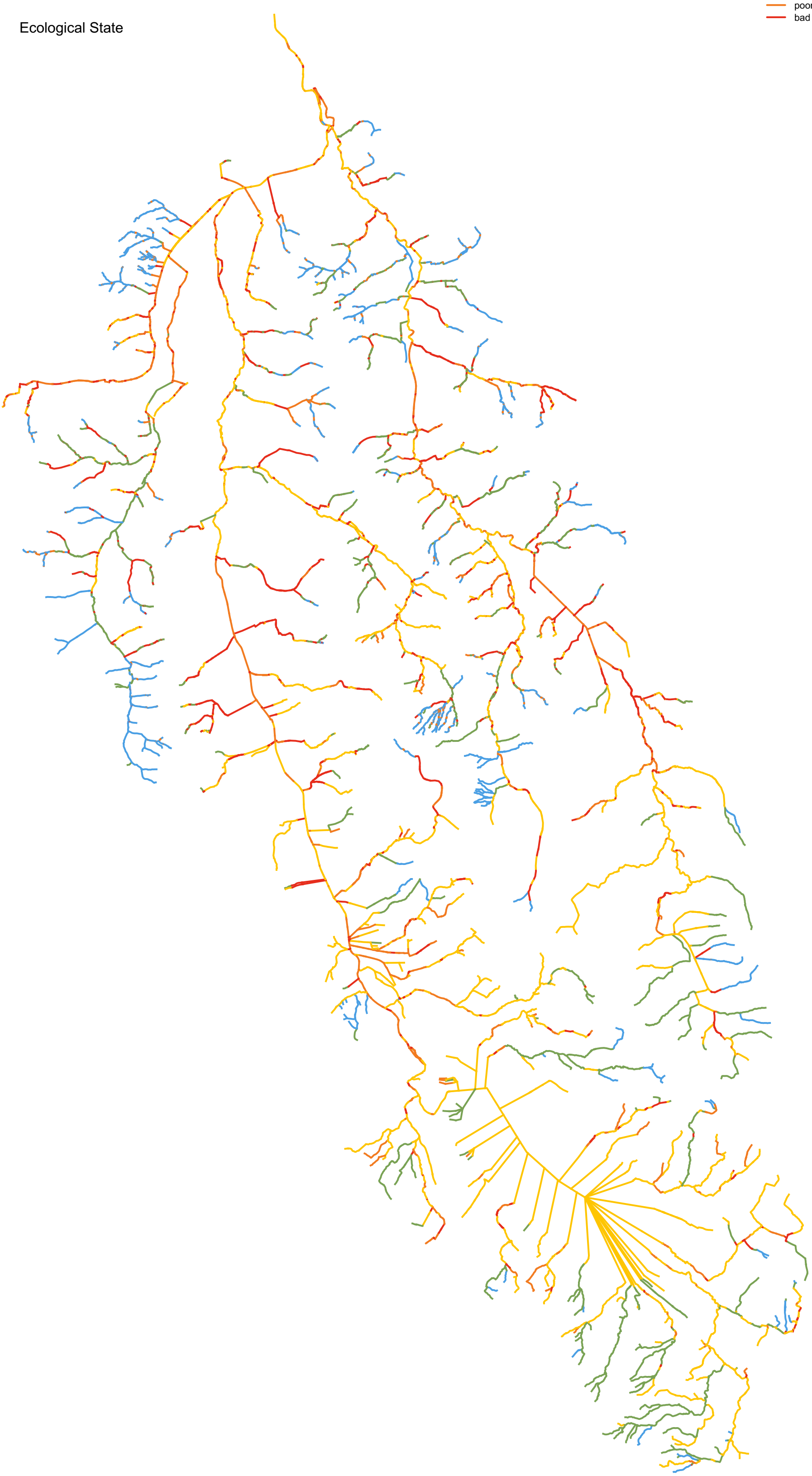


Micropollutant State



Ecological State

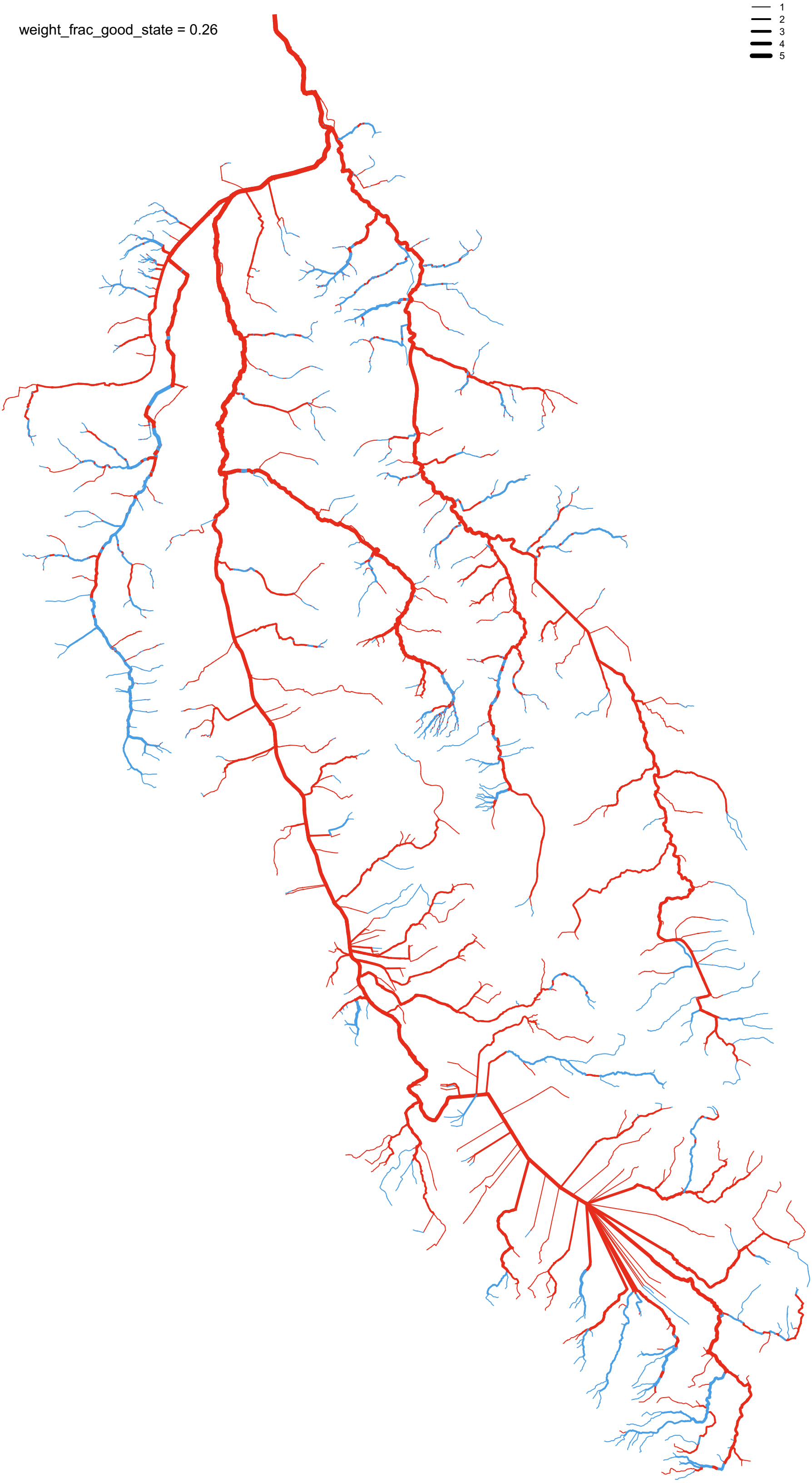
high
good
moderate
poor
bad



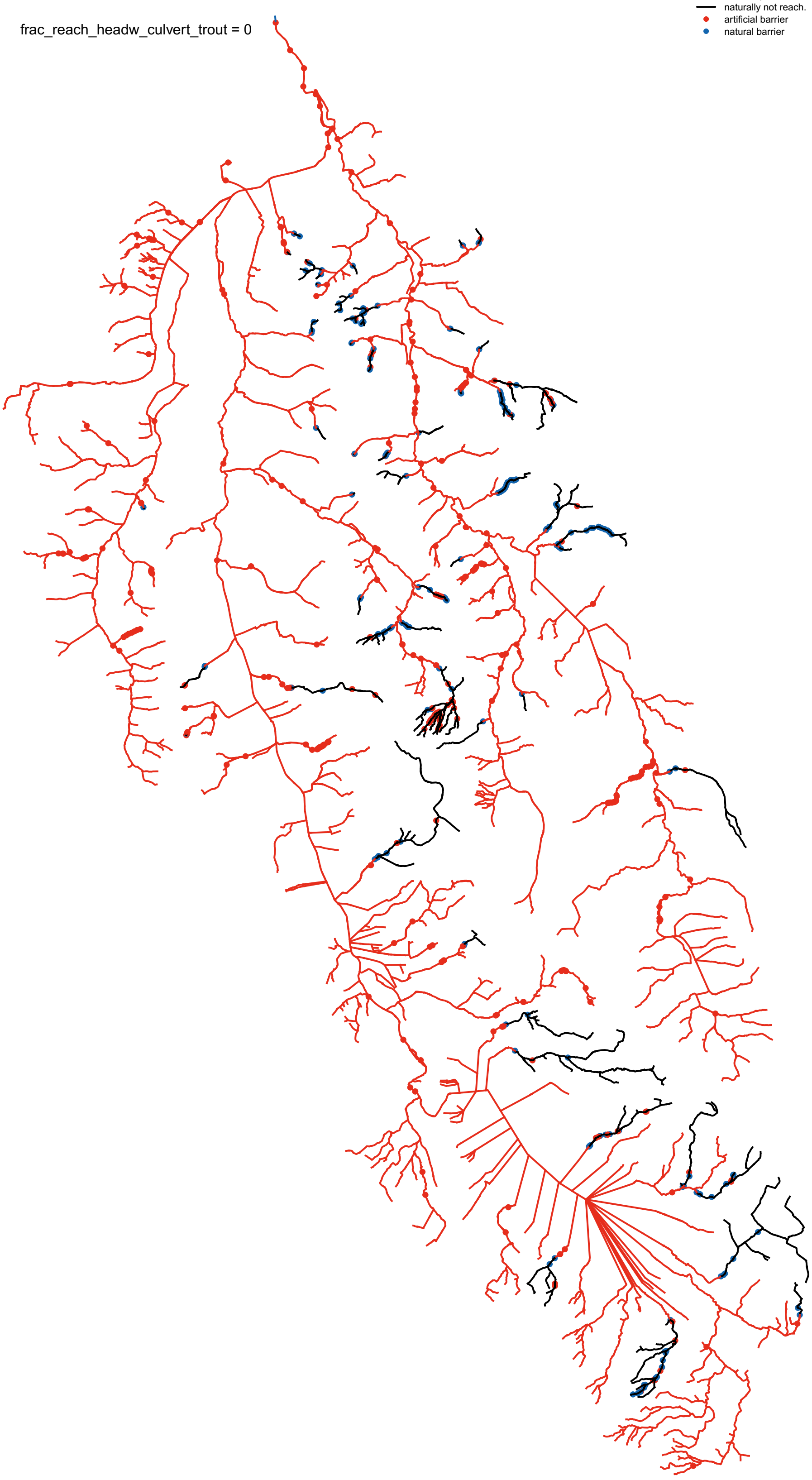
weight_mean_reach_state = 0.5

high
good
moderate
poor
bad
stream order:
1
2
3
4
5

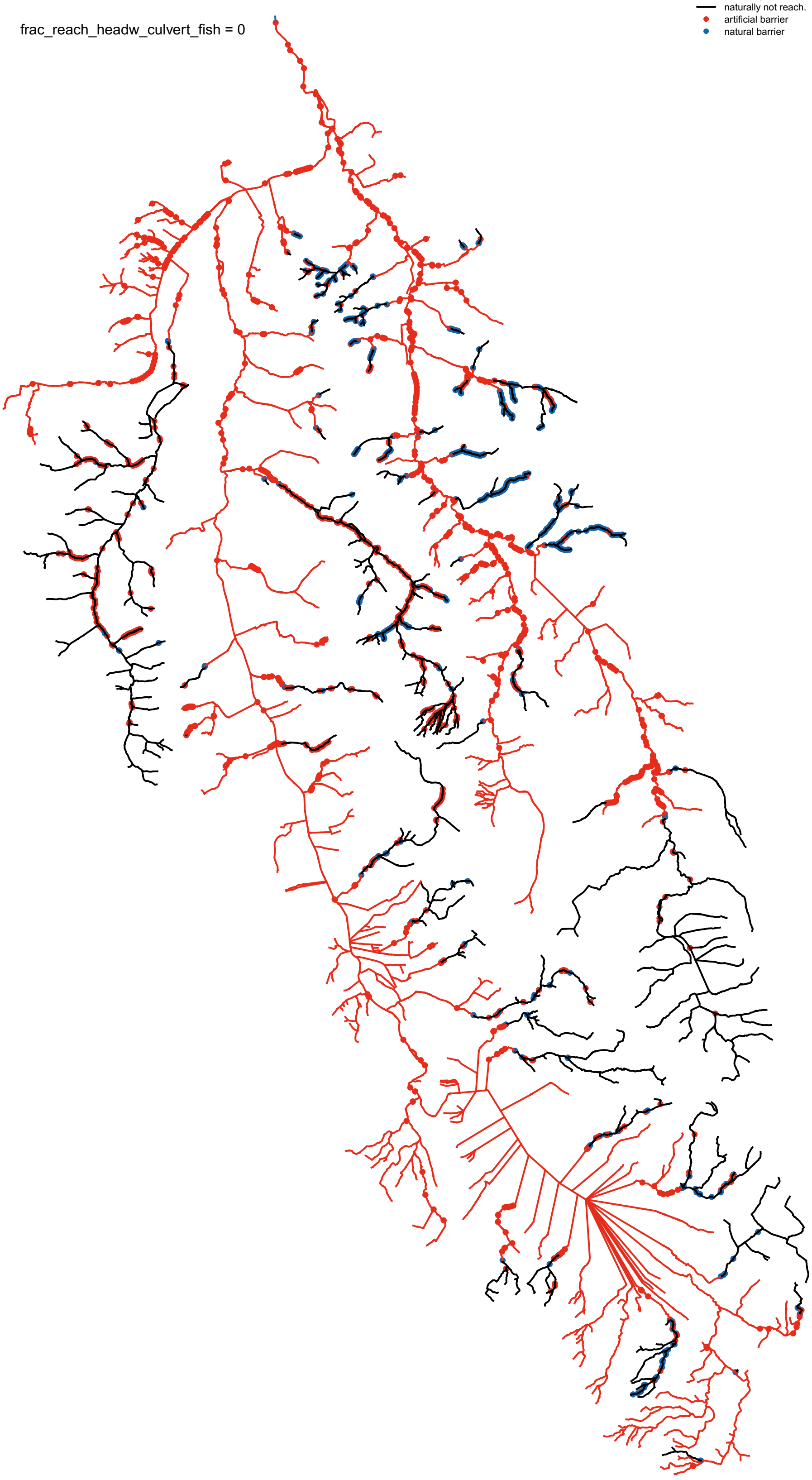
weight_frac_good_state = 0.26



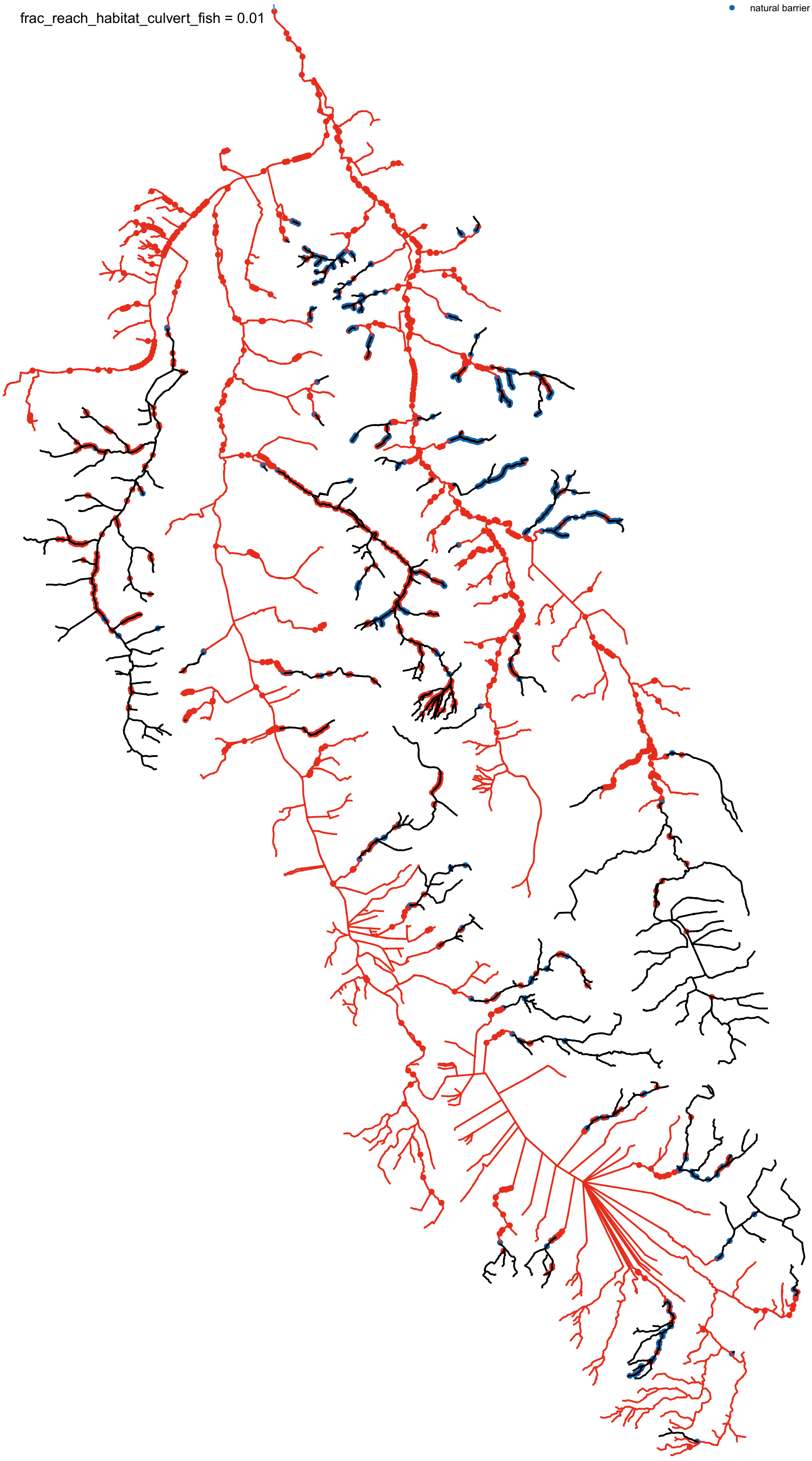
frac_reach_headw_culvert_trout = 0



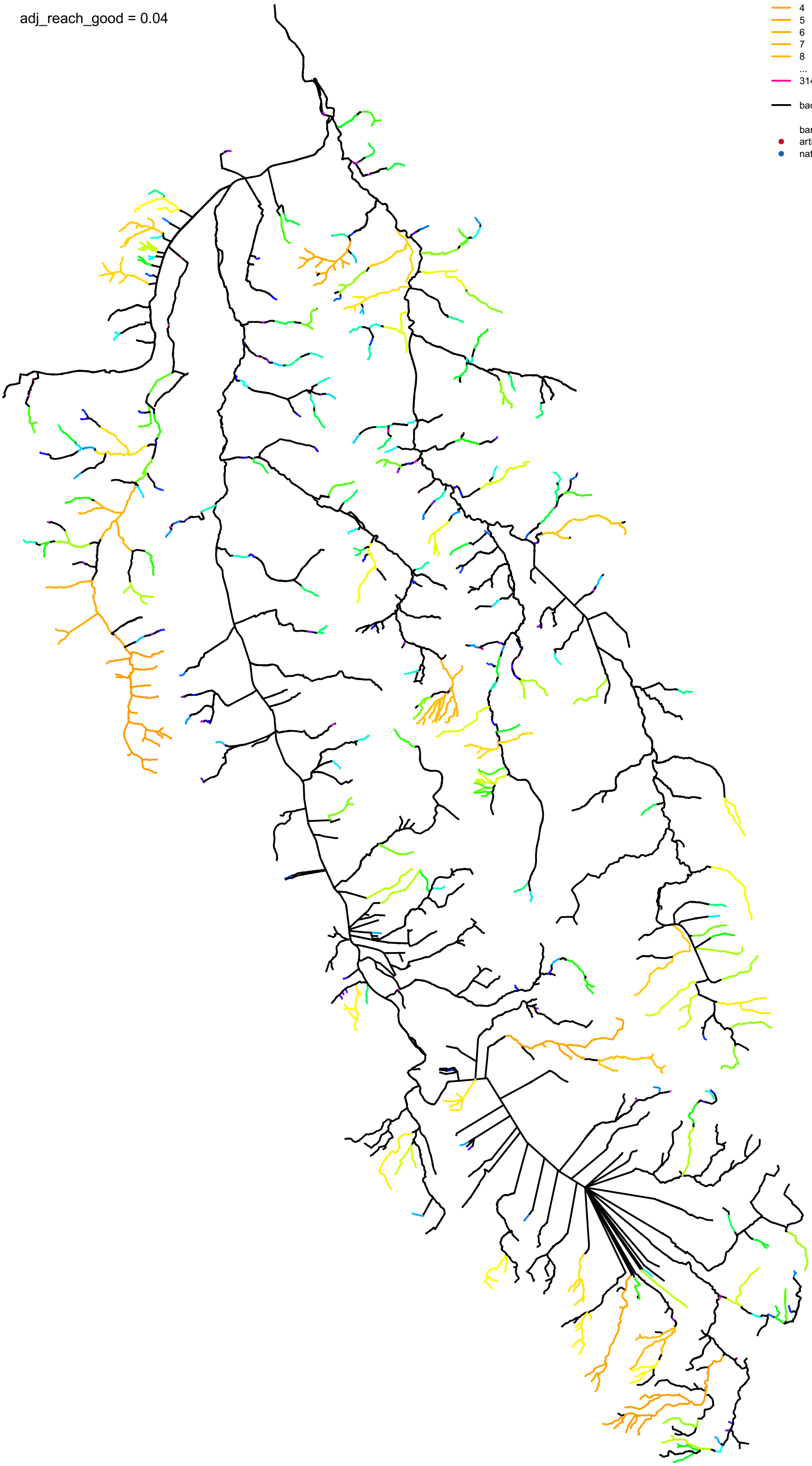
frac_reach_headw_culvert_fish = 0




frac_reach_habitat_culvert_trout = 0.01
reachable
not reachable
naturally not reach.
artificial barrier
natural barrier


frac_reach_habitat_culvert_fish = 0.01
reachable
not reachable
naturally not reach.
artificial barrier
natural barrier

adj_reach_good = 0.04



adj_reach_good_trout = 0.05

region
1
2
3
4
5
6
7
8
...
590

bad

barriers:
artificial
natural

adj_reach_good_fish = 0.05

region
1
2
3
4
5
6
7
8
...
1372

bad

barriers:
artificial
natural

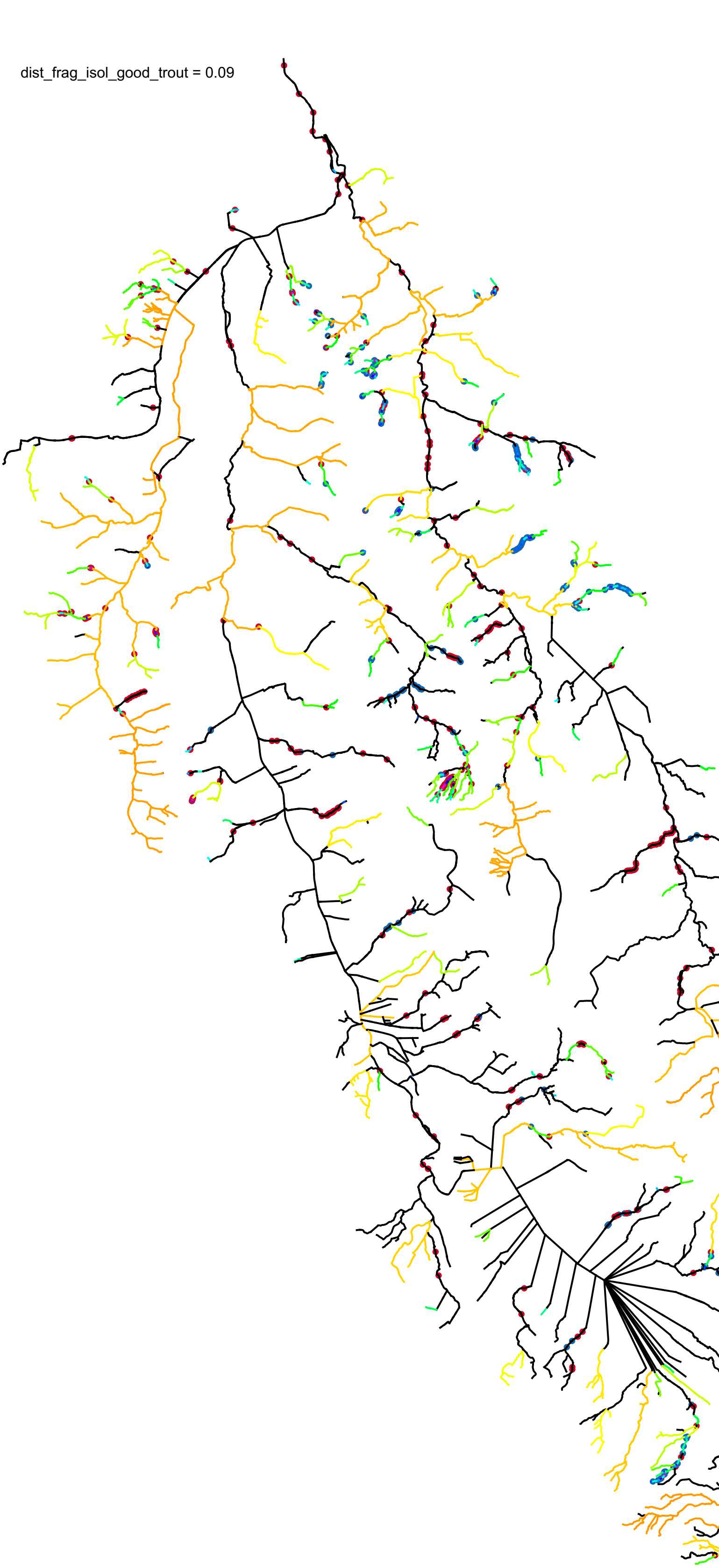
dist_frag_isol_good = 0.16

region
1
2
3
4
5
6
7
8
...
75

bad

barriers:
artificial
natural

dist_frag_isol_good_trout = 0.09

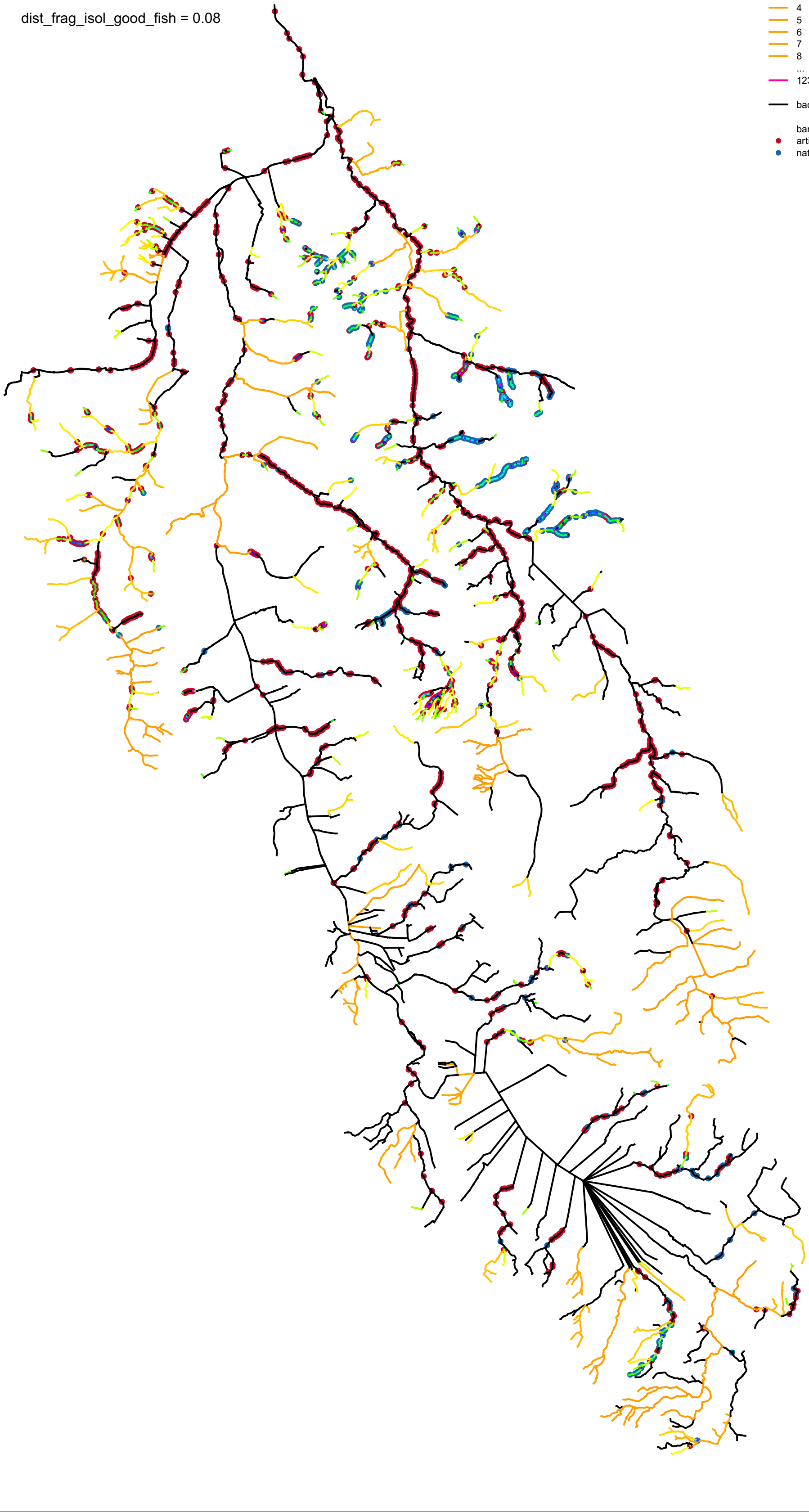


dist_frag_isol_good_fish = 0.08

region
1
2
3
4
5
6
7
8
...
1233

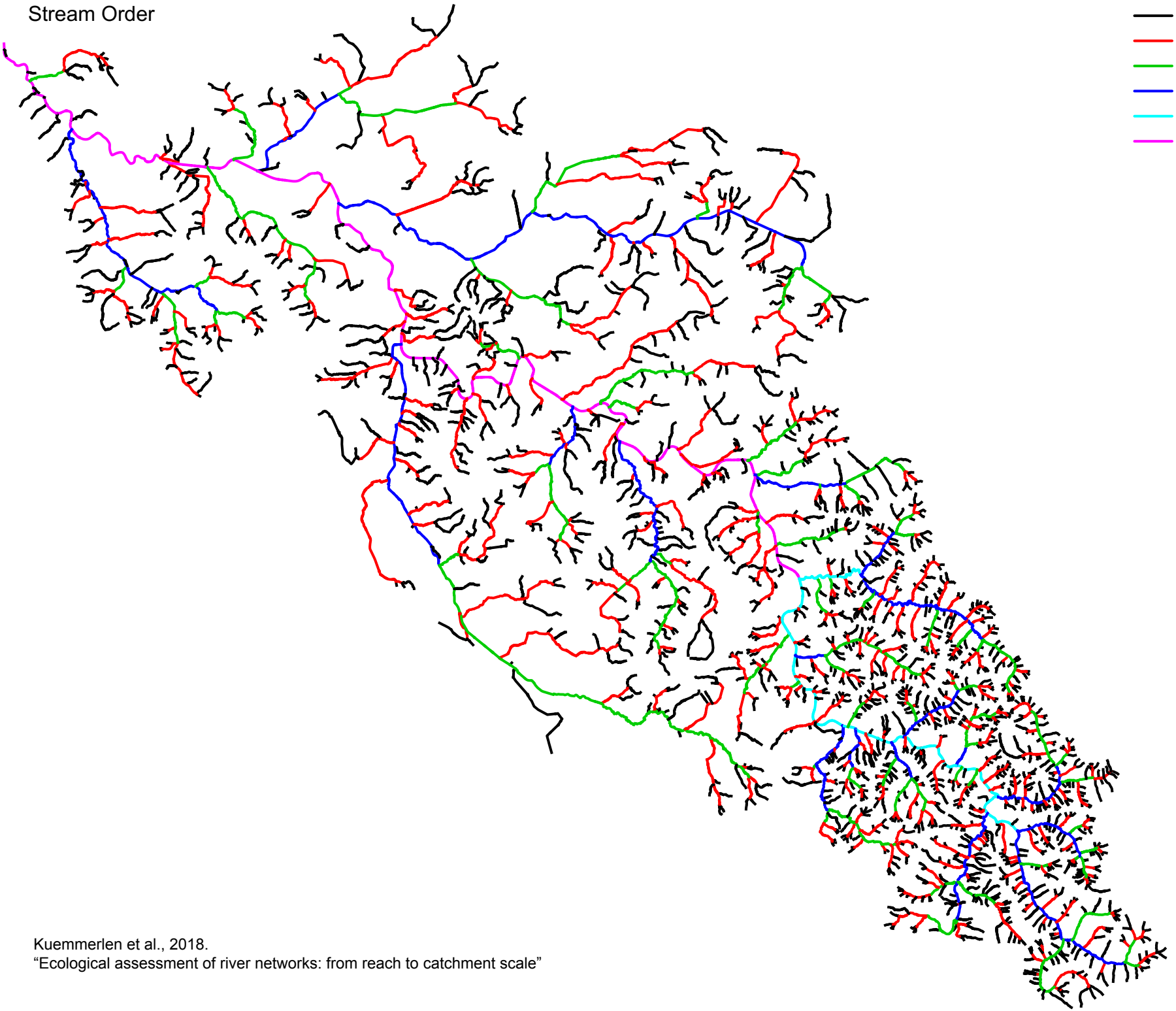
bad

barriers:
artificial
natural

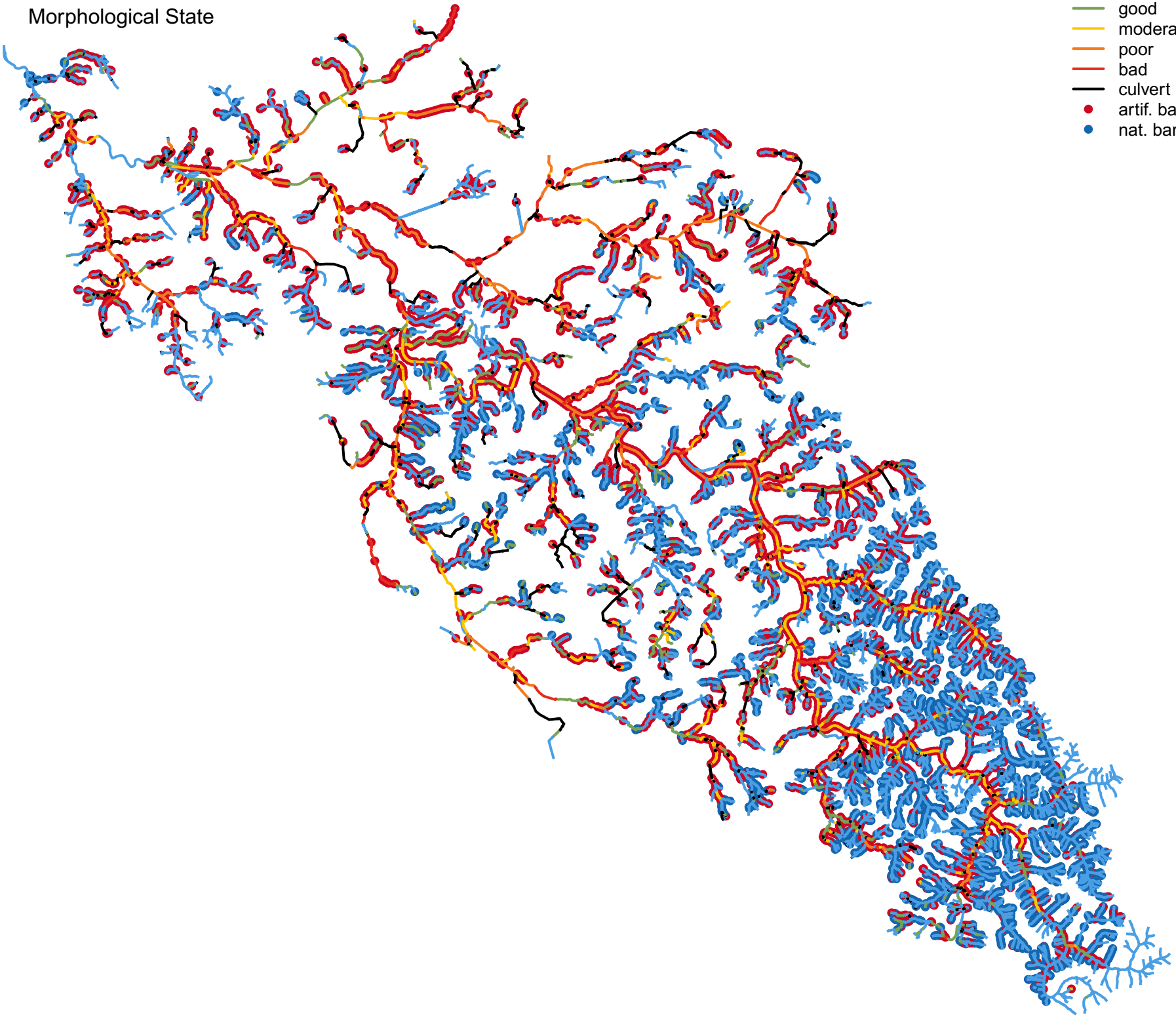


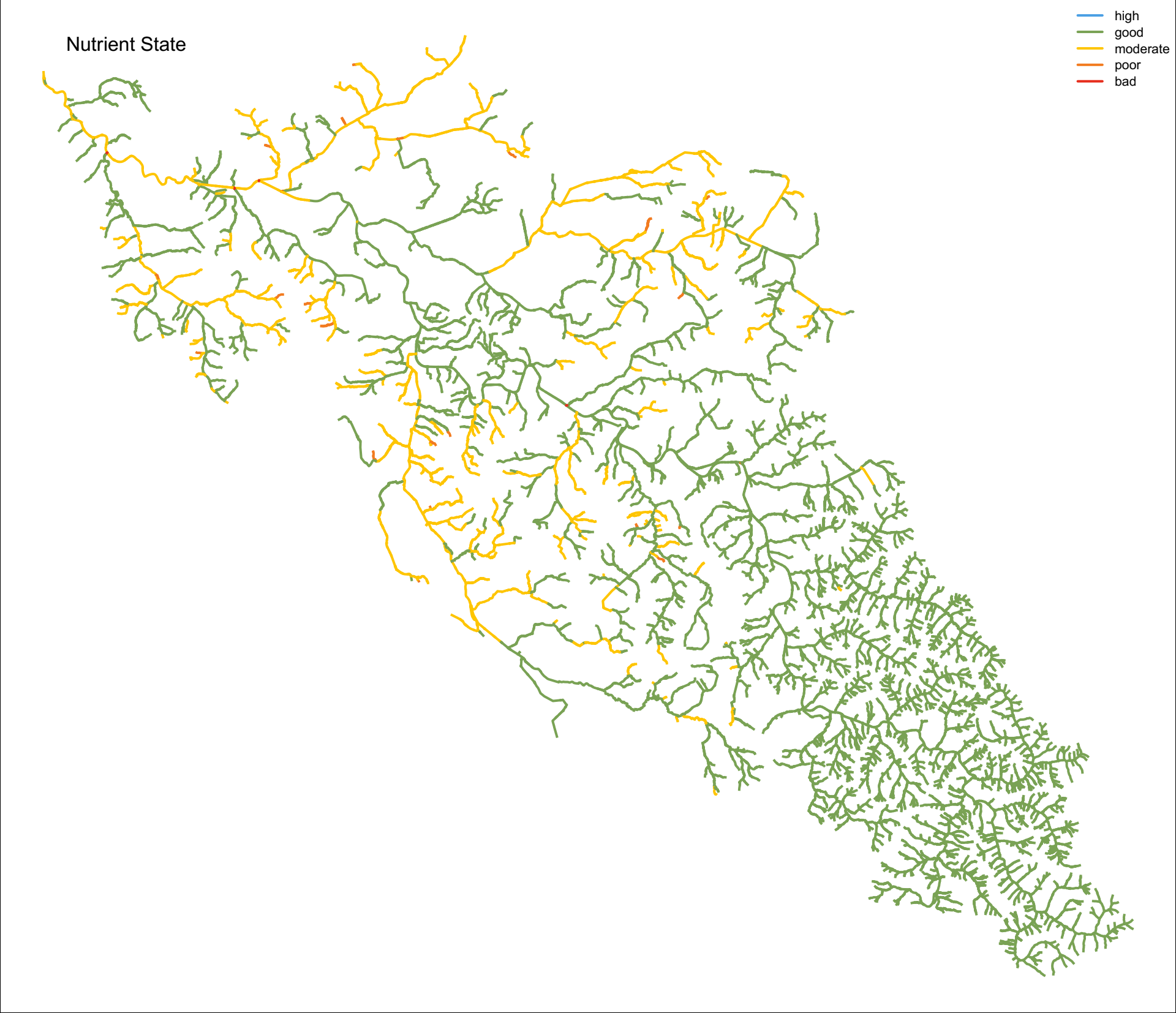
int_hab_div = 0.25

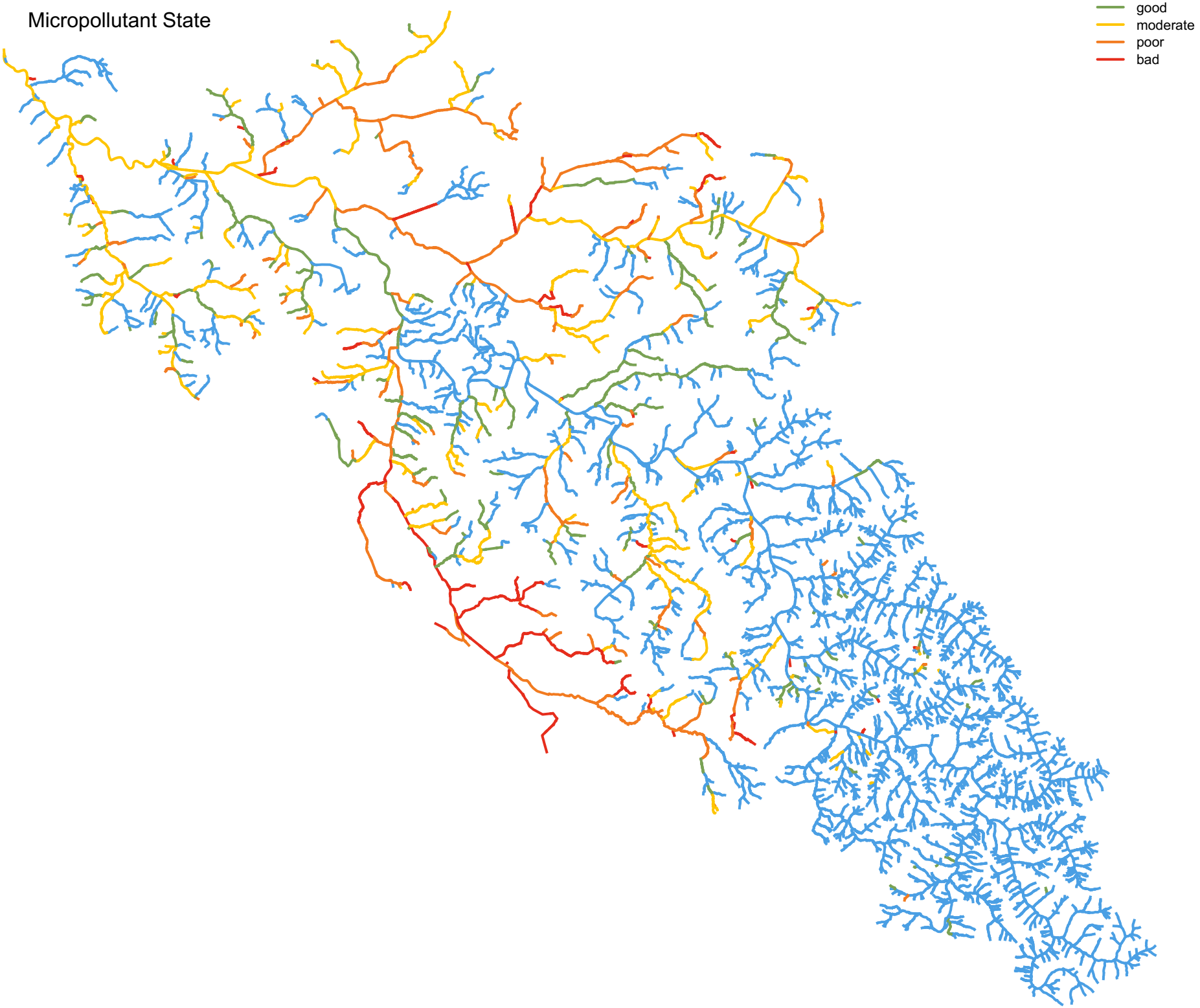
type:
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
state:
good
bad

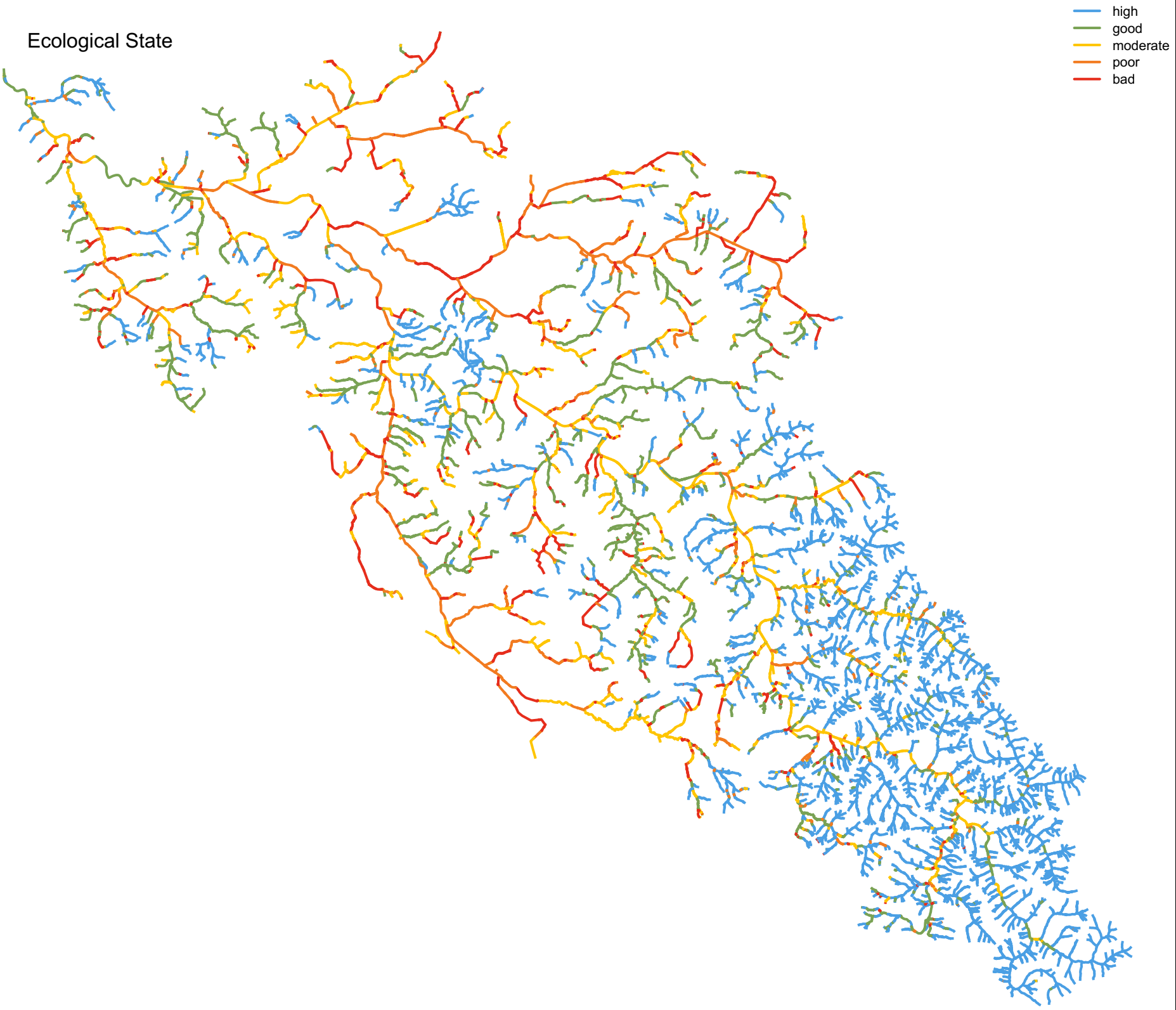


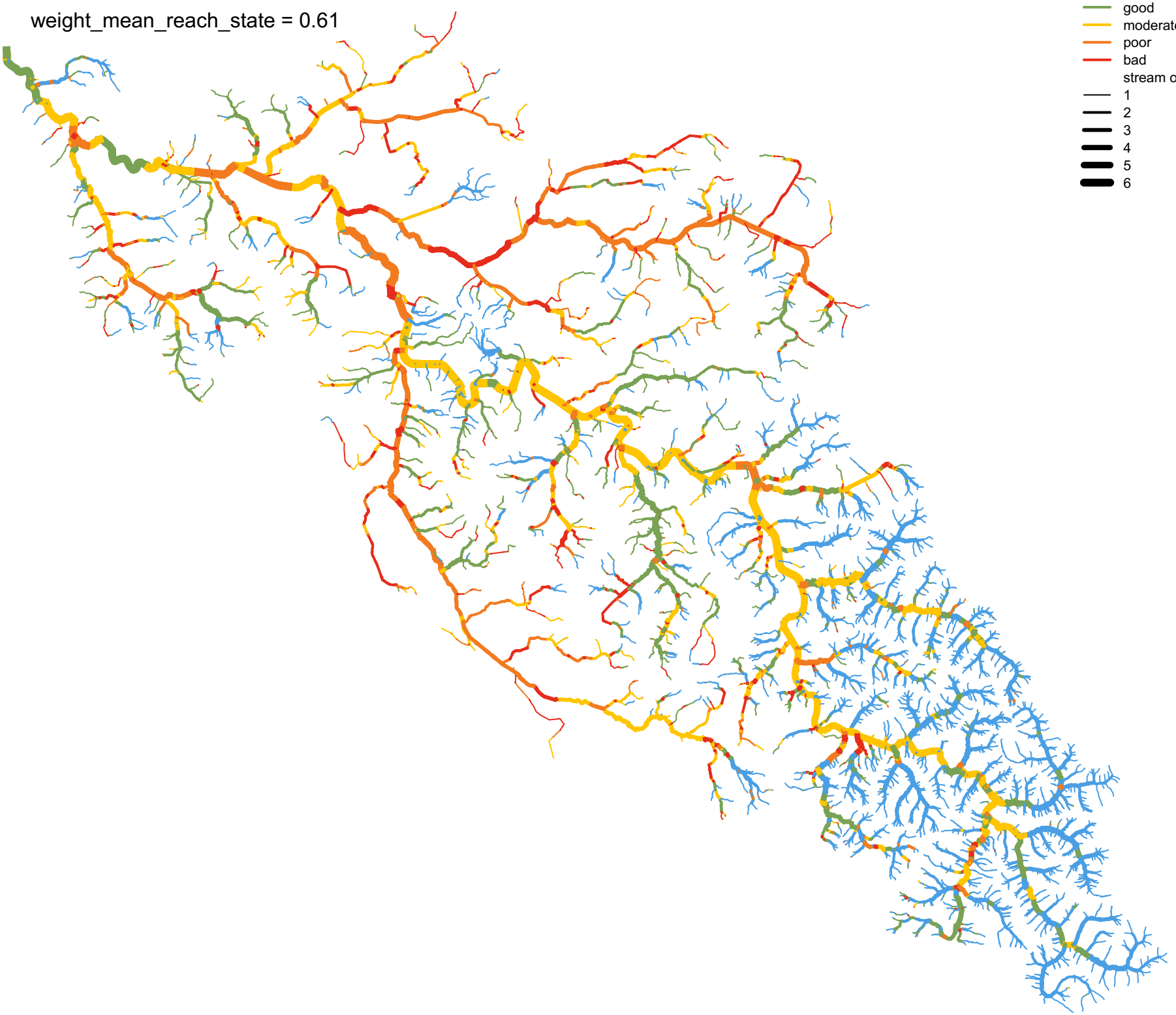
Kuemmerlen et al., 2018.
“Ecological assessment of river networks: from reach to catchment scale”

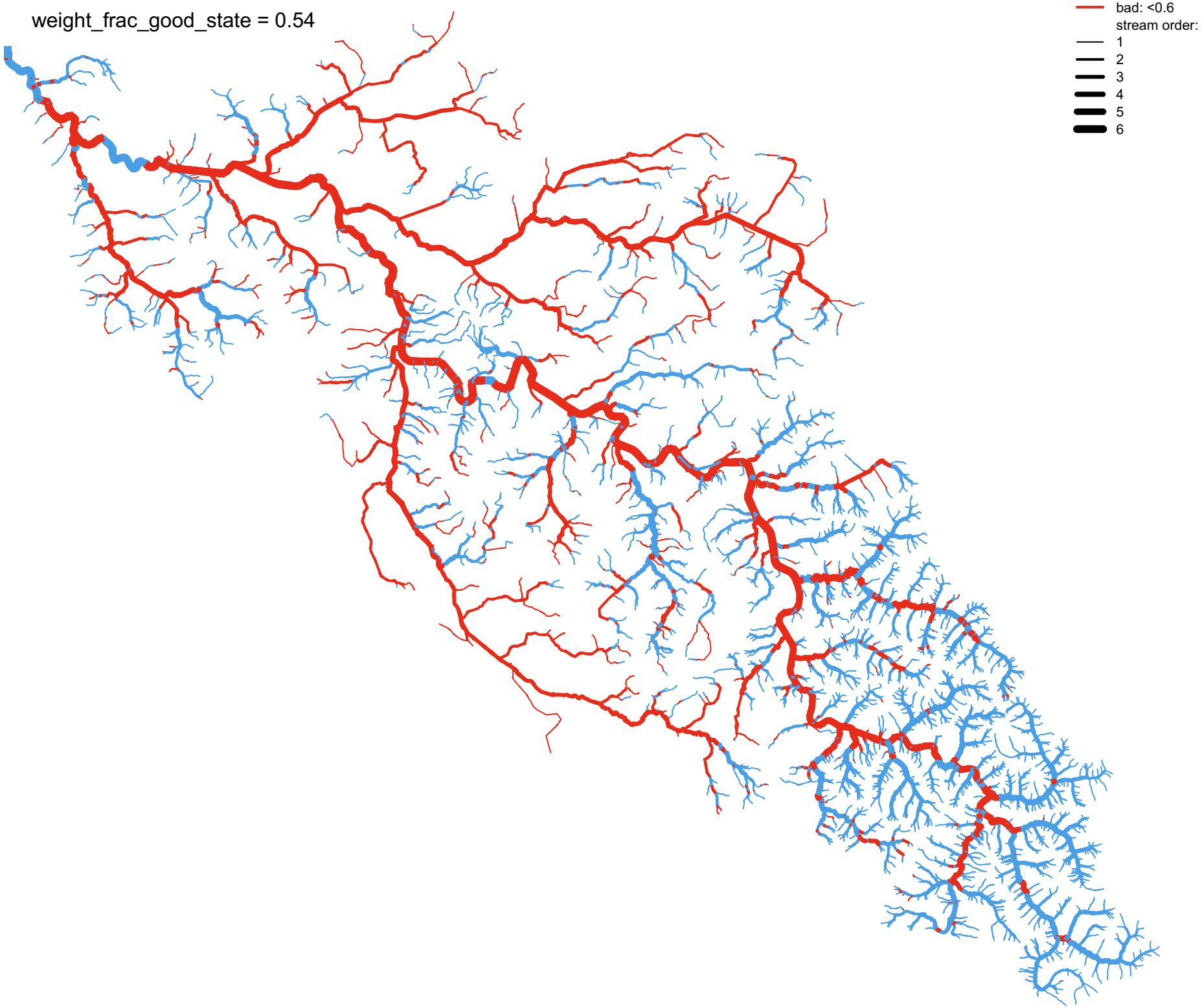

Morphological State
high
good
moderate
poor
bad
culvert
artif. barrier
nat. barrier

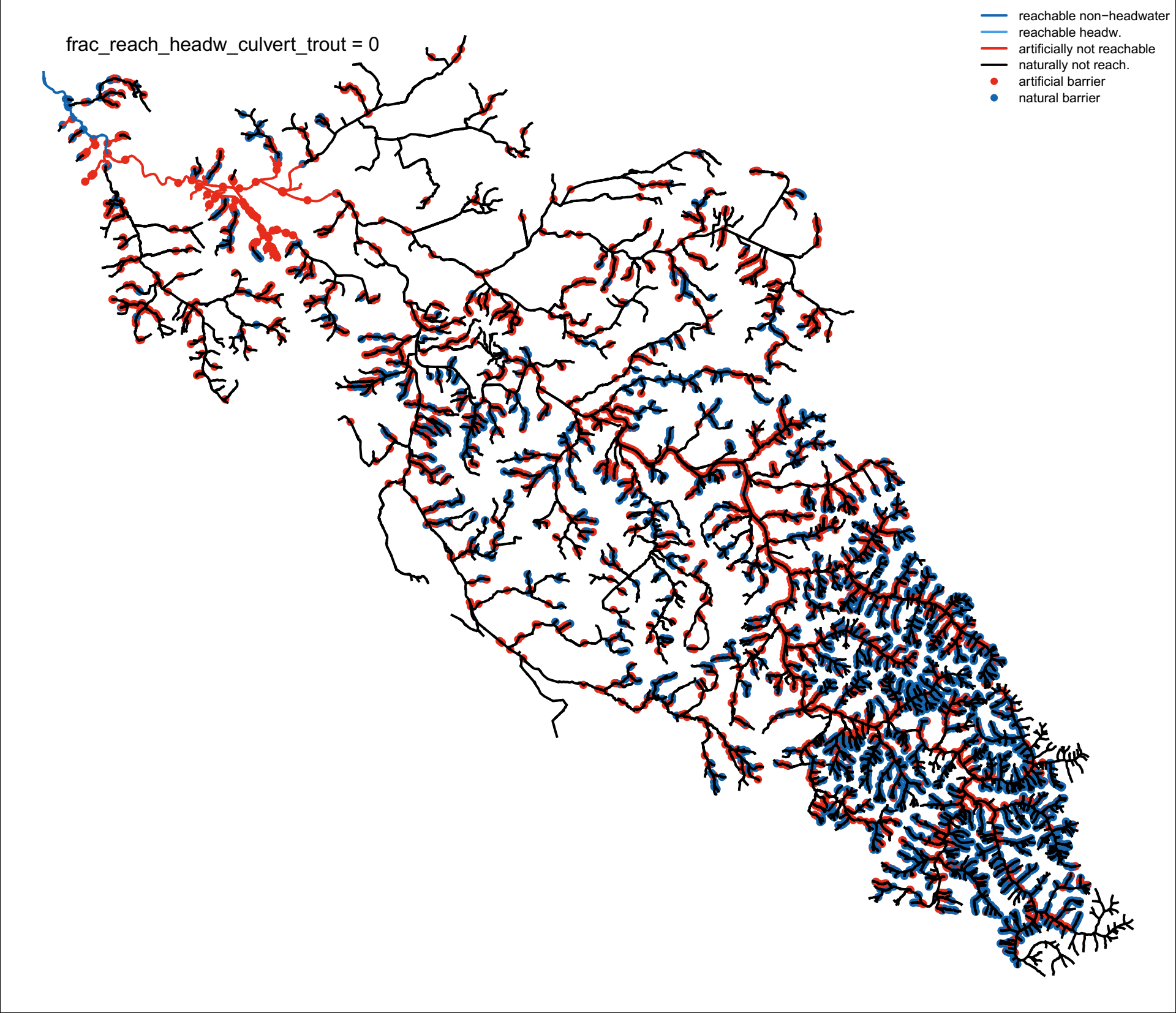

Nutrient State
high
good
moderate
poor
bad

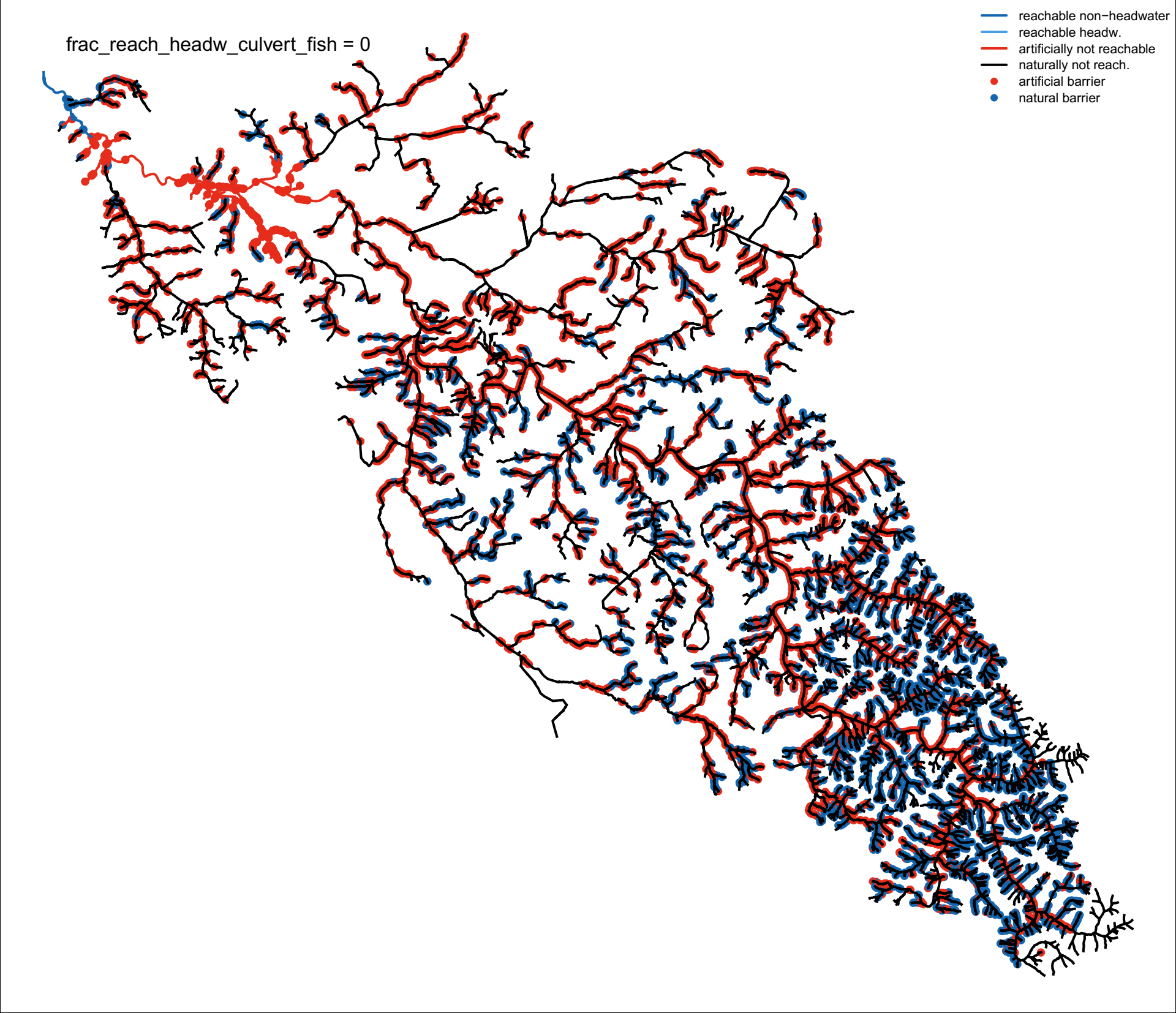

Micropollutant State
high
good
moderate
poor
bad

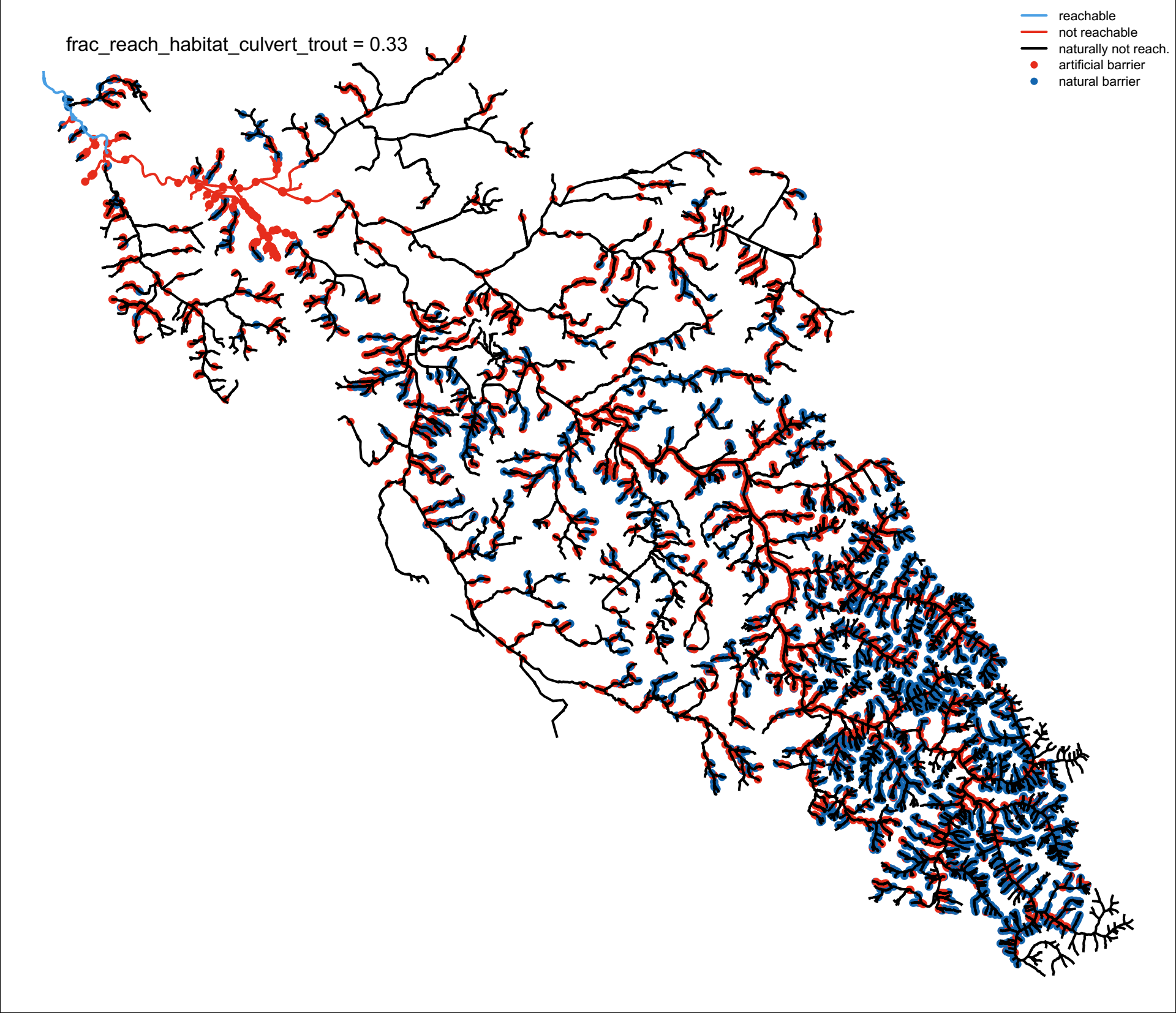

Ecological State
high
good
moderate
poor
bad

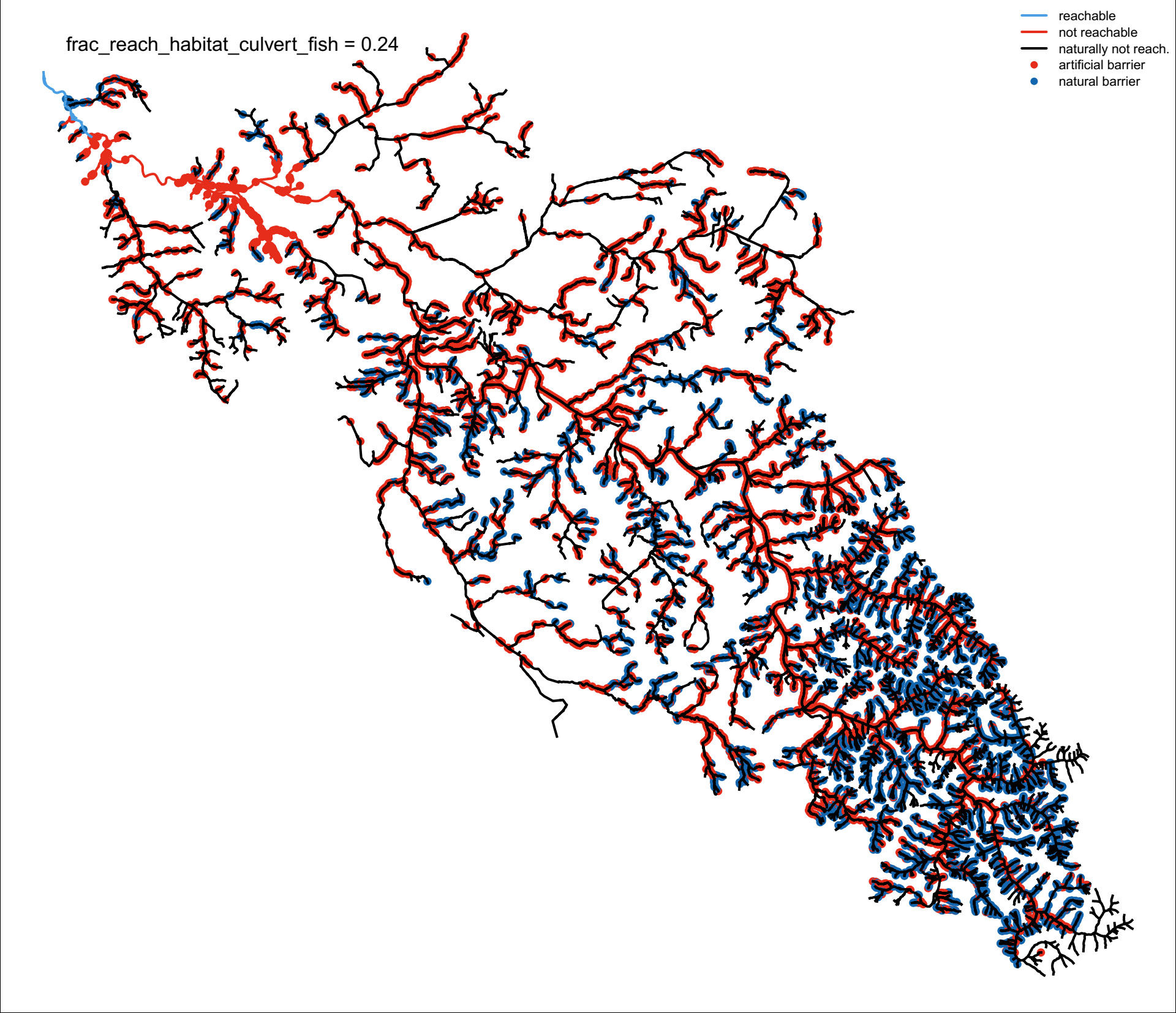

weight_mean_reach_state = 0.61
high
good
moderate
poor
bad
stream order:
1
2
3
4
5
6

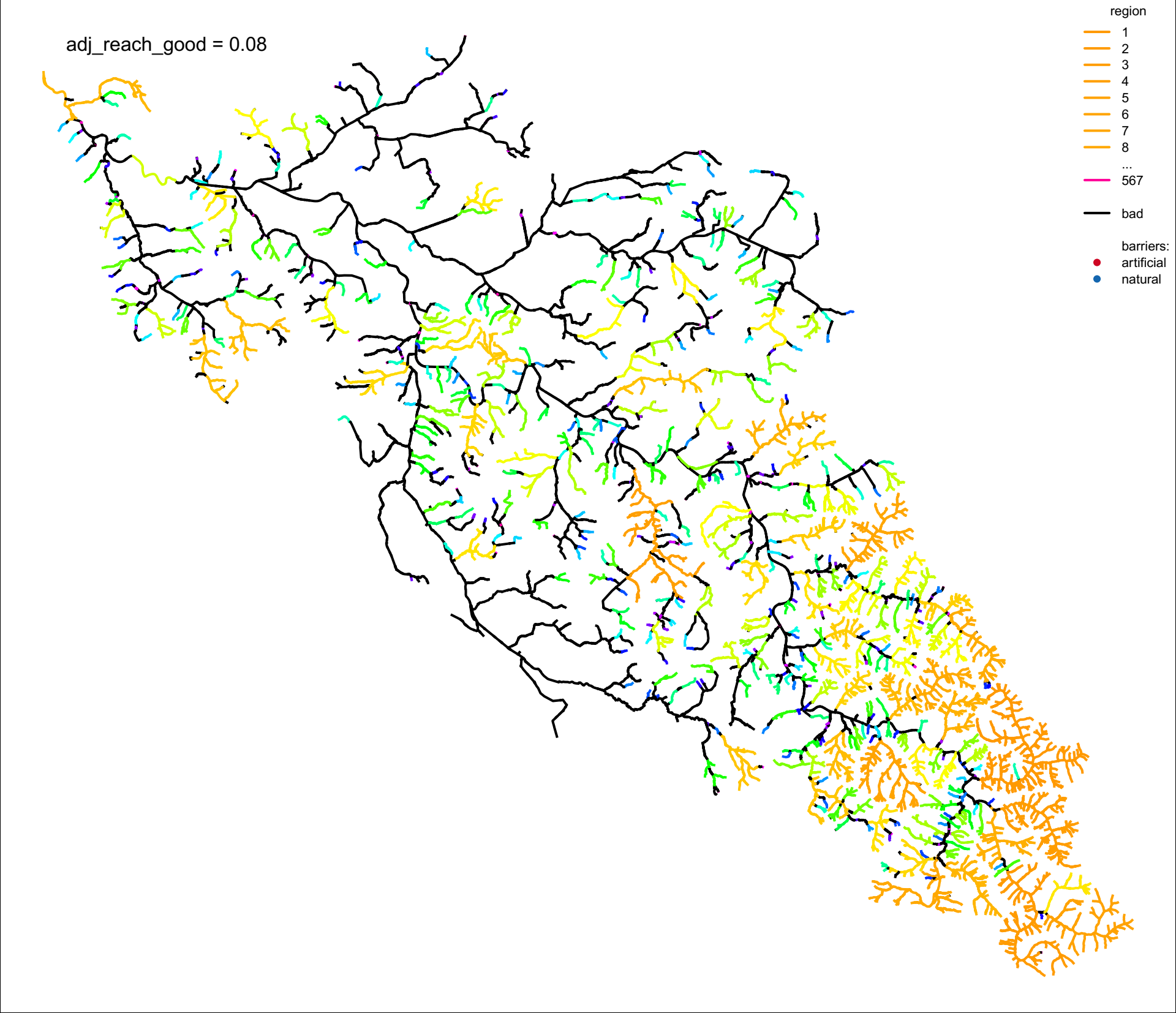

weight_frac_good_state = 0.54
good: >=0.6
bad: <0.6
stream order:
1
2
3
4
5
6

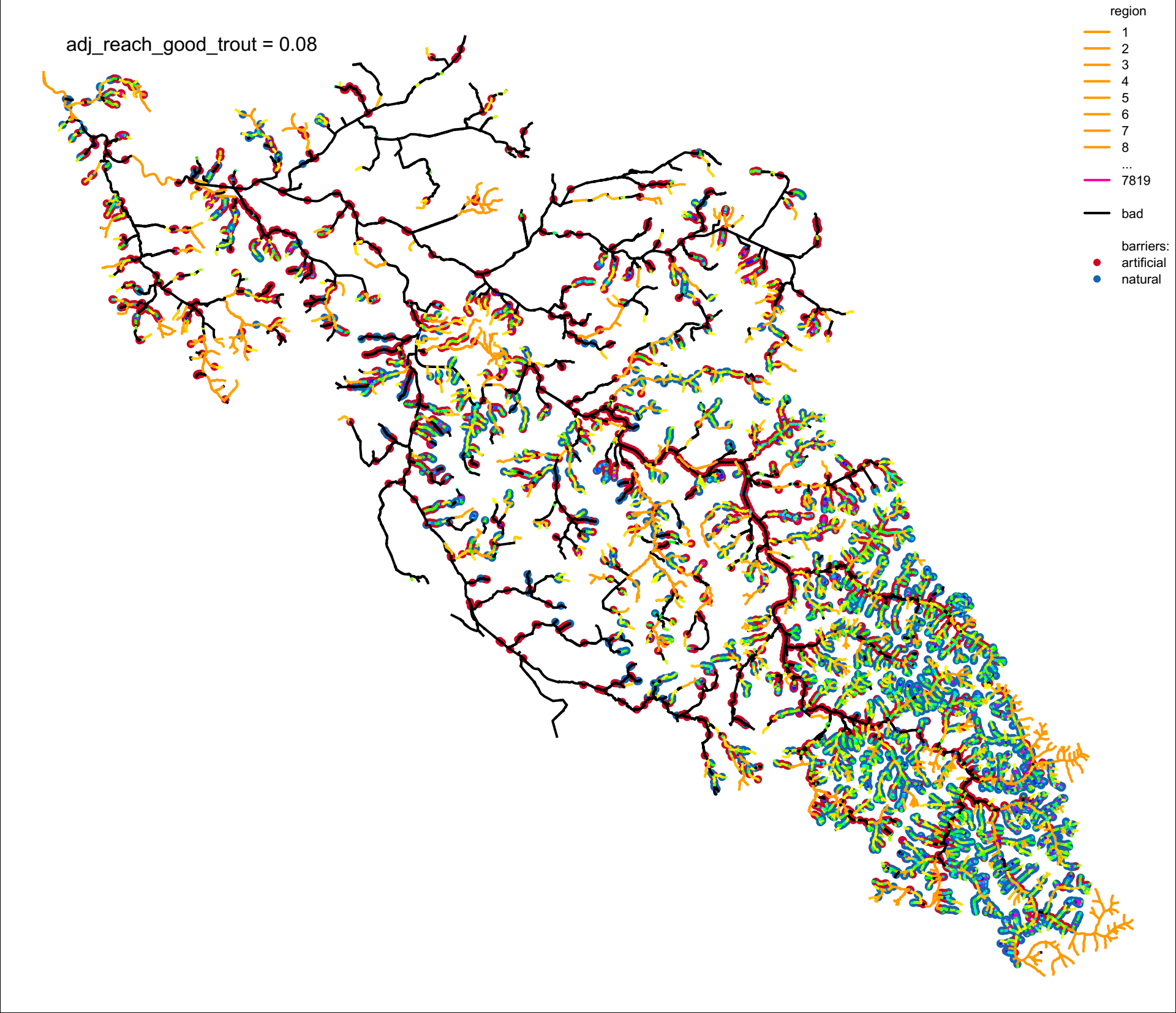

frac_reach_headw_culvert_trout = 0
reachable non−headwater
reachable headw.
artificially not reachable
naturally not reach.
artificial barrier
natural barrier

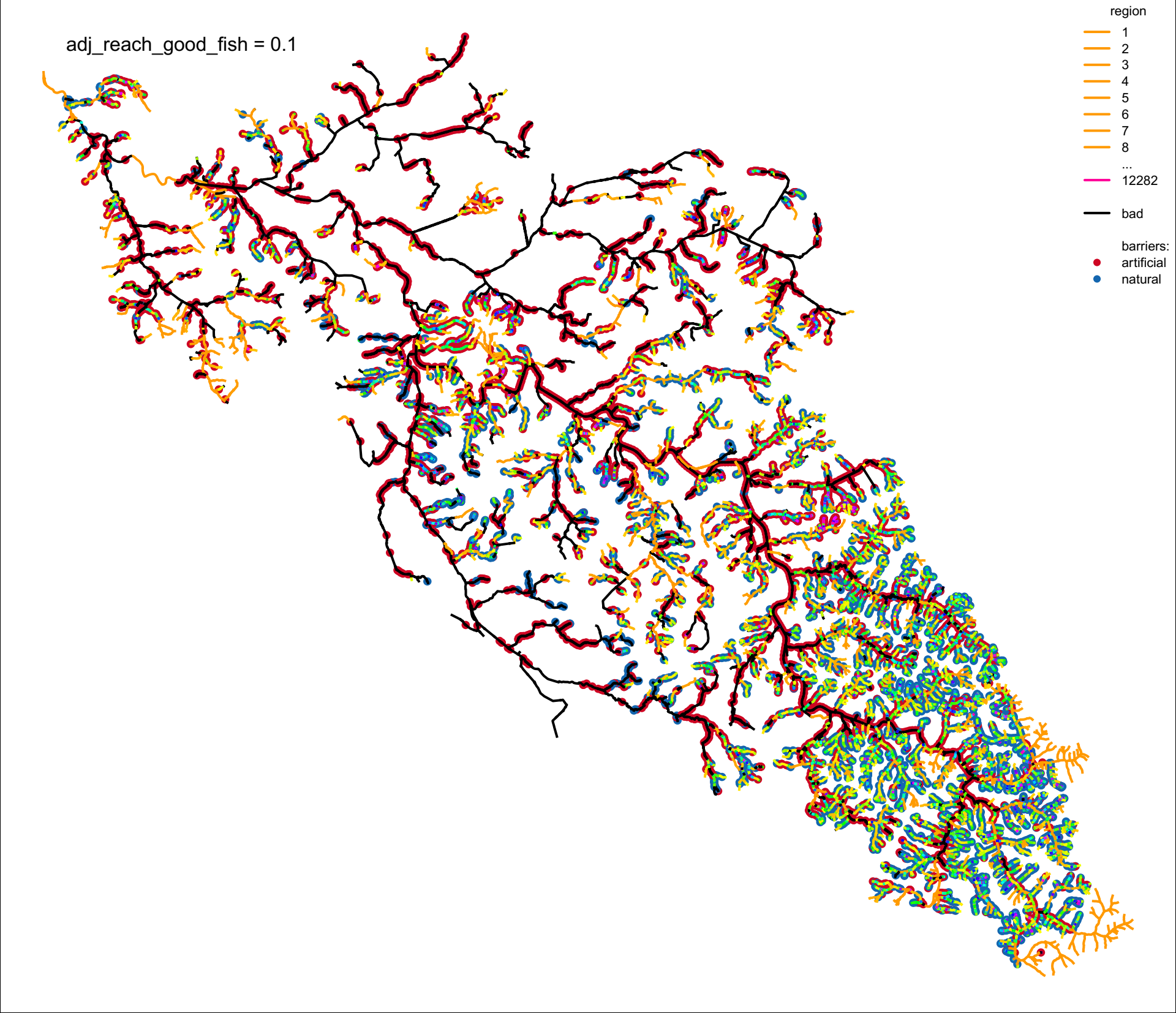

frac_reach_headw_culvert_fish = 0
reachable non−headwater
reachable headw.
artificially not reachable
naturally not reach.
artificial barrier
natural barrier

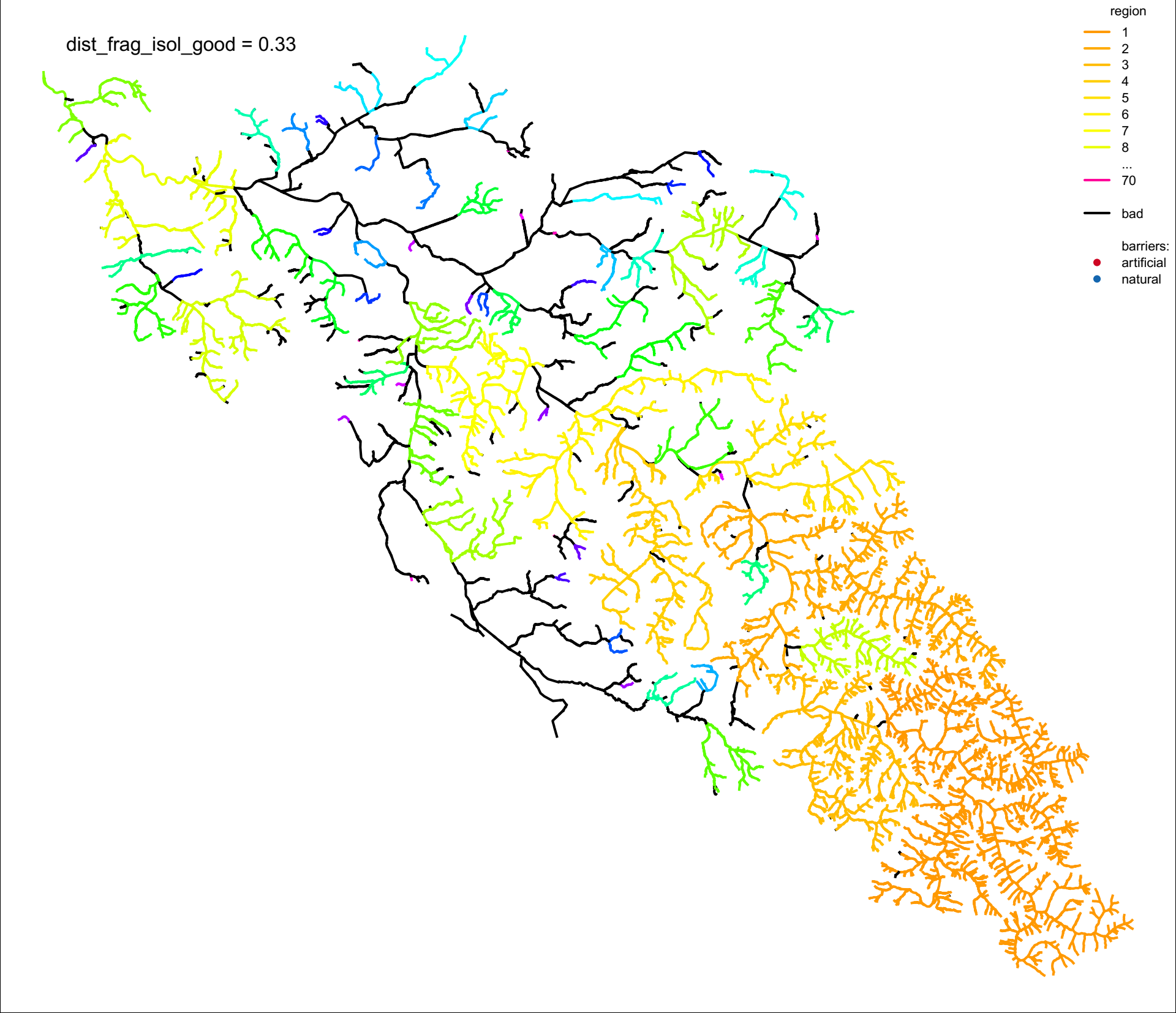

frac_reach_habitat_culvert_trout = 0.33
reachable
not reachable
naturally not reach.
artificial barrier
natural barrier

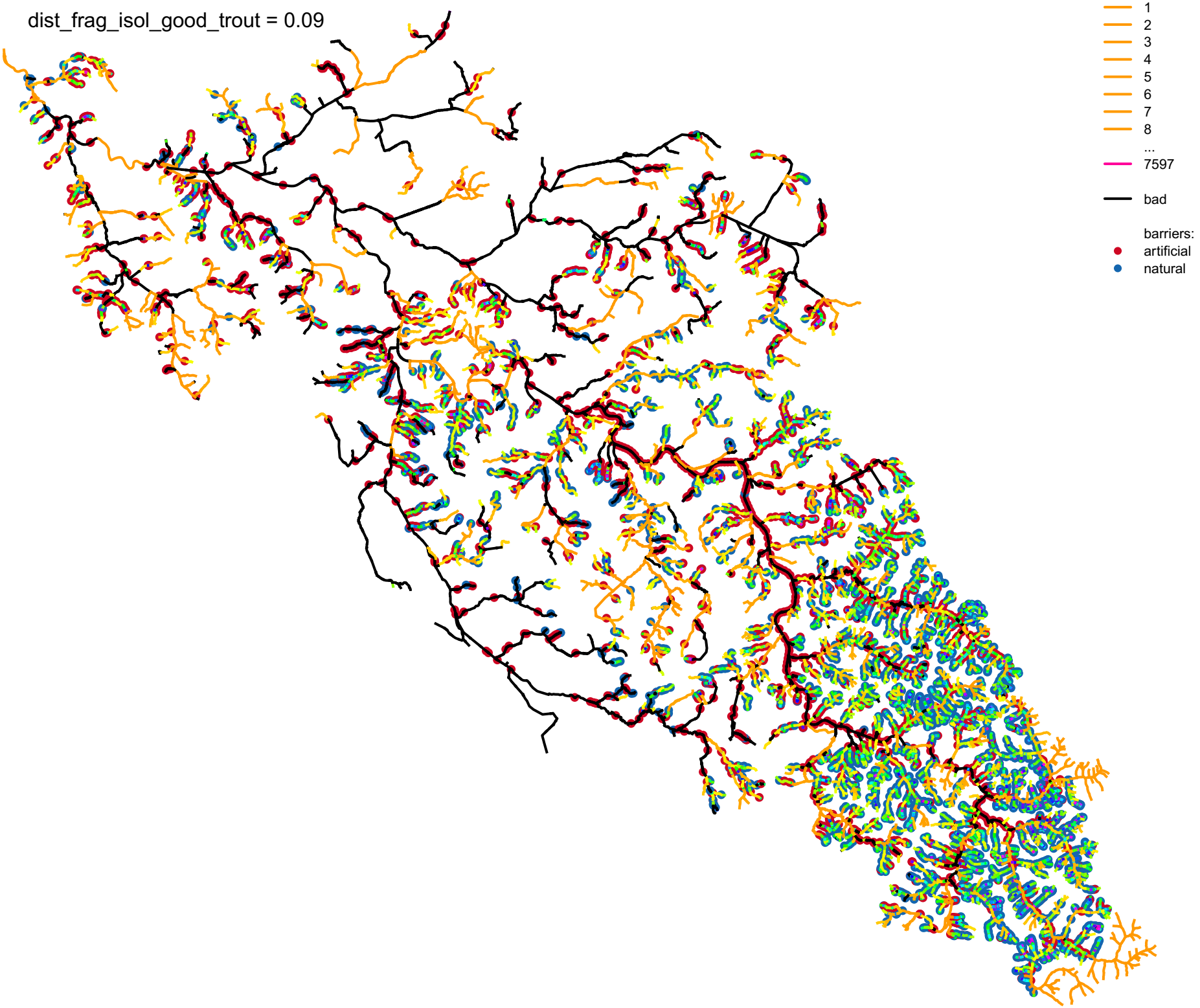

frac_reach_habitat_culvert_fish = 0.24
reachable
not reachable
naturally not reach.
artificial barrier
natural barrier

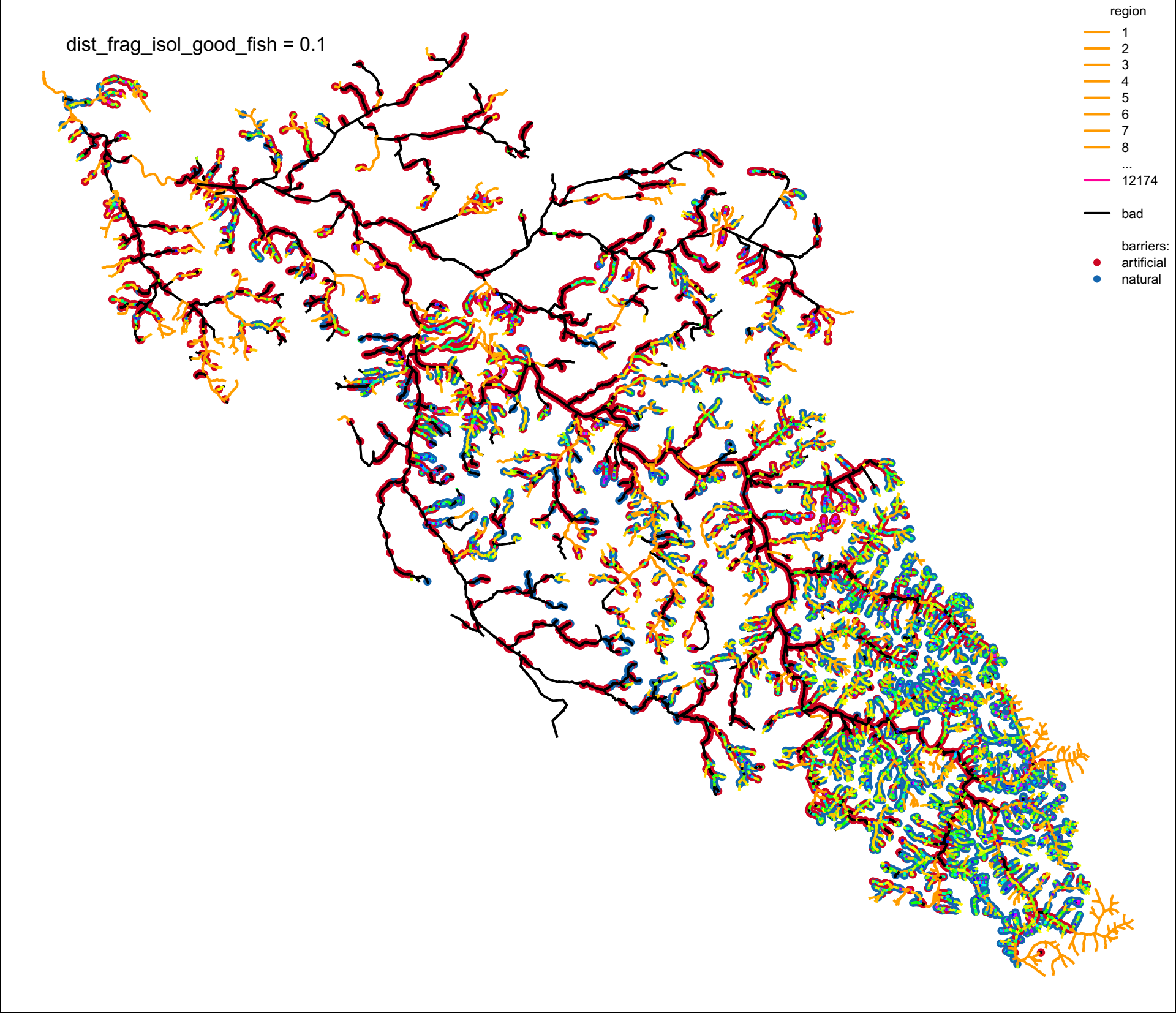

adj_reach_good = 0.08
region
1
2
3
4
5
6
7
8
...
567
bad
barriers:
artificial
natural

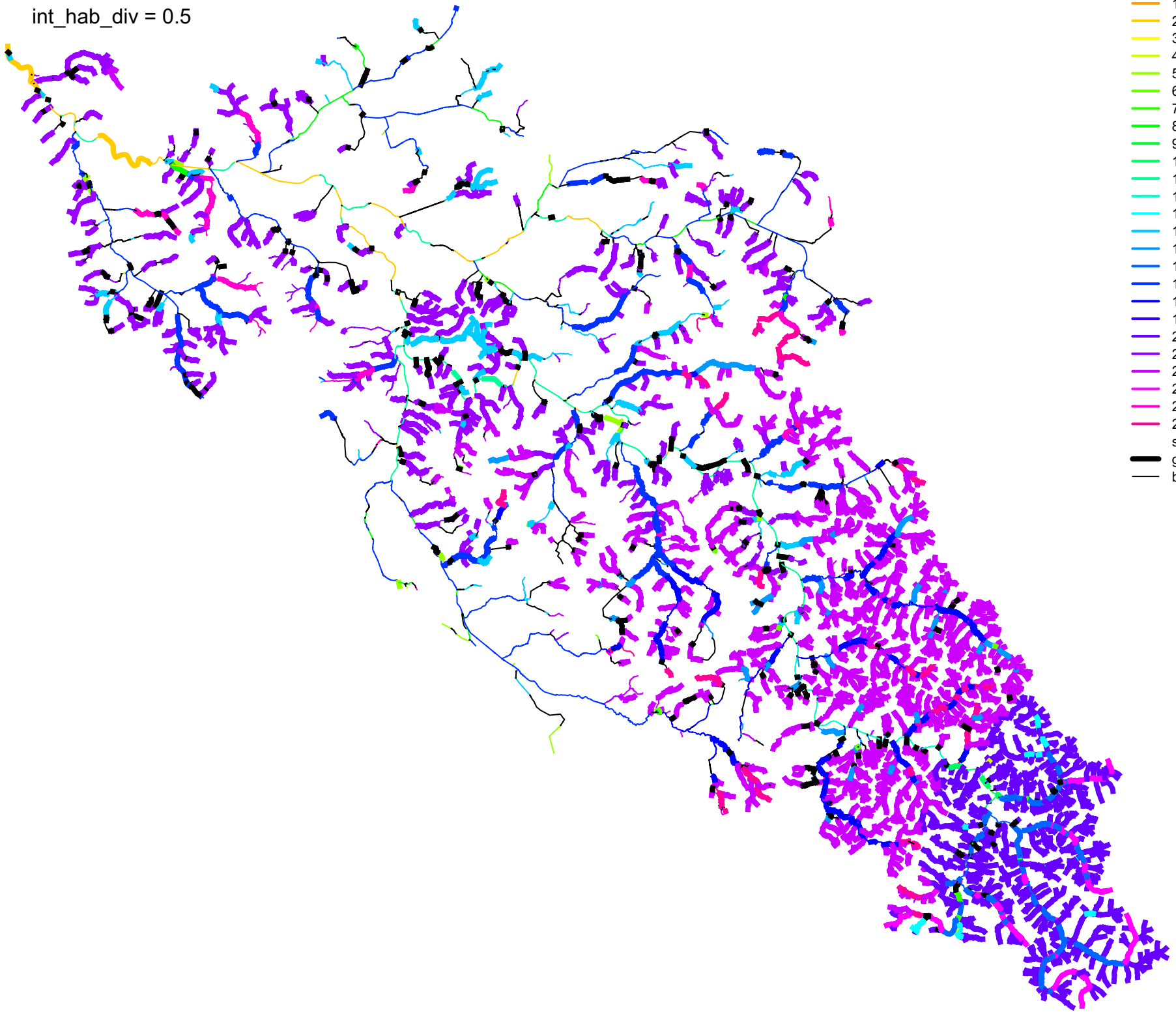

adj_reach_good_trout = 0.08
region
1
2
3
4
5
6
7
8
...
7819
bad
barriers:
artificial
natural


adj_reach_good_fish = 0.1
region
1
2
3
4
5
6
7
8
...
12282
bad
barriers:
artificial
natural


dist_frag_isol_good = 0.33
region
1
2
3
4
5
6
7
8
...
70
bad
barriers:
artificial
natural


dist_frag_isol_good_trout = 0.09
region
1
2
3
4
5
6
7
8
...
7597
bad
barriers:
artificial
natural


dist_frag_isol_good_fish = 0.1
region
1
2
3
4
5
6
7
8
...
12174
bad
barriers:
artificial
natural


int_hab_div = 0.5
type:
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
state:
good
bad