The culverts effect on fish migration based on SWAT model in Mayi River

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contents

1. Introduction

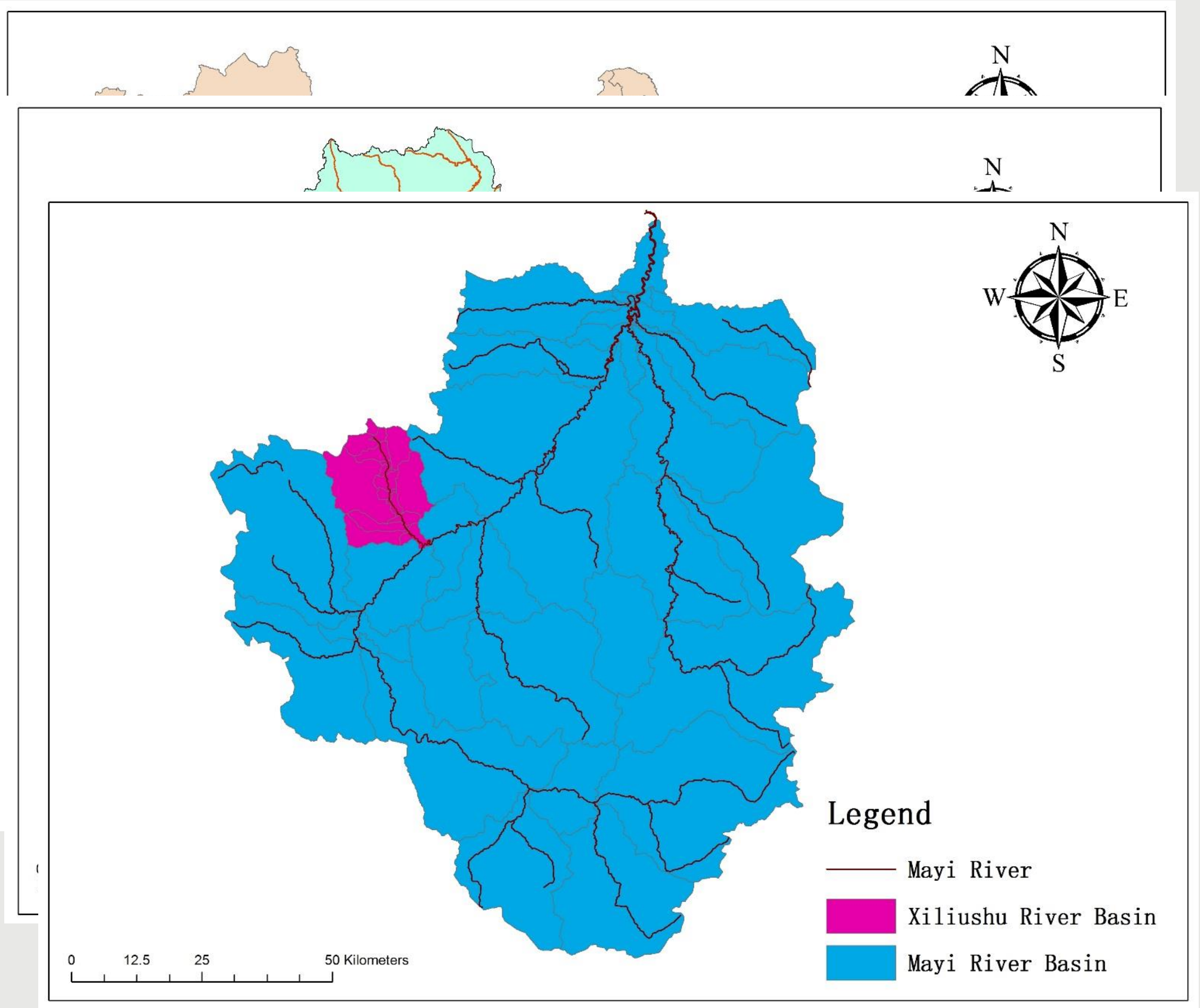
Barriers, such as dams and culverts, alter current velocity, water depth and create vertical drops at outflows that change the hydrology and thermal regimes of aquatic systems.

There is an increasing concern about the road crossings such as culverts altering fish habitat and disrupting river connectivity.

How to quantify the effect of culverts on fish migration and river longitudinal connectivity becomes meaningful.

One method proposed by Cote for quantitatively evaluating the cumulative impacts of barriers on river network is the DCI (Dendritic Connectivity Index).

2. Study area: Mayi River Basin

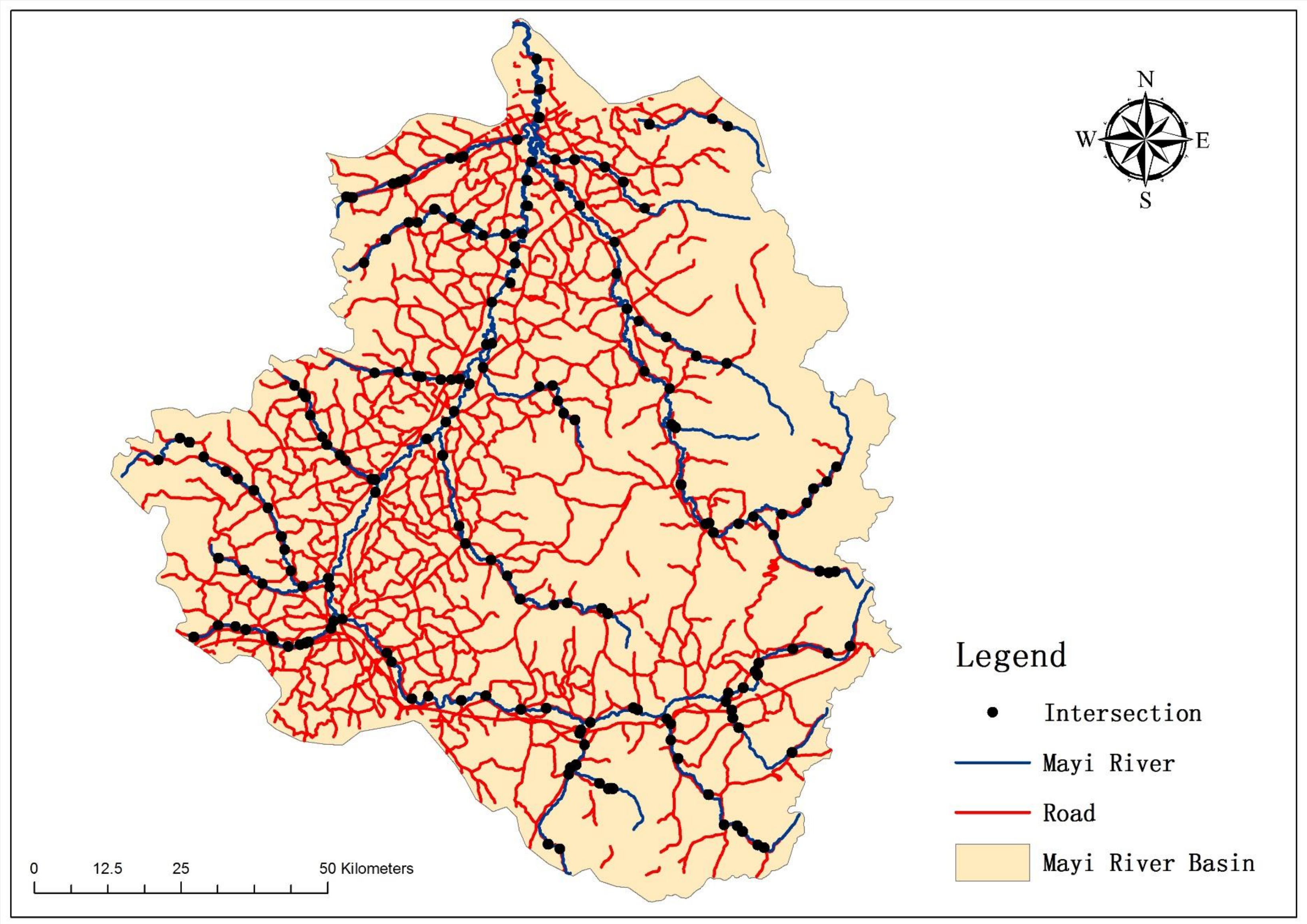


Mayi River is an important tributary of Songhua River in the Northeast China.

The Mayi River Basin comprises an area of 11734.18 km^2 at an elevation of 700m.

Meanwhile, Xiliushu River is a tributary of Mayi River.

2. Study area: Mayi River Basin

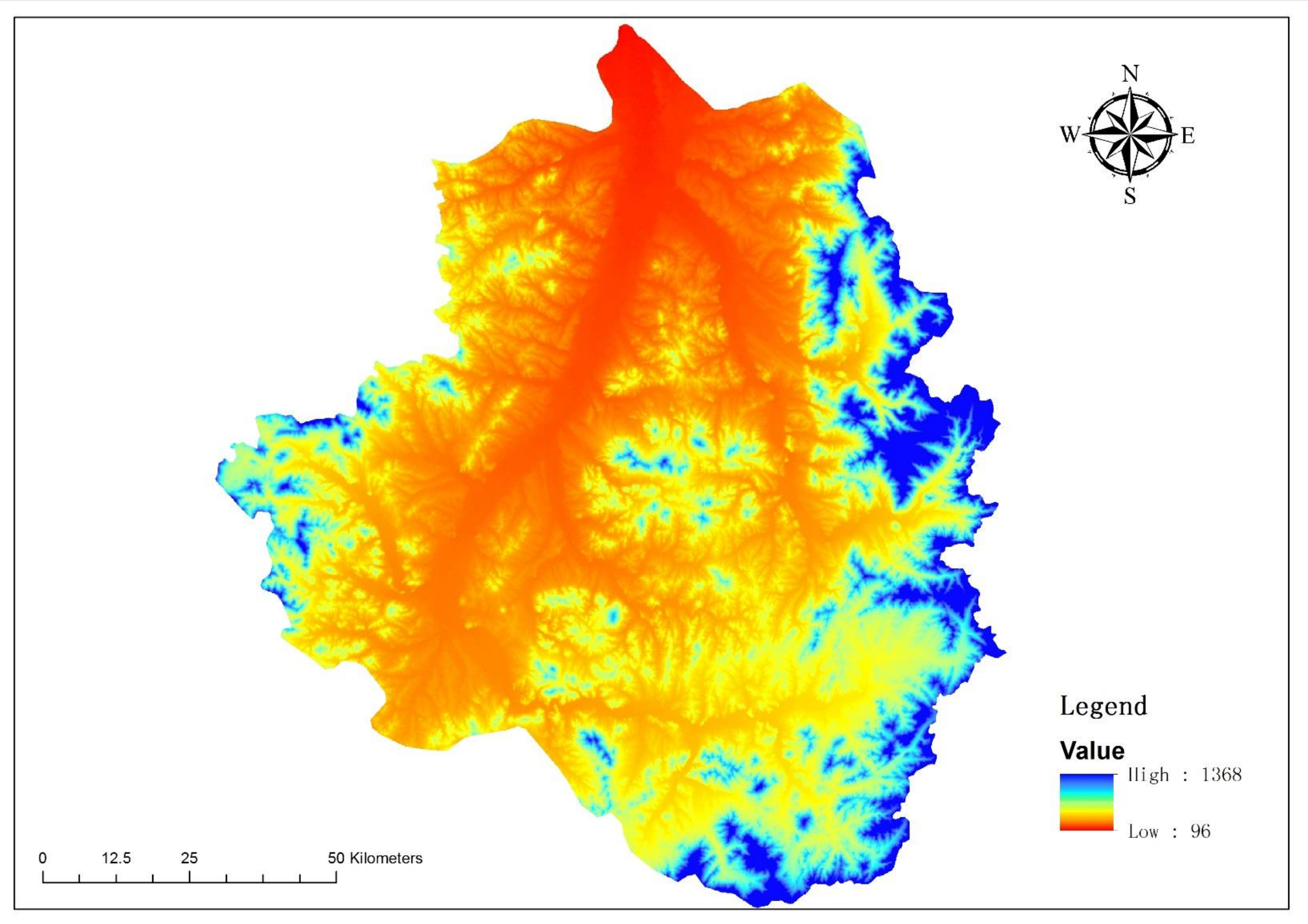


Road systems and river networks frequently intersect, often with significant consequences for river and stream ecosystems.

The 168 intersections are possibly road crossings such as bridges and culverts.

3. SWAT model of Mayi River Basin

Data basis---Spatial database: DEM

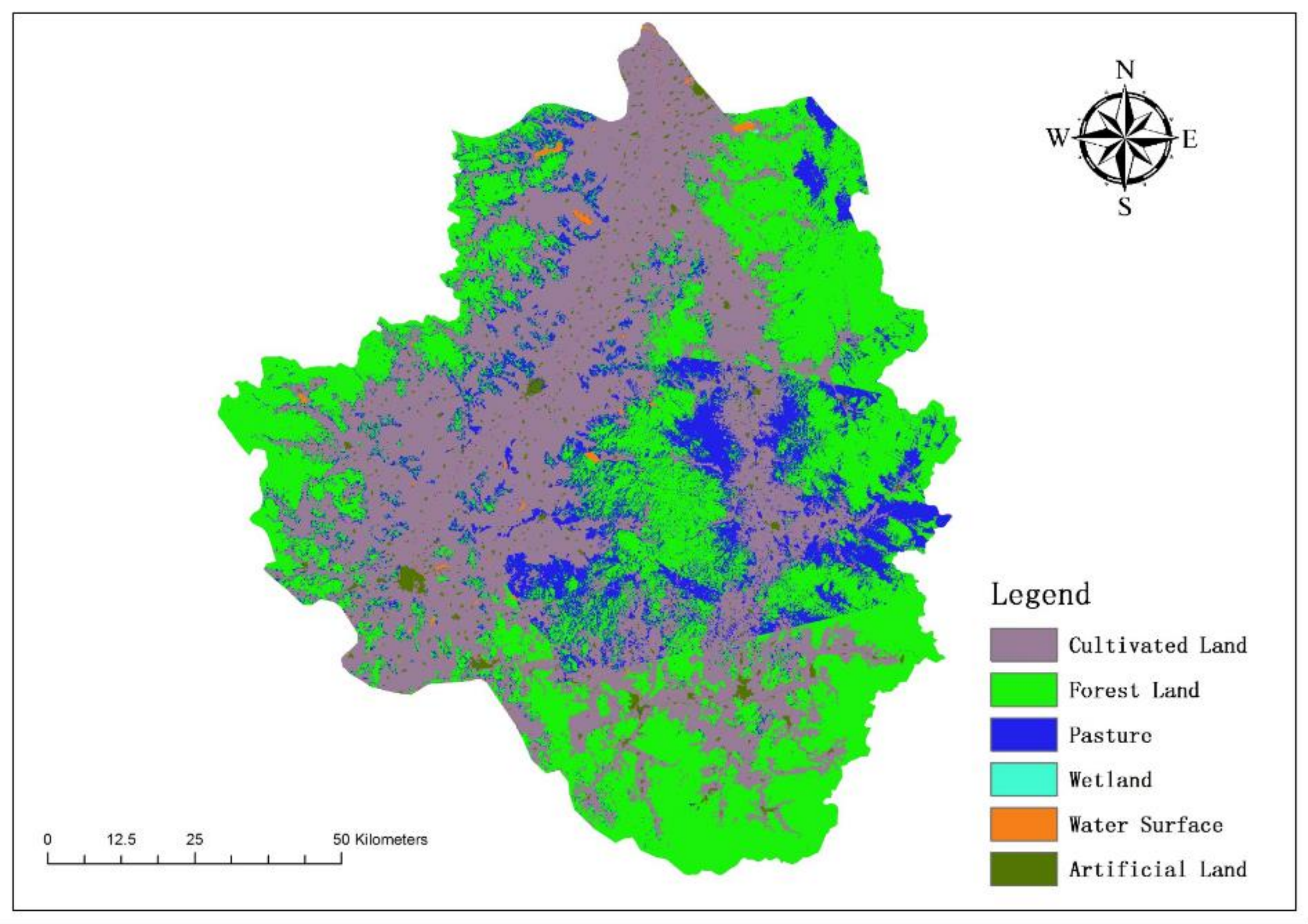


DEM of Mayi River Basin

A 90 m by 90 m resolution DEM was downloaded from SRTM website.

3. SWAT model of Mayi River Basin

Data basis---Spatial database: Land use



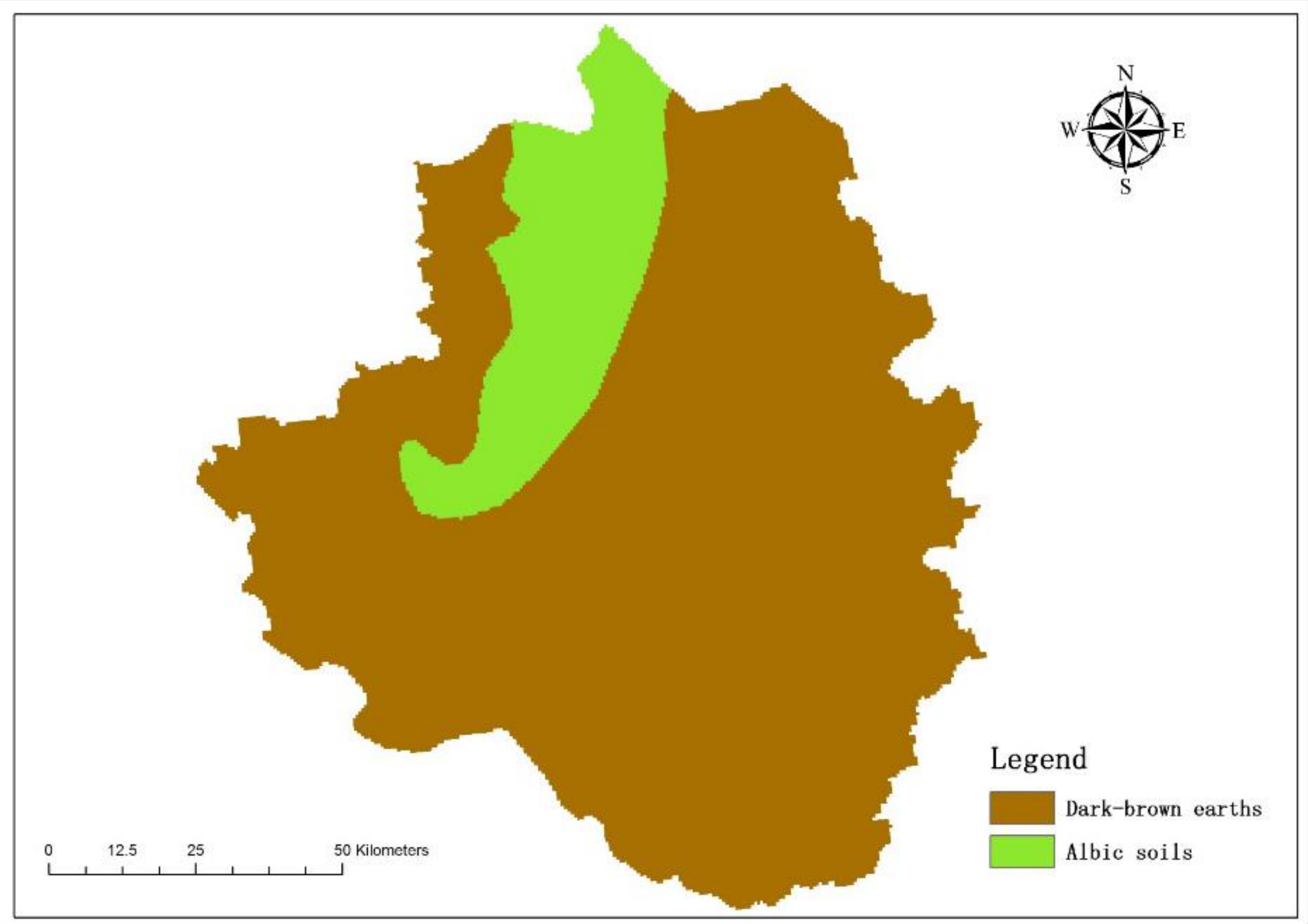
Land use in Mayi River Basin

The land use map of the study area was obtained from “Globe Land30-2010”.

There are more than 40% of Mayi River Basin is cultivated land.

3. SWAT model of Mayi River Basin

Data basis---Spatial database: Soil type



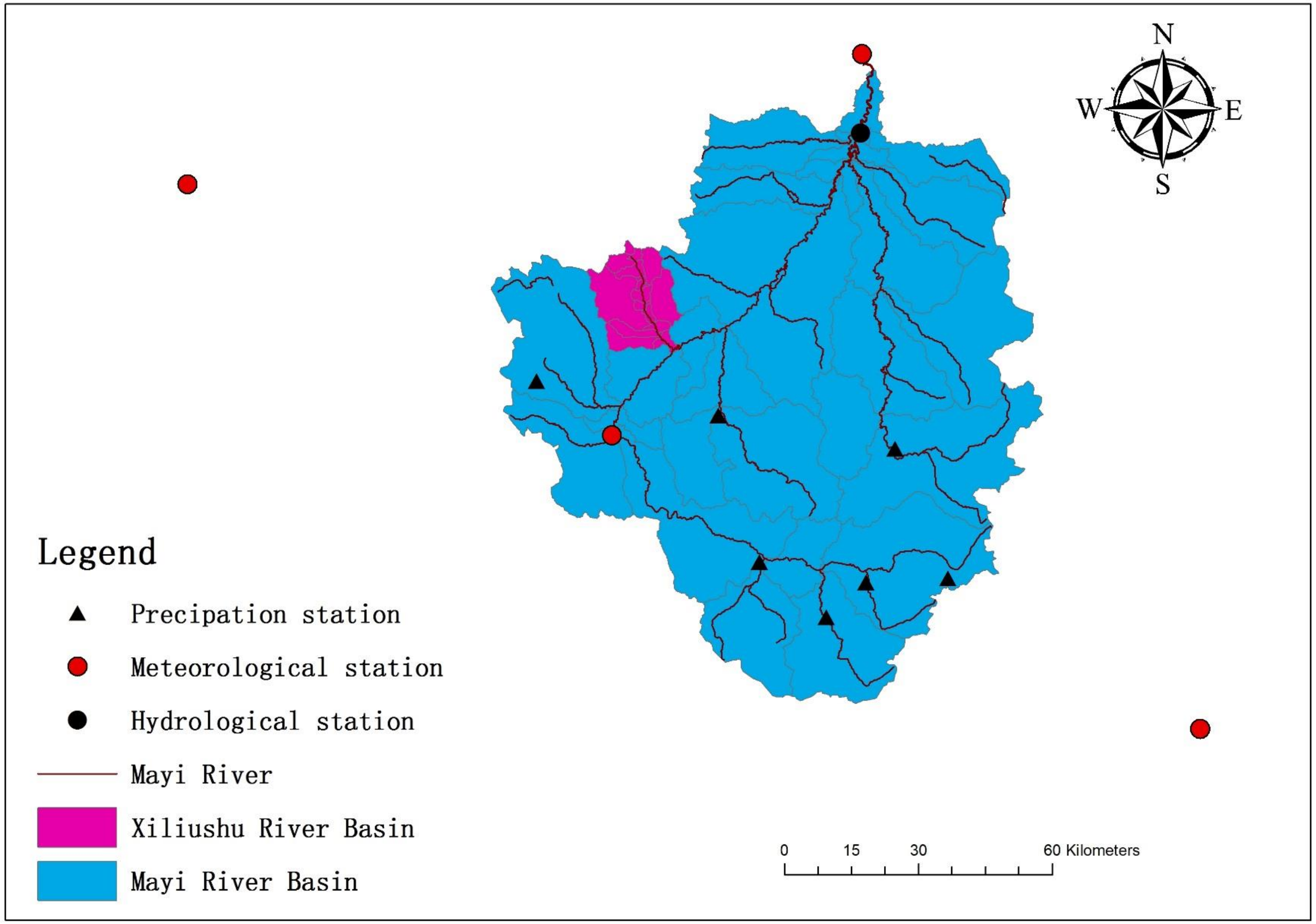
Soil type in Mayi River Basin

Spatial soil data were from Institute of Soil Science, Chinese Academy of Sciences.

Major soil types in the basin are the Dark brown earths and Albic soils.

3. SWAT model of Mayi River Basin

Data basis---Attribute database



The weather generator was created by the meteorological at four weather stations (Shangzhi, Tonghe, Harbin, and Mutankiang).

Daily stream flow record is from Lianhua hydrological obeservation station.

3. SWAT model of Mayi River Basin

Model calibration and validation

The calibration and uncertainty analysis were done using SUFI-2 in SWAT CUP.

10 parameters were tested for sensitivity analysis for the simulation of the daily average stream flow in the research.

Number	Sensitive parameters	Lower and upper bound	Final fitted value
1	HRU_SLP	0-1	0.41
2	SNOCOVMX	5-300	267.38
3	SNO50COV	0.05-0.5	0.48
4	SOL_BD	0.9-2.5	1.14
5	ALPHA_BF	0-1	0.99
6	CH_K2	-0.01-500	327.86
7	BIOMIX	0-1	0.39
8	CANMX	0-100	73.92
9	SMFMX	0-20	8.7
10	SMFMN	0-20	10.42

3. SWAT model of Mayi River Basin

Model calibration and validation

Stream flow calibration and validation results at Lianhua hydrological observation station

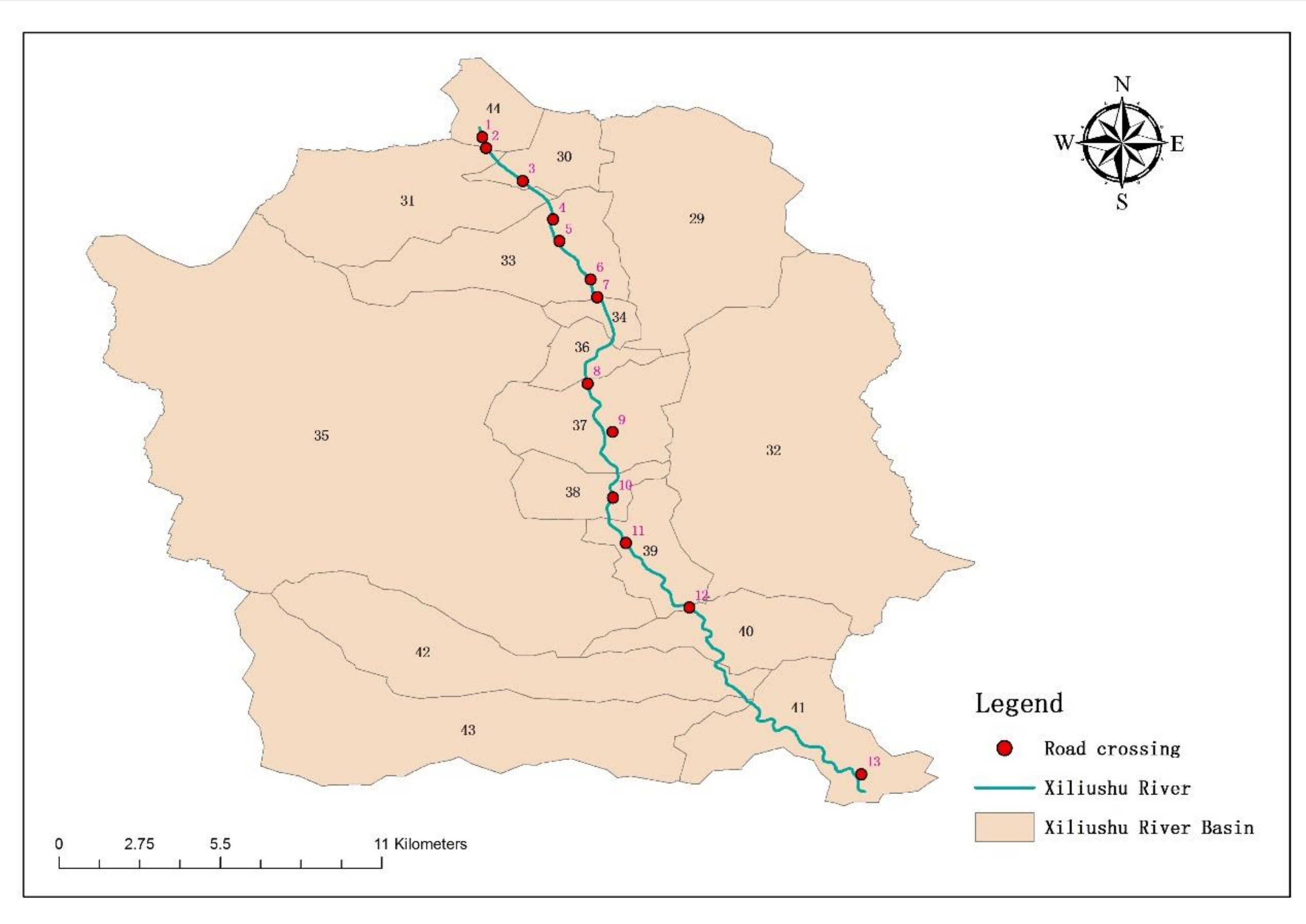
Period	Average daily value (m^3/s)		R^2	E_{ns}	RE
	observation	simulation			
2009-2011	52.49	47.51	0.73	0.73	9.50
2012-2013	73.90	53.41	0.73	0.66	24.81

The E_{ns} (Nash-Suttclife coefficient) and R^2 (coefficient of determination) values showed that there is a good agreement between the measured and simulated daily stream flows for calibration period.

During the period of validation, the E_{ns} and R^2 were 0.73 and 0.66, respectively.

4. Culvert effect on potamodromous fish migration in small scale

Culvert location in Xiliushu River



The location of barriers in Xiliushu River Basin

The construction data of culverts in Xiliushu River Basin is from our investigation in 2015.

Through the investigation, there are 13 barriers in the river. Number 1, 2 and 12 are culverts, others are bridges that the span length are all greater than 6 m.

The culvert effect is expressed by the fish passability that is modeled by FishXing.

4. Culvert effect on potamodromous fish migration in small scale

Investigation in Xiliushu River

4. Culvert effect on potamodromous fish migration in small scale

Culvert construction in river

Bridges are generally considered to be completely passable by all fish species, whereas culverts vary in terms of passability, depending on factors such as diameter, length, slope, outlet configuration, and other characteristics that influence a fish's ability to migrate through.

The low and high flow of the culvert in the FishXing model is on the basis of SWAT model result in 2013.

Culvert construction and flow in Xiliushu River Basin

Number	Shape	Diameter (cm）	Length (m)	Low flow (m^3)	High flow (m^3)
1	circular	96	5.0	0	2.961
2	circular	100	4.4	0	2.961
12	circular	70	5.4	0	26.71

4. Culvert effect on potamodromous fish migration in small scale

FishXing model

FishXing models organism capabilities against culvert hydraulics across a range of expected stream discharge.

The fish passability can be described by the percent of flow range that is passable for fish.

$$P = \frac{Q_p}{Q_{high} - Q_{low}}$$

Q_p — the flow section that the fish can pass the culvert,

Q_{high} — the high flow in the nearby of culvert,

Q_{low} — the low flow in the nearby of culvert.

4. Culvert effect on potamodromous fish migration in small scale

In the study, we focus on 4 main potamodromous fishes, *Leuciscus waleckii* (Amur ide), *Esox reicherti (Amur pike)*, *Carassius auratus gibelio* (Silver prussian carp) and *Cyprinus carpio haematopterus* (Amur carp).

Cyprinus carpio haematopterus

Leuciscus waleckii

Esox reicherti

Carassius auratus gibelio

4. Culvert effect on potamodromous fish migration in small scale

Fish characteristics

In the study, 4 main potamodromous species in Xiliushu River are selected to assess river longitudinal connectivity, fish characteristic are shown in Table.

The characteristics of potamodromous fishes

Species	Length (cm)	Prolonged swimming speed (m/s)	Speed range (m/s)	Burst swimming speed (m/s)	Burst time to exhaustion (s)
leuciscus leuciscus	10-21.4	0.39	0.46-0.9	0.68	20
Esox reicherti	12.68-65.49	0.25	0.19-0.47	-	-
Carassius auratus gibelio	20	0.53	0.15-0.91	1.37	10
Cyprinus carpio haematopterus	30	0.9	1.22-4.27	2.74	10

4. Culvert effect on potamodromous fish migration in small scale

Fish pasability

The fish passability is relative to culvert shape, construction and fish characteristics.

The passability of 4 species in number 12 culvert are relatively lower than other two culvert, it may be the effect of long length and higher flow. *Leuciscus waleckii* (Amur ide) and *Esox reicherti (Amur pike)* are more likely to be affected by 3 culverts than *Carassius auratus gibelio* (Silver prussian carp) and *Cyprinus carpio haematopterus* (Amur carp).

The result of fish passability in Xiliushu River

Number	Fish passability (%)			
	Leuciscus waleckii	*Esox reicherti*	*Carassius auratus gibelio*	*Cyprinus carpio haematopterus*
1	10.7	4.3	21.7	54.7
2	12.4	5.3	25.1	59.3
12	0.7	0.3	11.2	28.7

4. Culvert effect on potamodromous fish migration in small scale

Analysis the culvert effect on fish migration

Number 1 and 12 culvert have extremely effect on potamodromous fish migration.

Number 2 culvert have very effect on potamodromous fish migration.

Classification of effect on fish migration

Mean fish passability (%)	Effect
0≤value≤25	extremely
25＜value≤50	very
50＜value≤75	moderate
75＜value≤100	good

The effect of culverts on fish migration

Culvert number	Mean fish passability (%)	Effect
1	22.8	extremely
2	25.5	very
12	10.2	extremely

4. Culvert effect on potamodromous fish migration in small scale

Dendritic Connectivity Index

The formula for calculating river longitudinal connectivity requires dividing the river into segments, where segments are separated by barriers.

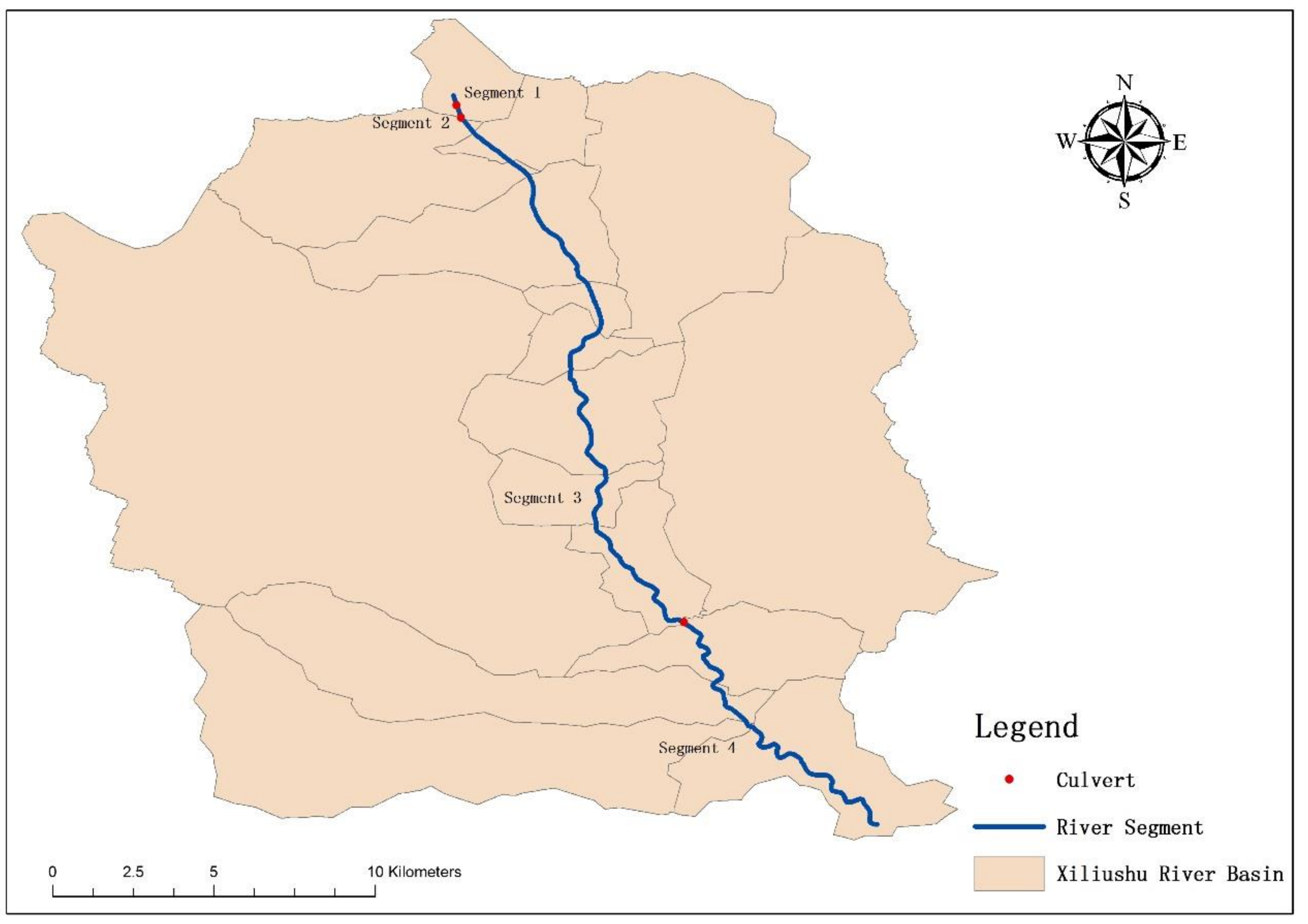
The formula is:

$$DCI = \sum_{i=1}^{n}\sum_{i=1}^{n} c_{ij} \cdot \frac{l_i}{L} \cdot \frac{l_j}{L} * 100$$

l —the length of segment i and j,

c_{ij} — the passability between segments i and j,

L — the total stream length.



River segment distribution in Xiliushu River

4. Culvert effect on potamodromous fish migration in small scale

River longitudinal connectivity in Xiliushu River

The mean value of Dendritic Connectivity Index is 57.68, it is more than half of the maximum 100.

Even the passability value of *Leuciscus waleckii* (Amur ide) and *Esox reicherti (Amur pike)* are much lower than *Carassius auratus gibelio* (Silver prussian carp) and *Cyprinus carpio haematopterus* (Amur carp), all the Dendritic Connectivity Index values are exceed 50, it indicates that the value is affected by segment length and total river length.

Dendritic Connectivity Index in Xiliushu River

Species	Dendritic Connectivity Index
Leuciscus waleckii	54.17
Esox reicherti	52.61
Carassius auratus gibelio	57.65
Cyprinus carpio haematopterus	66.30
Mean	57.68

5. Culvert effect on cold water fish migration in large scale

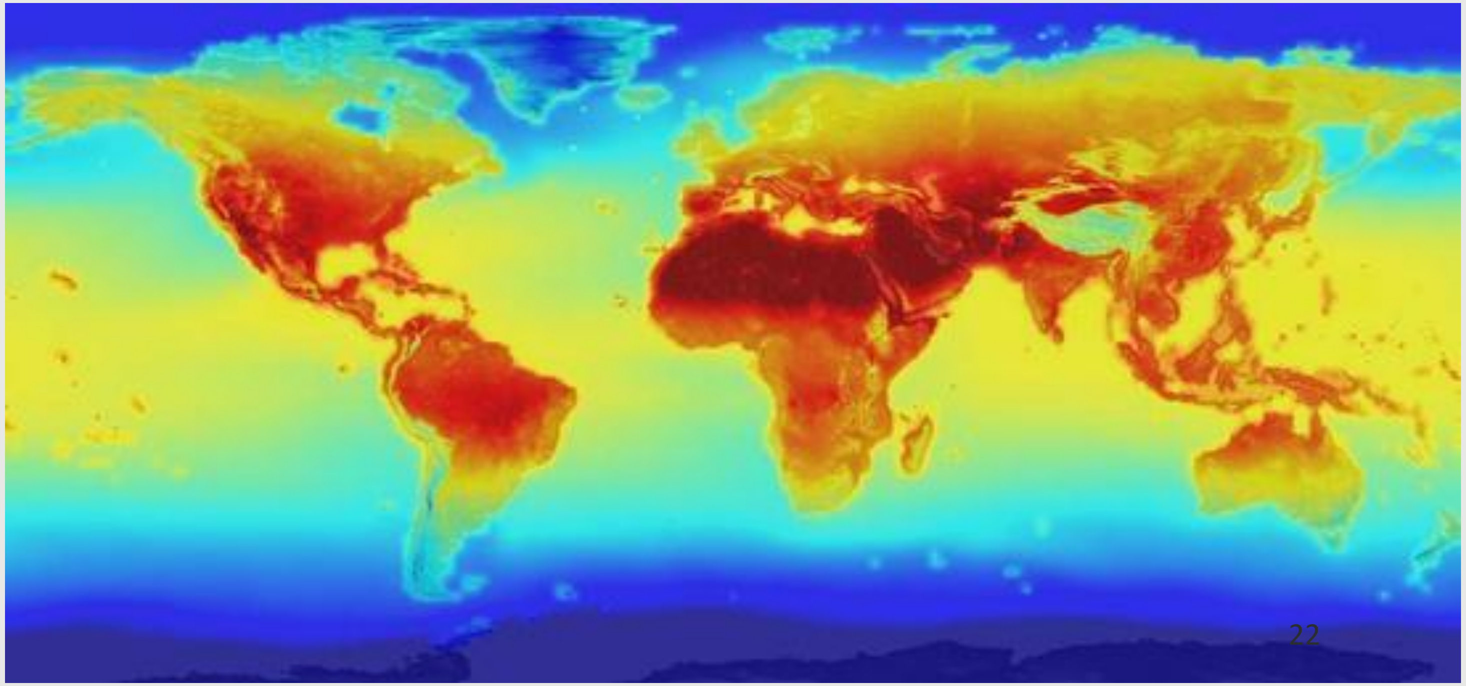
Cold water fish

The cold water fish live in the water temperature of 0-22℃.

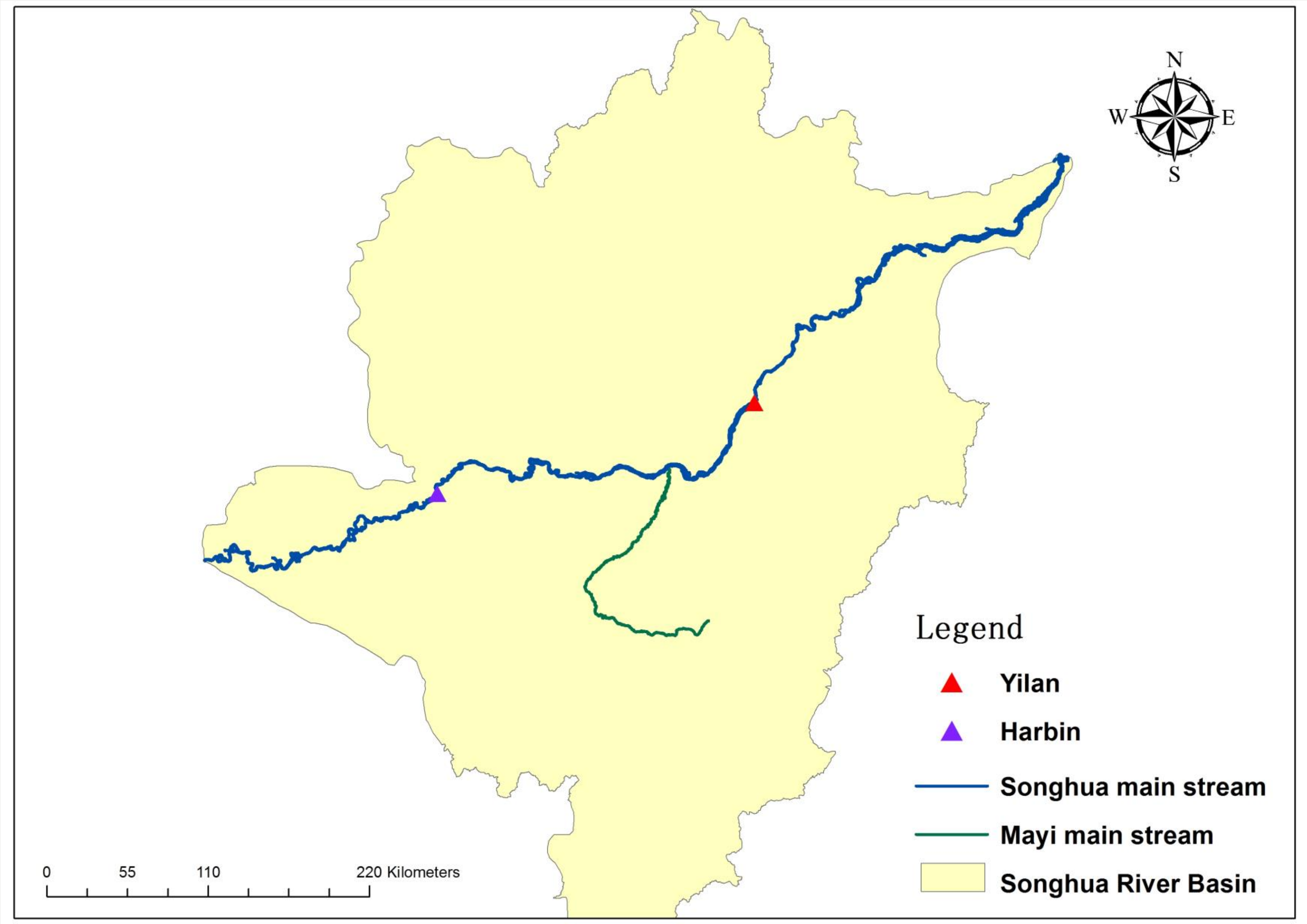
If the water temperature exceeds 22℃, the cold water fish will appear seriously discomfort, stop feeding and grow, even death finally.

So when the water temperature exceeds to a certain extent, the fish will move between main stream and tributary.

In the background of global warming, the movement of cold water fish need to be concerned.



5. Culvert effect on cold water fish migration in large scale



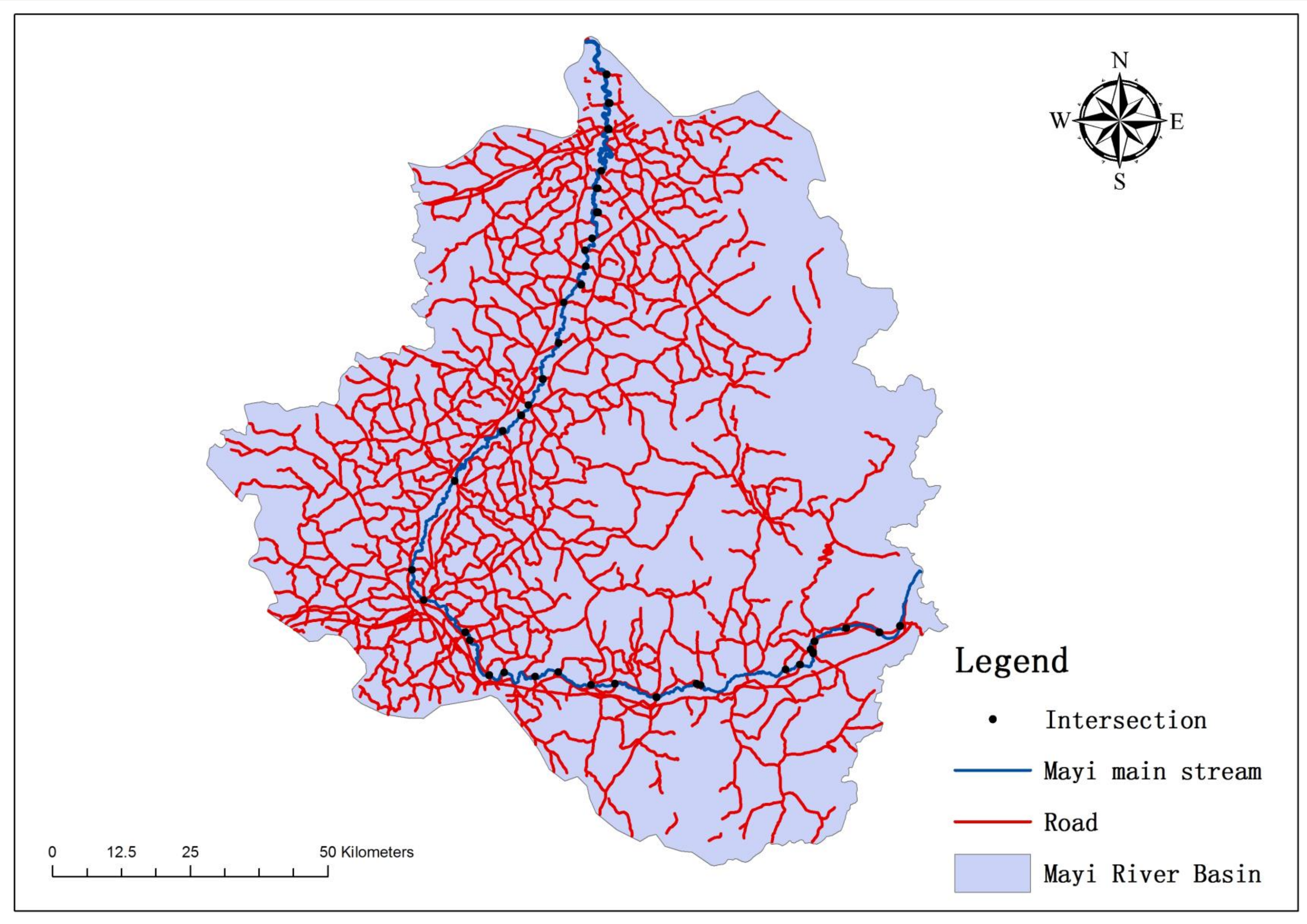
We focus on the cold water fish movement between Songhua main stream (Harbin to Yilan) and Mayi main stream.

5. Culvert effect on cold water fish migration in large scale

Cold water fish in Songhua main stream

Species	Common name
Lampetra reissneri (Dybowski)	Reissner Lamprey
Lampetra japonica (Martens)	Arctic Lamprey
Coregonus ussuriensis (Berg)	Ussuri cisco
Leuciscus waleckii	Amur ide
Nemacheilus nudus (Bleeker)	Elongate loach
Esox reicherti (Dybowski)	Amur pike
Lota Lota (Linnaeus)	Burbot

5. Culvert effect on cold water fish migration in large scale

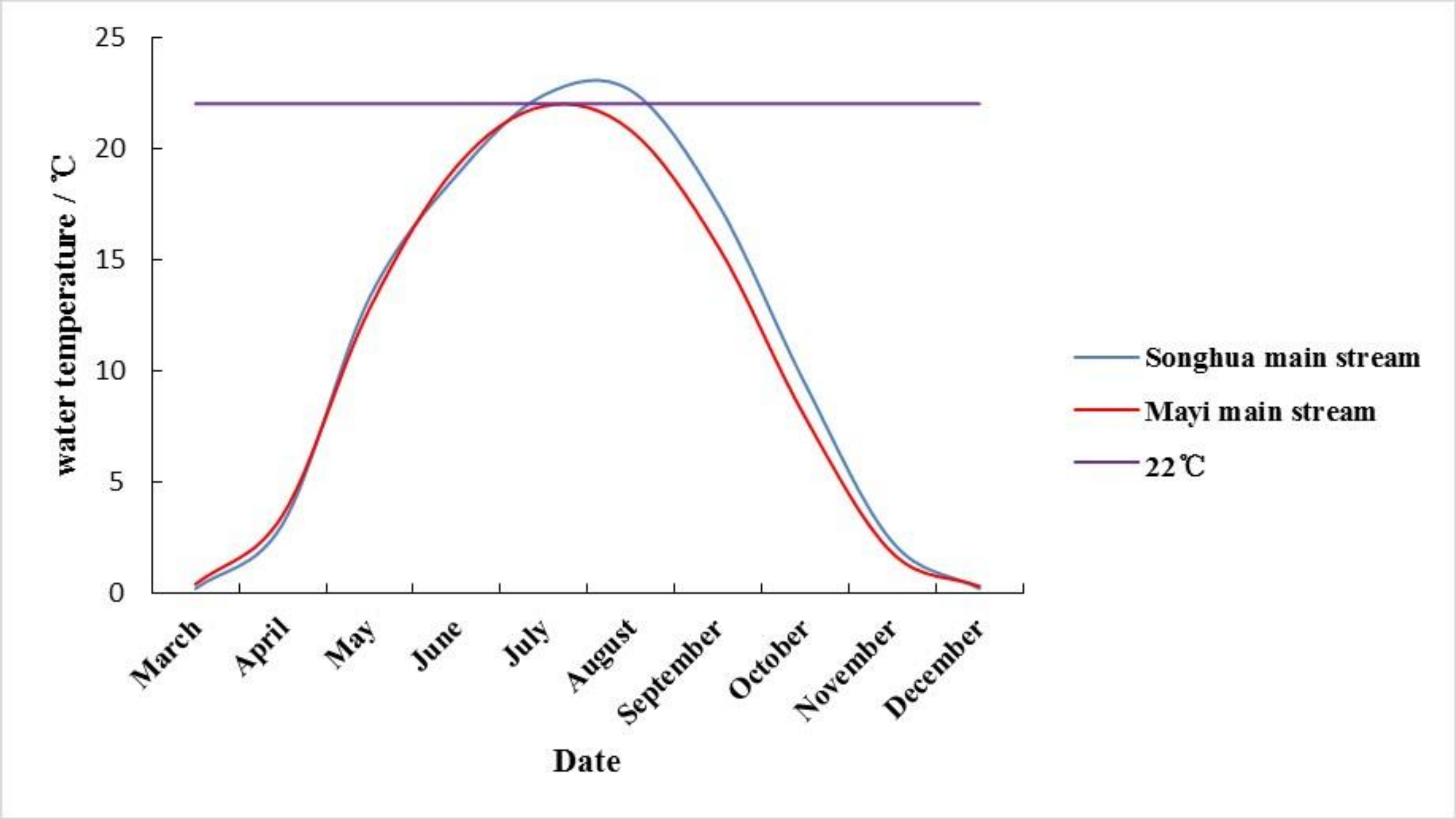


The constructions of the road crossing will be calculated based on the average daily stream flow in subbasins.

The calculation method has already been validated in Xiliushu River Basin.

5. Culvert effect on cold water fish migration in large scale

Water temperature variation in river



The monthly average water temperature from 2011 to 2013

In July and August, the water temperature exceeds 22℃.

The cold water fish is influenced obviously.

5. Culvert effect on cold water fish migration in large scale

Water temperature simulation of Songhua main Stream (Harbin to Yilan)

$$t = 0.74 \cdot T - 0.14 \cdot \theta + 0.036 \cdot p - 30.078$$

t —water temperature,

T —air temperature,

θ — solar radiation,

p — air pressure.

The comparison between measured data and simulation data in Songhua main stream (Harbin to Yilan)

Station	Data	Measured data (℃)	Simulation data (℃)	Absolute error	Relative error (%)
Harbin	2010_6_1	20.8	19.10	-1.70	-8.18
	2010_6_2	21.2	19.99	-1.21	-5.69
	2010_6_3	21.2	20.42	-0.78	-3.68
	2010_6_4	21.2	21.95	0.75	3.55
	2010_6_5	21.0	21.51	0.51	2.41
	2010_6_6	20.8	19.63	-1.17	-5.62
	2010_6_7	21.2	21.69	0.49	2.30
	2010_6_8	22.0	23.57	1.57	7.14
	2010_6_9	22.2	23.83	1.63	7.34
	2010_6_10	22.8	23.86	1.06	4.67
Yilan	2010_6_1	12.8	13.75	0.95	7.42
	2010_6_2	13.4	14.81	1.41	10.49
	2010_6_3	15.0	14.79	-0.21	-1.38
	2010_6_4	13.8	15.14	1.34	9.69
	2010_6_5	14.0	15.90	1.90	13.57
	2010_6_6	14.2	15.60	1.40	9.88
	2010_6_7	15.4	16.04	0.64	4.14
	2010_6_8	16.0	17.18	1.18	7.39
	2010_6_9	17.3	17.78	0.48	2.76
	2010_6_10	17.0	17.21	0.21	1.26

5. Culvert effect on cold water fish migration in large scale

Water temperature simulation of Mayi main stream

$$t = 0.679 \cdot T + 4.394 \cdot r - 0.24 \cdot \omega + 0.838$$

t — water temperature,

T — air temperature,

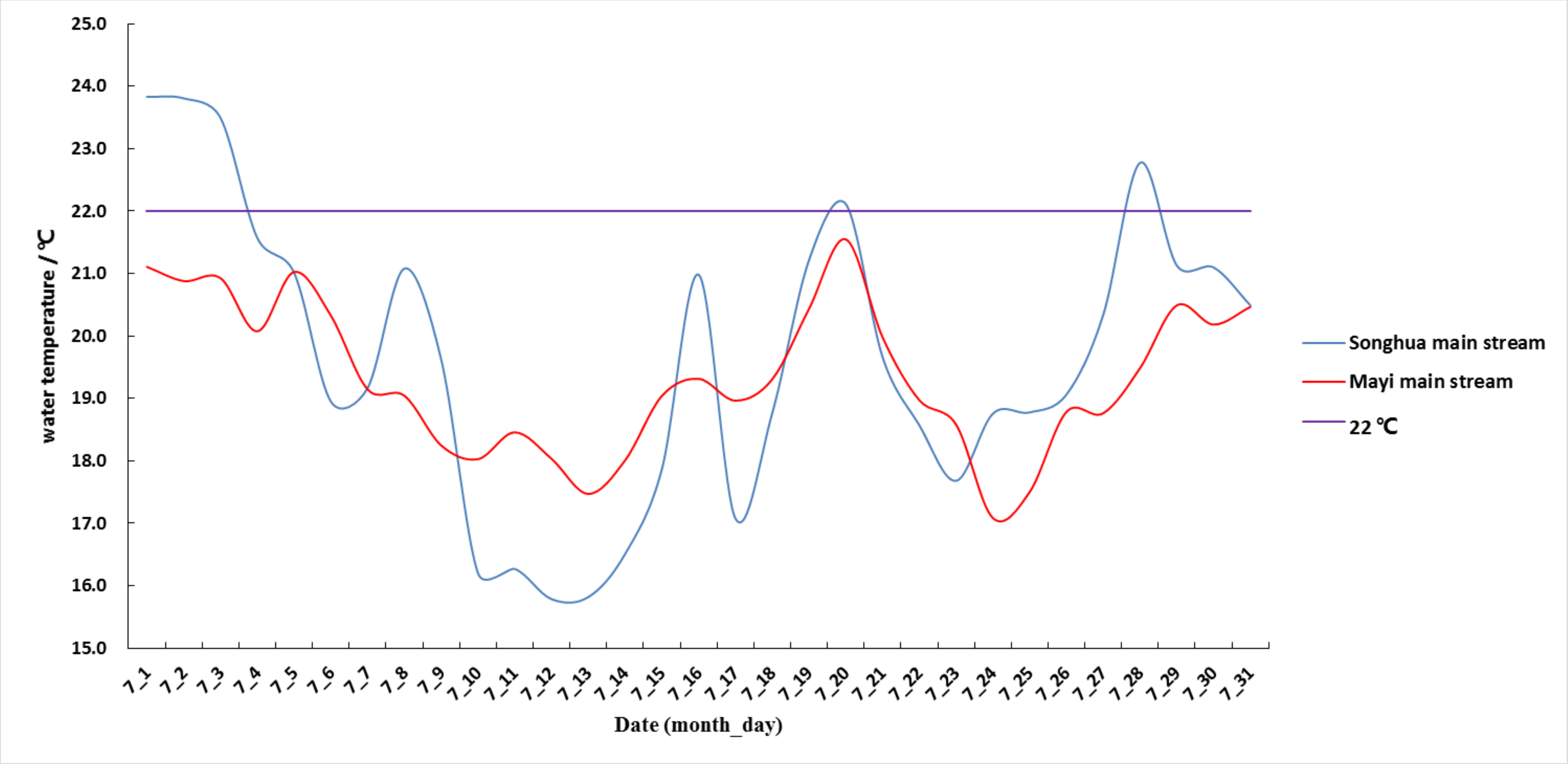
r — relative humidity,

ω — wind speed.

The comparison between measured data and simulation data in Mayi main stream

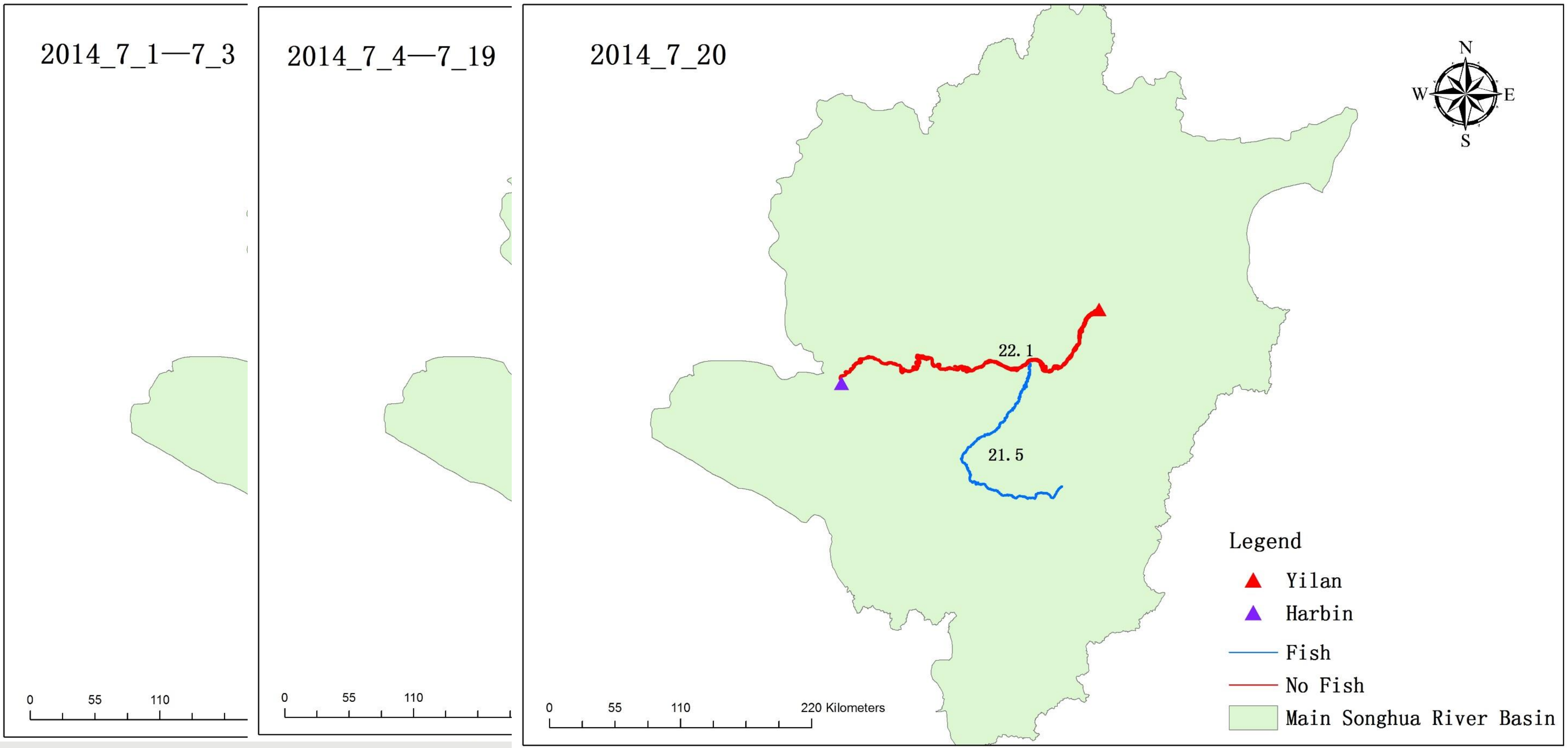
Station	Data	Measured data (℃)	Simulation data (℃)	Absolute error	Relative error (%)
Shangzhi	2010_6_1	19.2	17.41	-1.79	-9.32
	2010_6_2	19.1	17.58	-1.52	-7.95
	2010_6_3	18.6	17.71	-0.89	-4.77
	2010_6_4	19.6	18.60	-1.00	-5.09
	2010_6_5	19.4	17.83	-1.57	-8.08
	2010_6_6	18.8	17.17	-1.63	-8.67
	2010_6_7	19.5	19.03	-0.47	-2.43
	2010_6_8	20.0	19.59	-0.41	-2.07
	2010_6_9	19.8	20.05	0.25	1.24
	2010_6_10	22.2	20.90	-1.30	-5.85
Lianhua	2010_6_1	18.6	17.21	-1.39	-0.07
	2010_6_2	18.2	17.98	-0.22	-0.01
	2010_6_3	17.4	17.22	-0.18	-0.01
	2010_6_4	18.8	19.15	0.35	0.02
	2010_6_5	18.8	18.45	-0.35	-0.02
	2010_6_6	18.8	17.51	-1.29	-0.07
	2010_6_7	19.0	18.62	-0.38	-0.02
	2010_6_8	19.0	19.27	0.27	0.01
	2010_6_9	19.4	19.75	0.35	0.02
	2010_6_10	19.6	20.27	0.67	0.03

5. Culvert effect on cold water fish migration in large scale



Water temperature prediction in Songhua main stream and Mayi main stream in July 2014

5. Culvert effect on cold water fish migration in large scale



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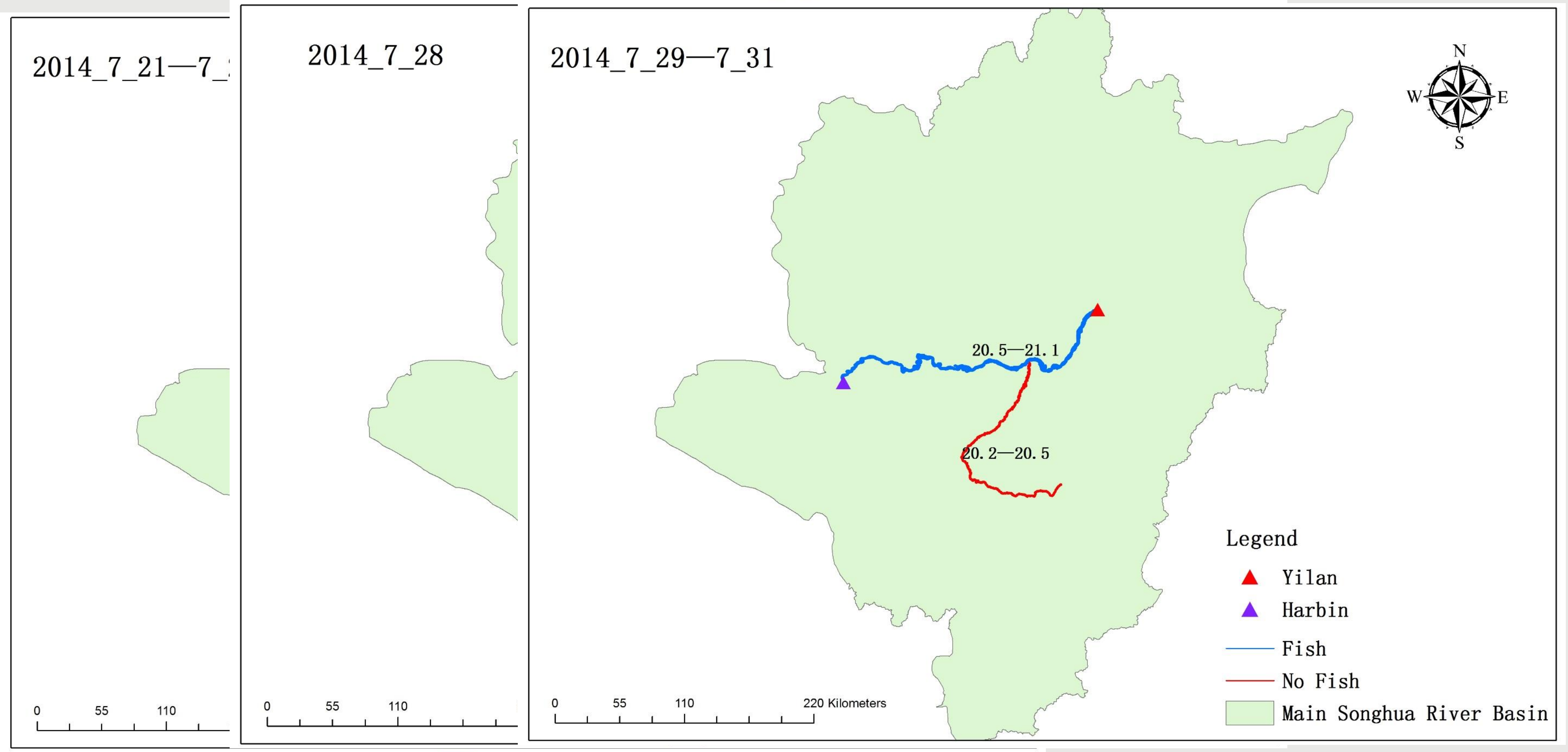
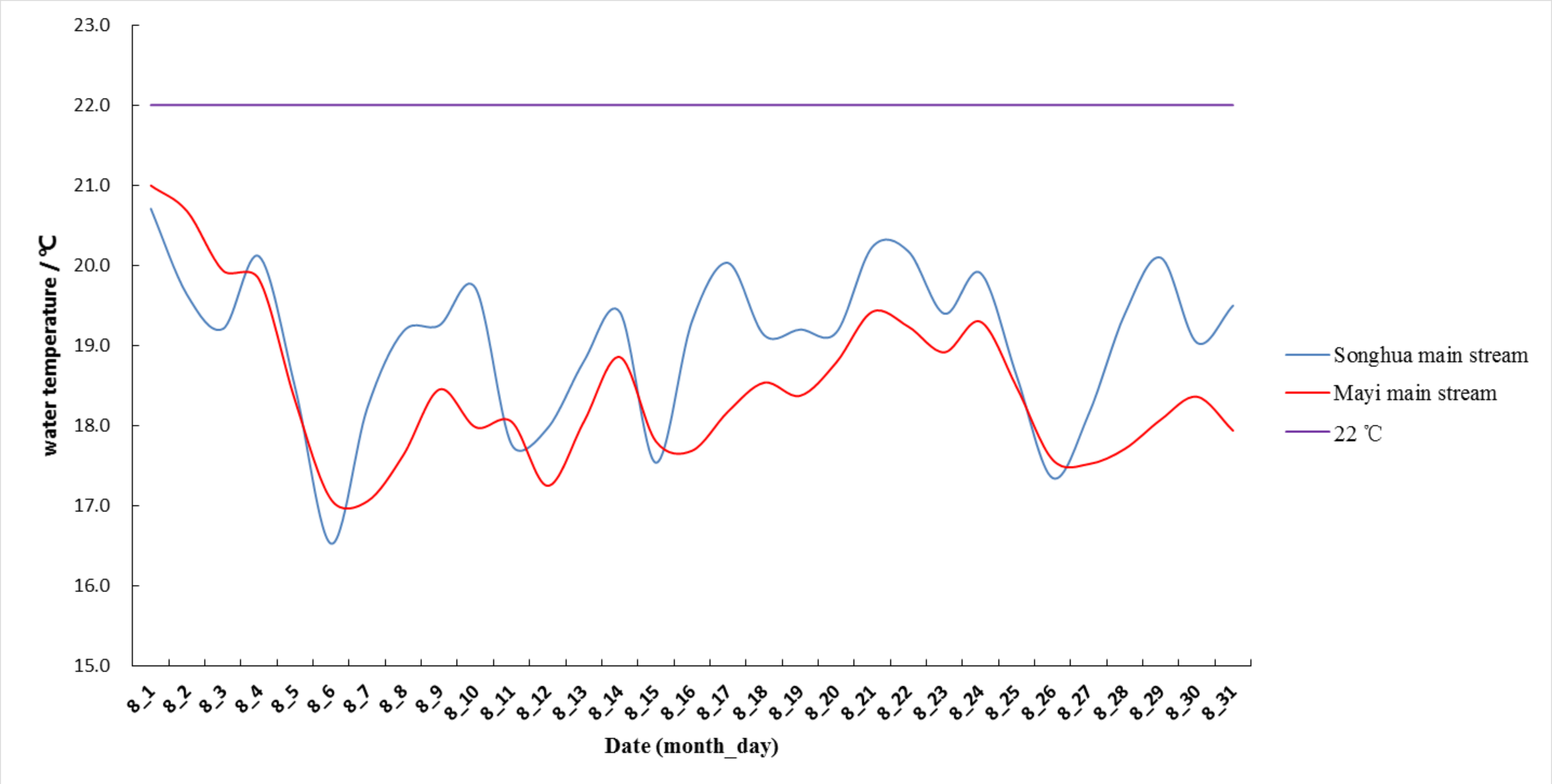


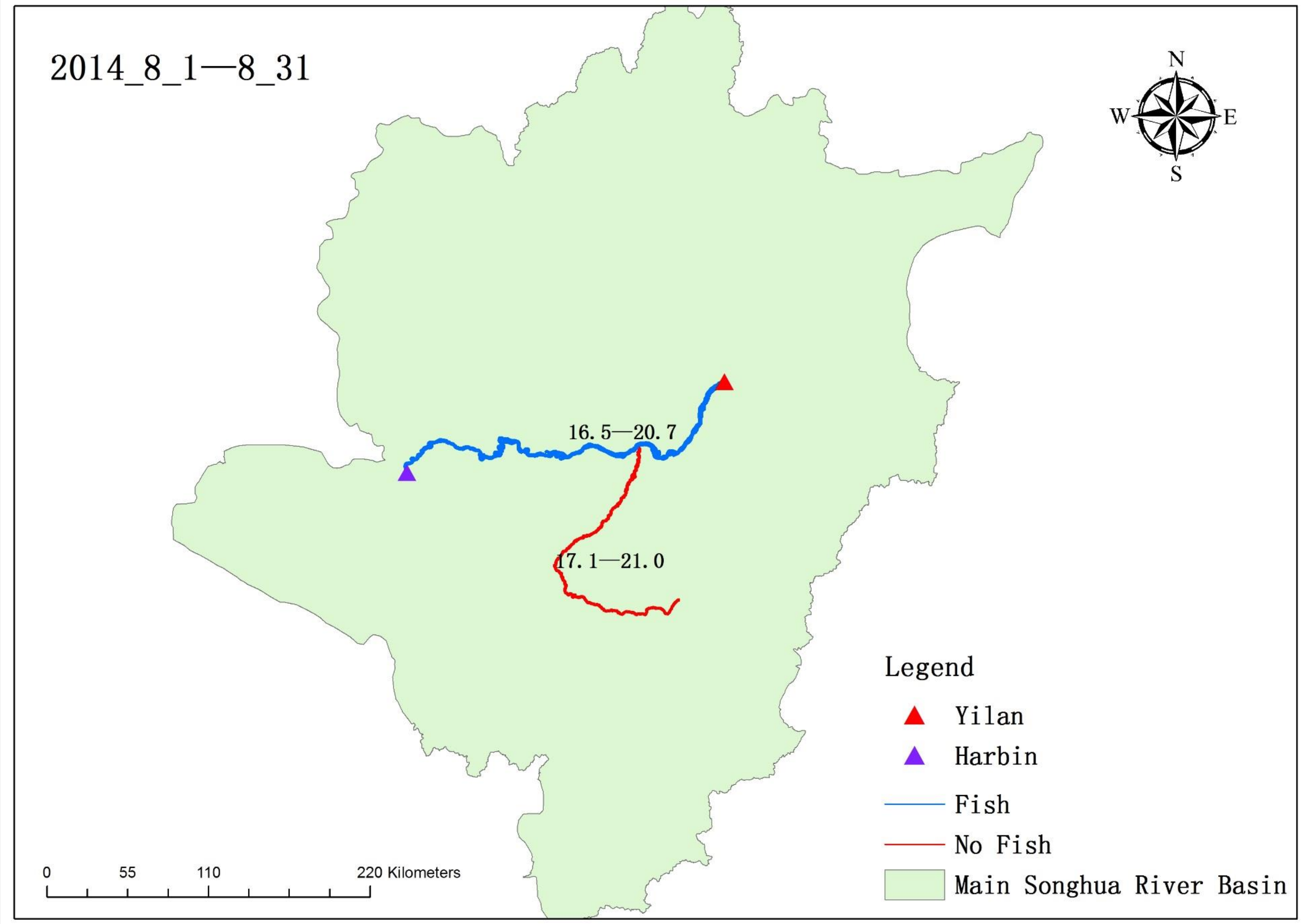
5. Culvert effect on cold water fish migration in large scale



In August, the average daily water temperature both less than 22°C.

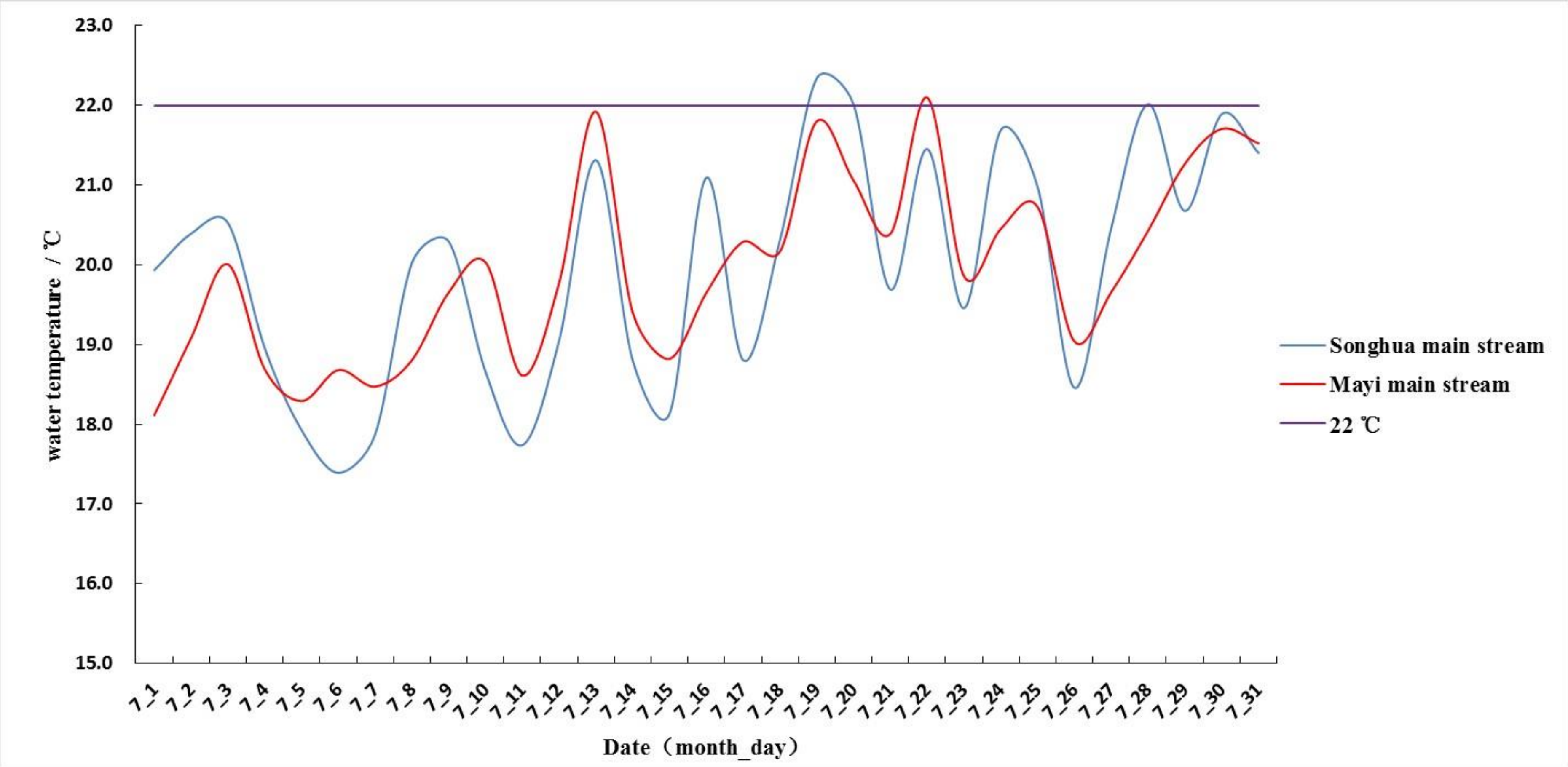
Water temperature prediction in Songhua main stream and Mayi main stream in Agust 2014

5. Culvert effect on cold water fish migration in large scale



In August, the fish stay in Songhua main stream.

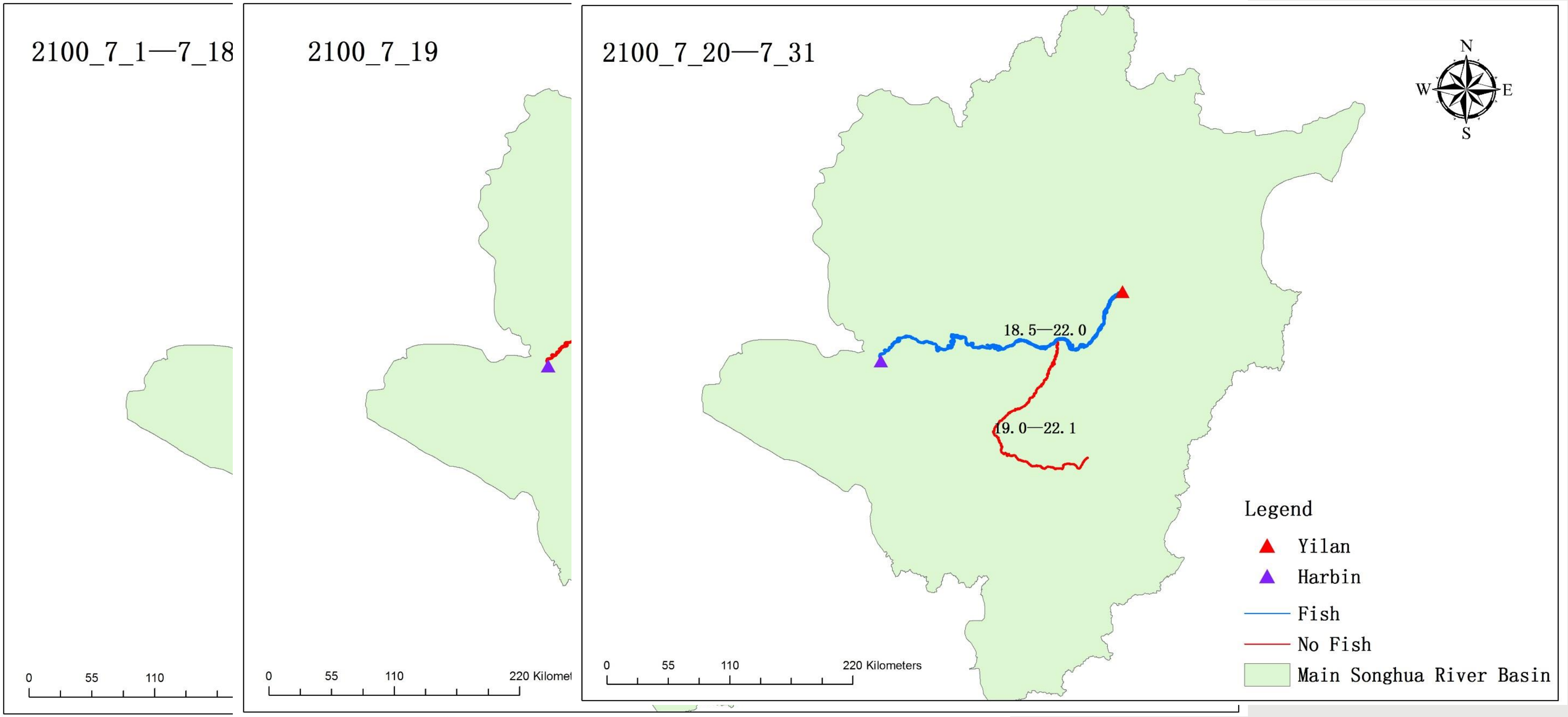
5. Culvert effect on cold water fish migration in large scale



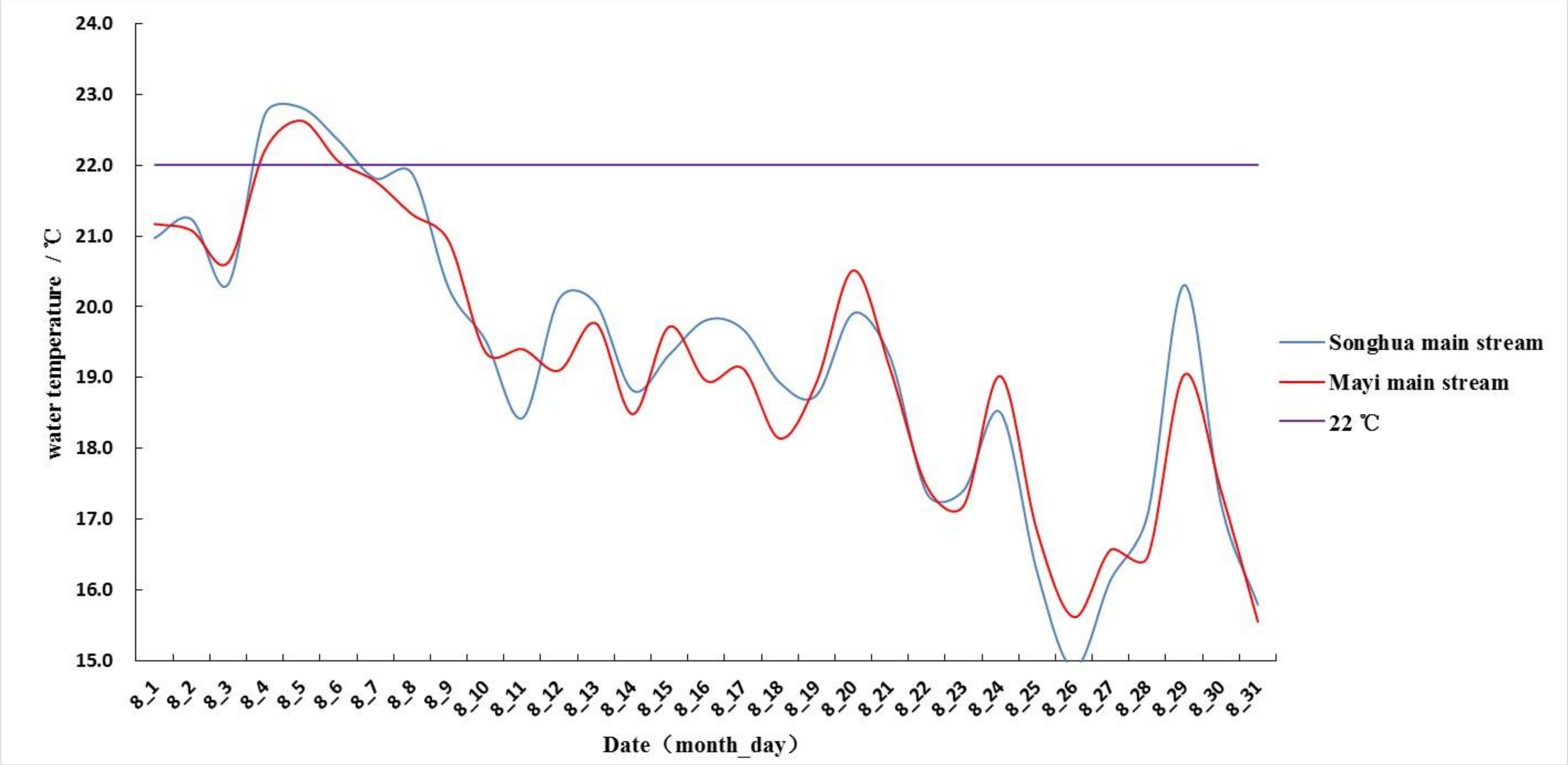
The data of 2100 temperature is from the global data set of NASA released on June 9, 2015.

Water temperature prediction in Songhua main stream and Mayi main stream in July 2100

5. Culvert effect on cold water fish migration in large scale



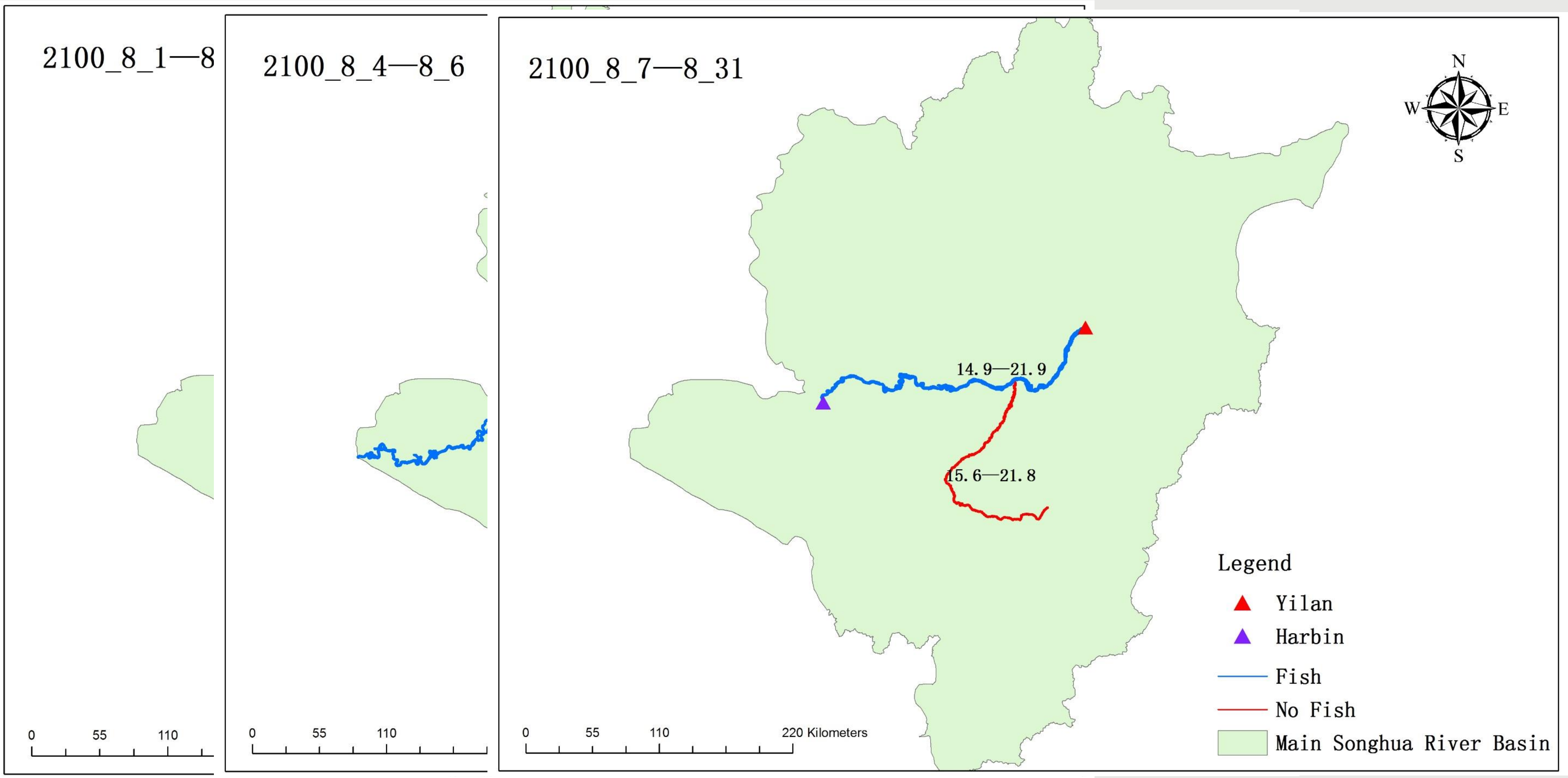
5. Culvert effect on cold water fish migration in large scale



In August 4 to 6, the average daily water temperature both exceed 22℃.

Water temperature prediction in Songhua main stream and Mayi main stream in August 2100

5. Culvert effect on cold water fish migration in large scale



5. Culvert effect on cold water fish migration in large scale

Discussion

1. In July, the cold water fish movement variation is not obviously. But the time point changes.

2. In August, the cold water fish movement changes greatly.

Date	Change days	Percentage (%)
July, 2014	5	16.1
July, 2100	1	3.2
August, 2014	0	0
August, 2100	3	9.7

5. Culvert effect on cold water fish movement in large scale

Prospective result

1. The calculation of culverts construction in Mayi main stream.
2. The culvert effect on cold water fish migration.
3. The quantify of river longitudinal connectivity under climate change.

Thank you!