University of Gastronomic Sciences
Università degli Studi di Scienze Gastronomiche

The Role of Geological diversity in Shaping Trout Species in the Soča Valley

Reshma Giji

Submitted for the degree of Masters in World Food Cultures and Mobility

Supervisor: Roberta Cevasco

Master’s program director: Simone Cinotto

Pollenzo

October 2025

`

Dedication

"In the beginning was the Word, and the Word was with God, and the Word was God. The same was in the beginning with God. All things were made by him; and without him was not anything made that was made. In him was life; and the life was the light of men. And the light shineth in darkness; and the darkness comprehended it not."

- *John 1: 1-5*

I dedicate this research to my Lord and Savior, Jesus Christ, the Author and Finisher of my faith. To my dearest mother, who, above all, gave us the greatest gift – the knowledge of God. Without Him, nothing would have been possible. Mama, your faith and trust in God stand as a testament to how far the Lord has led me thus far. To the best older brother, one could ever have, thank you for the constant guidance and unwavering support. Even within with your busy schedule, thank you for always finding time for me. To the cutest younger brother in the whole world, thank you for all the little ways you have helped me and for always being available to answer my calls. And to my sister, who I love dearly, thank you for everything. To Bince, my dear friend, who has taken the 7:37 a.m. bus with me every morning and stayed at the Tavole until 4 p.m. Along with the many cappuccinos and croissants, thank you for your presence while writing this thesis. And last but not least, thank you, Geetika, for being a true and lovely friend. In every step, thank you for the support and the delicious meals you have prepared. To my manager, Alan, thank you for providing me the time despite the busy season to write this thesis. And finally, to the many friends I have made in this Master's program and at Hisa Franko, but could not name, thank you for everything.

`

Acknowledgement

I would like to humbly express my deepest gratitude to my supervisor, Professor Roberta Cevasco for the constant support and guidance during this research. Thank you for all the time and much patience, that you have poured into helping me. I would also like to thank my program director, Professor Cinotto for everything that he has done for our class. Additionally, I would also like to thank Dr. Klemen Teran, for providing all the necessary geological maps for this study. I would like to express my gratitude to Blaž Močnik, thank you for the detailed answers about the trout, and for providing the ecological maps. I would also like to thank Nejc Hvala, for taking the time to show the locations around the Soča Valley relating to the trout populations. Last but surely not the least, I would like to convey my appreciation to Eric Sivec. Thank you for showing me around the Kobarid Fish Farm and taking time out of your work to talk about the trout populations. Your much knowledge about native and non-native trout populations has been a true pleasure to listen to. I would like to say thank you to all the fishermen I have met and spoken too, I have a great regard for your profession and have loved seeing not just your expert skills but also how you steward this passion into conserving the trout populations while providing food for the community.

Reshma Giji

September 2025

`

Table of contents

Definitions………………………………………………………………………………..……6

List of Figures …………………………………………………………………………….…12

List of Tables ……………………………………………………………………….......15

Thesis Outline ……………………………………………………………………….......16

Abstract …………………………………………………………………………………19

Chapter I: Introduction

1.1 Life and food **…………………………………………………………………………...20**

1.2 Research Aim and Questions **………..…………………………………………………….21**

1.3 Background **………………………………………………………………………….22**

Chapter II: Materials and Methods

2.1 Study Area **……………………………………………………………………...…...29**

2.2 Google Earth Engine **……………………………………………………….….….……31**

2.3 Interviews **……………………………………………………………………………36**

2.4 Maps **…………………………………………………………………………………37**

Chapter III: Results

3.1 Geological Characterization **……………………….……...…………………………….……40**

`

3.2 Ecological Status of the Soča River ……………………………………………………**51**

Chapter IV: Discussion

4.1 Interpreting geological findings …………………………………..…………………**61**

4.2 Interpreting ecologic findings …………………………………………………………**65**

4.3 Implications of the research …………………………………………………………**68**

4.4 Further research …...…………………………………………………………………...**76**

Chapter V: Conclusion

5.1 Summary ………………………………………………………………………………**80**

References…..…………………………………………………………………………82

`

Definitions

Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Emissivity Database (ASTER-GED) – this is a NASA-developed dataset that provides information on how efficiently the Earth's surface emits thermal radiation. It is generated from ASTER satellite data.

Allochthonous Species – species that originate outside of its current location and has been introduced to a new environment, either intentionally or unintentionally, by human activity.

Aquifers - a body of permeable rock which can contain or transmit groundwater.

ArcGIS – this is a comprehensive geospatial platform developed by Esri, widely used for creating, managing, analyzing, mapping, and sharing geographic information.

ARSO Geoportal – a platform provided by the Slovenian Environment Agency (ARSO) to make environmental data accessible to the public.

Bohinj Glacier – a massive glacier, that no longer exists, that carved out the glacial valley where Slovenia's largest natural lake, Lake Bohinj, is located.

Corine Land Cover 2006 – it is a European dataset that provides information on land cover and land use in Europe, specifically for the year 2006.

Cretaceous Sediments – sedimentary rocks formed during the Cretaceous Period, such as chalk, limestone, sandstone, shale, and conglomerate.

Devonian Period – a geological period within the Paleozoic Era, lasting from roughly 419.2 to 358.9 million years ago.

`

Fluvial Erosion – is the process where running water in streams and rivers detach and remove material from the Earth's surface, including the riverbed and banks.

Garden of Eden – the beautiful garden, described in the Bible, made by God for Adam and Eve.

Geospatial Datasets – a collection of data that includes information related to locations on the Earth's surface.

Glaciofluvial Sediments – these are deposits of sand, gravel, and other particles transported and deposited by meltwater streams, that flow from glaciers and ice sheets.

Google Earth Engine (GEE) – a computing platform that allows users to run geospatial analysis on Google's infrastructure.

Holocene Period – the current geological epoch, lasting from approximately 11,700 years ago to the present day.

Ice Streams – fast-flowing corridors of ice within an ice sheet, moving much faster than the surrounding ice.

Lacustrine Sediments – deposits found at the bottom of lakes and ponds that are usually made of fine-grained materials like silt, clay, and organic matter, that accumulate over time due to still water conditions.

Laminar Current – describes water moving in smooth, parallel layers with little mixing, creating a quiet, straight, and orderly stream.

Last Glacial Maximum – the period during the last ice age when ice sheets reached their maximum extent.

`

Late Pleistocene till – glacial deposits left behind during the latter part of the Pleistocene epoch, roughly between 129,000 and 11,700 years ago.

Lowland Deposits – layers of unconsolidated sediment that accumulate in low-lying areas called lowlands, such as river valleys, coastal plains, and basins.

Mesozoic Period – a geological time period lasting from approximately 252 to 66 million years ago.

Miocene Epoch – a geological epoch spanning from approximately 23 to 5 million years ago.

Moraines – a mass of rocks and sediment carried down and deposited by a glacier, typically as ridges at its edges or extremity.

Multispectral Scanner (MSS) – a remote sensing instrument that captures images of the Earth's surface using multiple spectral bands.

National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL) – it is a research and development center managed by the California Institute of Technology (Caltech) for NASA.

National Center for Atmospheric Research (NCAR) – it is a federally funded research and development center committed to research and education in atmospheric science and related scientific fields.

National Centers for Environmental Prediction (NCEP) – provides national and global weather, water, climate, and space weather guidance, forecasts, warnings, and analysis.

Oligocene Epoch – a geological epoch spanning from roughly 33 to 23 million years ago.

`

Operational Land Imager (OLI) – an instrument that captures images of Earth's surface in the visible, near-infrared, and shortwave-infrared portions.

Orthorectified – a process that corrects geometric distortions in aerial or satellite images, making them geometrically accurate and suitable for mapping.

Parallel Ice Sheet Model (PISM) – this is an open-source, high-resolution computer program for simulating the behavior and evolution of glaciers and ice sheets, including those in Greenland and Antarctica.

Pleistocene Glacier – an extensive glaciation that occurred during the Pleistocene epoch, which began around 2.6 million years ago.

Post-Last Glacial Maximum – this period is categorized the gradual melting of massive ice sheets and a subsequent rise in sea level, along with significant changes in Earth's climate and ecosystems.

Precambrian Period – the earliest period in earth's history that records vast majority of Earth's existence.

Pre-Last Glacial Maximum – refers to the period and glaciation that occurred before the Last Glacial Maximum (LGM). This was the period of maximum ice sheet extent during the last glacial period, occurring around 20,000 years ago.

Quaternary Period – this is the most recent geological period, spanning from 2.6 million years ago to the present day.

Relief Production – the increase in the difference in elevation between high and low points in a landscape, primarily due to glacial erosion.

`

Riparian Vegetation – this refers to the plant life growing along the banks of rivers or other bodies of water.

River Engineering – this is a branch of civil engineering focused on controlling, modifying, and managing rivers for human and environmental benefit, including flood control, irrigation, navigation, and hydroelectric power generation.

Short-Wave Infrared (SWIR) – this is part of the electromagnetic spectrum with wavelengths from 0.9 to 1.7 micrometers.

Spectral bands – specific ranges of wavelengths within the electromagnetic spectrum that sensors capture to gather information about the Earth's surface.

Surface Emissivity – measures how effectively a material emits thermal radiation compared to a black body (a perfect emitter) at the same temperature.

Terminus – lower-most margin or end of a glacier.

Thematic Mapper (TM) sensor – an advanced, multispectral scanning sensor to receive higher image resolution, sharper spectral separation.

Thermal Infrared Sensor (TIRS) – a sensor that detects and measures thermal infrared radiation emitted by objects, which is related to their temperature.

TOA brightness temperature – measures the intensity of electromagnetic radiation emitted from Earth's atmosphere.

Total Column Water Vapor (TCWV) – it is the integrated mass of gaseous water in the total column of the atmosphere over an area of 1 m^2.

Triassic Period – a geological period spanning from 251.9 to 201.3 million years ago.

`

Upper Triassic and Jurassic Periods – geological time periods within the Mesozoic Era, often called the "Age of Reptiles.

Visible and Near-Infrared (VNIR) – this is part of the electromagnetic spectrum encompassing the visible light range (400-700 nm) and the adjacent near-infrared range (700-1000 or 1100 nm).

Water-bearing Unit – is a layer of rock or sediment that is saturated with groundwater and can transmit or yield water to wells or springs, with the most common type being an aquifer.

`

List of Figures

Figure 1: Generalized geological map of Slovenia

Figure 2: Extension of karst in Slovenia

Figure 3: Reconstruction of maximal glacier extent during the Late Pleistocene in the surroundings of Bled and Radovljica

Figure 4: Map of Kobarid

Figure 5: Soča River, starting from Čezsoča to Tolmin

Figure 6: Google Earth Engine processing chain to calculate water surface temperature (WST) of the Soča River, starting from Čezsoča to Tolmin

Figure 7: Historic geomorphological ice extent of the Alpine-Dinaric region

Figure 8: Modelled geomorphological ice extent of the Alpine-Dinaric region

Figure 9: Glacial landform of Čezsoča

Figure 10: Glacial landform of Kobaird

Figure 11: Glacial landform of Tolmin

Figure 12: Geological map of Bovec – Kobarid area

Figure 13: Geological map of Tolmin

Figure 14: Map showing flysch areas and structural units between Bovec and Kobarid

Figure 15: Topographic map of Čezsoča, Kobaird, and Tolmin

`

Figure 16: Soil map of Čezsoča.

Figure 17: Soil map of Kobaird.

Figure 18: Soil map of Tolmin

Figure 19: Vegetation map of Čezsoča, Kobarid and Tolmin

Figure 20: Vegetation map of Slovenia

Figure 21: Overview map of the Tolmin fishing district showing areas that, in accordance with nature conservation regulations special status – natural values

Figure 22: Assessment of the ecological status of surface water bodies in the Tolmin Fishing District

Figure 23: Spawning grounds of the Tolmin fishing district

Figure 24: Distribution of Isonzo (marble) trout in the Tolmin fishing area

Figure 25: Distribution of rainbow trout in the Tolmin fishing area

Figure 26: Shares of individual species in the average annual catch (kg) of salmonids in the period 2000-2014

Figure 27: Catch (number of fish) of Isonzo (marble) trout in the period 1986-2014

Figure 28: Rainbow trout catch (number of fish) in the period 1986-2014

Figure 29: Land Surface temperature (LST) of Soča River from Čezsoča to Tolmin from January 2021 to January 2022

`

Figure 30: Land Surface temperature (LST) of Soča River from Čezsoča to Tolmin during harvest months

Figure 31: River located in Bečje. The Tolmin Angling Club along with the local fishermen introduce around 200-300kgs of Rainbow trout and couple kilos of Marble trout here.

Figure 32: River located in Lipina. The Tolmin Angling Club along with the local fishermen introduce both the Rainbow trout and the Marble trout here.

Figure 33: River located in Otona. A lot of the Marble trout come here to spawn during the season.

Figure 34: River located in Velica Korita. This area is surrounded by gorges. Marble trout are found spawning here during season.

Figure 35: Located in Otona, the picture shows a cross-section view of the soil.

Figure 36: Polog rockfall in the Tolminka valley that occurred in 2004.

Figure 37: Kekec rockfall that occurred in 2007.

`

List of tables

Table 1: Common Fish and Fishing in the Soča Valley

Table 2: Satellite, Google Earth Engine dataset, path/row of the study area, equator crossing time (ECT), and available period for each Landsat satellite.

`

Thesis Outline

The following is an outline of the chapters composed in this thesis.

Chapter I: Introduction

1.1 Food and Nature

This paragraph introduces our crucial yet complex relationship with both nature and food.

1.2 Research Aim and Questions

The purpose of the study is presented in this part. It is compiled with research questions and the objectives that would help answer them.

1.3 Regional Geology

The region's geology is introduced here, providing the perfect foundation to understand the relationship between the Soča Valley and its trout.

Chapter II: Materials and Methods

2.1 Study Area

The primary area of study is the Soča Valley, located in three towns: Čezsoča, Kobaird, and Tolmin.

2.2 Google Earth Engine

Google Earth Engine serves as a fundamental tool for geospatial analysis in this research. This platform helps enable satellite datasets to capture the water surface temperature of the Soča River.

2.3 Interviews

`

To supplement this, qualitative information through semi-structured interviews were gathered.

2.4 Maps

The methodology relies heavily on the integration of both geological and ecological maps to build a comprehensive picture of the region.

Chapter III: Results

3.1 Geological Characterization

This chapter presents the findings from both Google Earth Engine and geological maps of the Soča Valley.

3.2 Ecological Status of the Soča River

This section displays maps showing the distribution of Marble and Rainbow trout throughout Slovenian rivers, as well as the locations of critical spawning grounds. Data from the interviews will be examined to understand the role of the fisherman and the trout species.

Chapter IV: Discussion

4.1 Interpreting geological findings

This section discusses the key findings extracted from geological maps, such as rock formations, riparian vegetation, and soil types.

4.2 Interpreting ecologic findings

`

It will also analyze the composition of the riverbed, the distribution of the Marble and Rainbow trout along the river and its tributaries.

4.3 Implications of the research

This chapter integrates geological and ecological analysis to answer the two research questions.

4.4 Further research

A groundwork will be laid for further research. It will concentrate on one of the problems that was addressed by Eric Sivec (a Fisherman from Kobarid Fish Farm).

Chapter V: Conclusion

5.1 Summary

This section will draw in all findings to highlight the importance of geology in creating the ideal environment for Marble and Rainbow trout to thrive.

`

Abstract

Geology has always played a distinct historical role in creating ecological habitats. Over the years, geological mechanisms such as tectonic activity and diagenesis carefully crafted the right habitat for ecosystems to thrive. The thesis aims to explore the relationship between the geological landscape of the Soča Valley and the ecological health of the Marble and Rainbow trout. Subsequent to this, geospatial analysis to understand the water surface temperature of the Soča River were conducted. In this study, a direct correlation was drawn between the glacial geomorphology of the Soča Valley and its trout habitat. The glacial activity that took place during the Late Pleistocene period is evidenced by both the reconstructed historic and modeled ice extents that shaped the mountain regions and valleys of Slovenia, creating the diverse landforms around the Soča Valley. This, in turn, produced distinct soil types upon which various riparian vegetation grows.

Additionally, it has also helped build the river beds where the Marble trout hide and spawn. Ecological assessments show that the Soča River and its tributaries have a good ecological status, indicating that their ecosystems are healthy and are in good hydrological condition. The Marble and Rainbow trout both thrive in cold water temperatures that are around 283.2K (10.0 °C) to 288.2K (15.0 °C). But data received through Google Earth Engine for the year 2021 show temperatures as high as 297K (23.9°C). In these high temperatures, the trout get easily exhausted, therefore reducing their feeding activity and hindering their growth.

`

Chapter I: Introduction

1.1 Introduction to food and nature

Nature ranks higher in the hierarchy and encompasses the macrocosm of food. As such, humans stand as middlemen between nature and food as an authoritative footprint. An apparent paradox that we observe is that this species, with an average height of 1.7m, dictates the supply and demand of food, as well as the prosperity and destruction of nature. And that too, not as a collective voice but an individual choice. Where a man’s heart dictates his actions and words, and he runs to satisfy his fleshly treasures. A testament of our absence from the Garden of Eden. We have toiled the ground and have run it close to extinction. And in our greed, we claim to be both a creator and its creation. Food and nature have become commodities for power and pride, maddening the eyes of those who behold them as such.

While the question of who is to lead this diabolical system is being studied and critiqued, I believe a wiser course of action is to study the interrelationship between food and nature and propose a valid response in our present climatic world. A response well away from the political voices and emotional gears that govern the minds of many, and this has led me towards the western part of Slovenia. A small country hidden within the borders of the Alpine mountains, renowned for its breathtaking landscapes, pristine rivers, and rich geological history. Among the various towns and villages nestled within the mountains, Kobarid stands out as an agricultural hub, with its fertile lands and thriving agricultural practices. Known as Kobarid in Slovenian and Caporetto in Italian, this village is located a few kilometers away from the Italian border (Ferrarin, 2024).

`

1.2 Research Aim, Questions and Objectives

This thesis aims to analyze the relationship between the geological landscape of the Soča Valley and the ecological health of its native and non-native trout species. A data-driven approach will be used, utilizing the capabilities of Google Earth Engine to analyze geospatial datasets. This research will explore how the Soča River's ecological environment created the ideal conditions for trout populations to thrive. The dissolution of carbonate-rich rocks not only reflects the emerald hue of the Soča River but could have played a role in affecting pH levels. Geological maps will be used to identify and map the types of rocks and minerals present in the Soča Valley. Interviews with both the local fishermen and the Fisheries Research Institute of Slovenia will be conducted to record the temperature and better understand the habitat of the present trout population.

The study will address these two research questions:

1) How do the geological formations in the Soča Valley influence the habitat and distribution of Marble and Rainbow trout species?
2) In what ways do the mineral composition and water temperature of the Soča River, influenced by the local geology, affect the health and growth of trout populations?

To answer these research questions, three objectives need to be addressed:

1) Analyze the geological characteristics of the Soča Valley, including the types of rocks and their influence on the river's physical structure.
2) Investigate if Soča River's mineral content, pH, and temperature impact trout populations, as a result of the region's geology.
3) Examine the distribution of trout species living in the Soča River among different geological features and habitat types.

`

1.3 Regional geology

Slovenia, characterized by its geology, tectonic and geomorphic processes, connects the Julian Alps, Dinaric Alps, Pannonian Basin, and the Adriatic Sea Basin. These four geological landscapes define the region's environment and agriculture and explain how the dominant valleys and ridges were formed. (Zorn, et.al, 2019) Going back 600 million years to the Precambrian period, metamorphic rocks formed from sediments, such as gneisses, mica schists, amphibolite, eclogites, marbles, and various schists (Buser, 2009), account for 4.1% of the landscape in northeast Slovenia (Pergo et al. 2019). During the Devonian period, thick layers of platy deep-sea limestones were compacted and cemented on top of each other along with shallow water reef limestones of corals. The discovery of fossils such as bivalves, ammonites, conodonts, and radiolarians in these rocks date back to this period (Buser, 2009).

Igneous intrusive rocks weren't present, until the Triassic period and the Miocene epoch, when the northward-moving African plate collided with the Eurasian block. As a result, large fault zones were broken up, and strong volcanic activity began in Štajerska and Gorenjska, resulting in eruptions and upward penetration of magma, scattering volcanic tuff on the mainland and the sea. At the end of the Oligocene Epoch, rivers deposited huge amounts of sand, gravel, and clay in the shallow sea area, compacting them into sandstones, conglomerate, and mudstones. These sedimented rocks, along with various types of limestone, were folded and partly overthrust due to crustal compression from the subduction of the African plate under the Eurasian plate. After which, seawater flooded the Štajerska and Dolenjska areas, bringing back the limestones and marls with bivalves, gastropods, coral, and sea urchins (Buser, 2009). (Figure1)

`

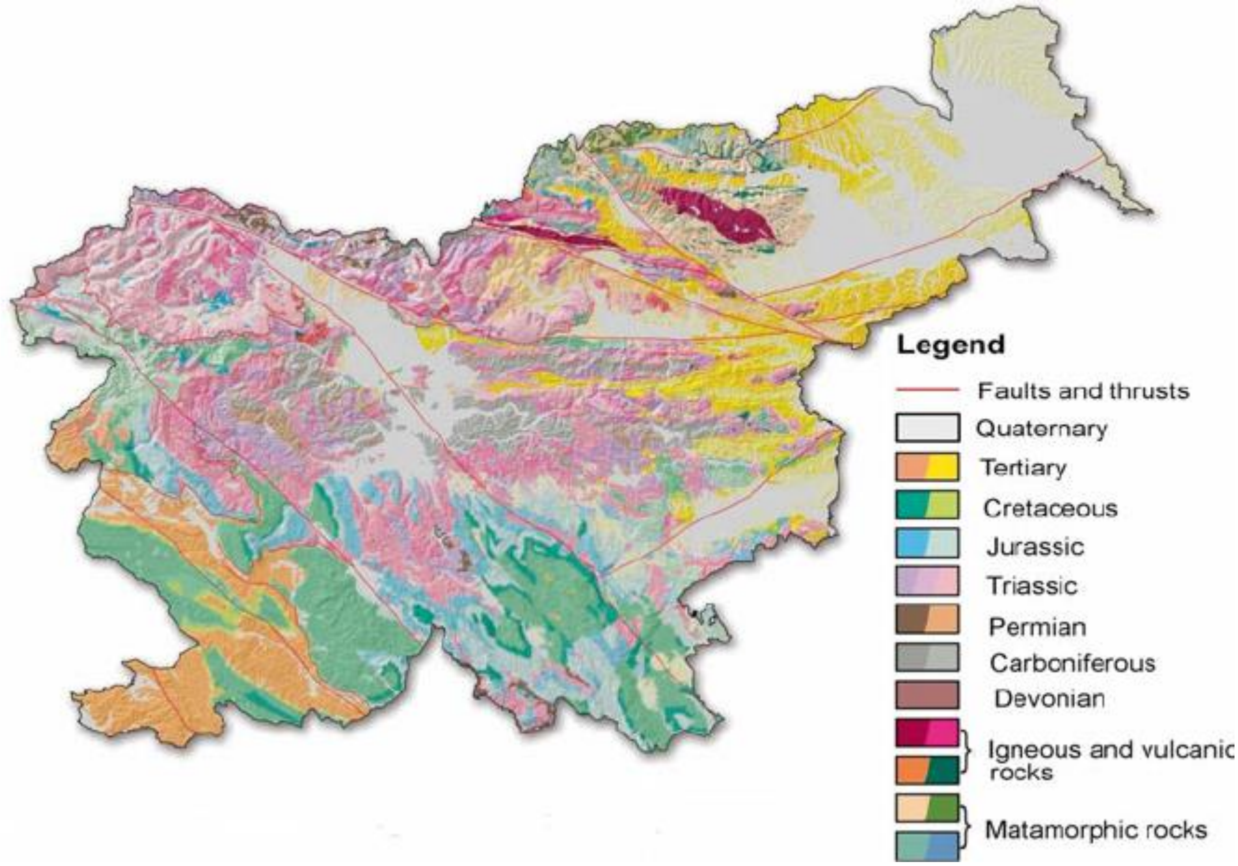


Figure 1: Generalized geological map of Slovenia (Auflič, Komac, and Šinigoj 2014)

The long-lasting uplift of limestone and dolomite regions dissolved soluble particles in water enriched with CO_2, and formed karst-like landforms. This landscape covers approximately 43% of Slovenia's surface area (Hajna, et.al, 2019). Acidic water permeated through fractures and joints in the carbonate bedrock, dissolved minerals to form caves. Majority of the karstic landforms are located in the western half of Slovenia. Differences in general morphology and hydrological conditions have divided the region into three karst areas: Alpine karst, Isolated karst, and Dinaric karst. (Figure 2) The Alpine karst dominates the Julian Alps and had evolved during the Upper Triassic limestone and dolomite period. While several factors influenced this, it is the uplift and the Pleistocene glacier that reshaped the fluvial valleys, thus spacing these karst plateaus with the highest peaks (Triglav 2864 m asl). Along the valleys, large karst springs

`

recharge the alpine rivers, such as the Soča, Sava, and Savinja. In certain places, the valleys were deepened faster than it was widened, which resulted in waterfalls created by karst springs, such as the Boka waterfall in the Soča valley and the Spring of Savica in the Sava River. On the other hand, areas where a karst is less developed, had springs of fissured aquifers that locally drained groundwater (Mihevc, et.al, 2016, 7). Alpine karst aquifers can store large amounts of water, and can recharge an average outflow of 115 m3/s (Petrič 2004). They have two discharges, one in May due to melting of snow and the other in October/November as a result of accumulated precipitation. The Alpine karst springs are important sources of drinking water, and fortunately, due to low population high up in the mountains, and relatively large distances from the big cities, they are not drained/exploited. These high plateaus are bare karst areas that offer highly effective infiltration runoff with their high precipitation (1600 to 3200 mm), and long and thick snow cover (Mihevc, et.al, 2016, 7).

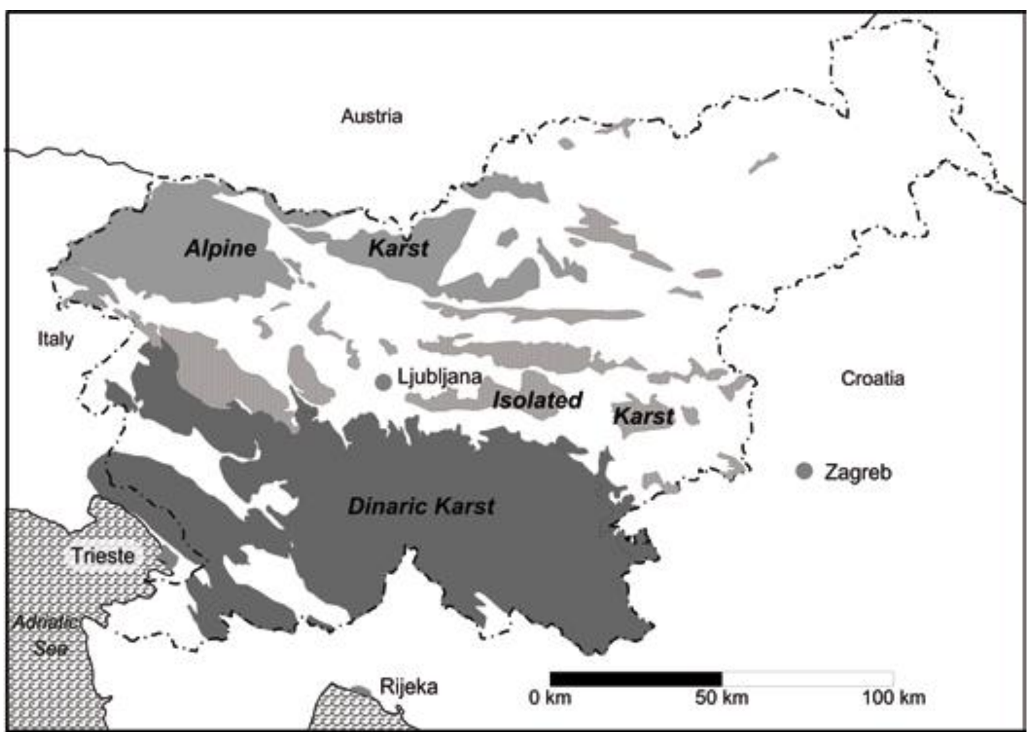


Figure 2: Extension of karst in Slovenia. Marked are the areas with limestone and dolomite and the three main types of karst: Alpine karst, Dinaric karst and Isolated karst (Mihevc et al. 2016).

`

The Pleistocene era carved the landscape we see today in Slovenia. Glaciers as thick as 900m formed ice caps over central parts of the Julian Alps, Kamnik-Savinja Alps, and Karavanke Mountains. Tectonic activity during the Quaternary period, introduced fluvial erosion, that relocated glacial sedimentary successions. Evidences of this are located in high mountain regions. Their erosional remnants are dispersed in alpine valleys, where moraines dominate the valley floors (Bavec, Verbič, 2011). Moraines are the key to determine past glacial activity and the impact it had on the landscape (Bendle, 2020). Ljubo Žlebnik, in his report about the Pleistocene of the Carniolan stated, "four generations of topographic moraines —all at a distance of less than 4 km apart—have been identified with fluvial valley fill, referred to as 'Würmian, Rissian, Mindelian and Günzian'" (Žlebnik 1971). Few authors have even concluded that the Late Pleistocene glacier went as far as the towns of Tolmin and Soči (Penck and Brückner,1909; Kuščer et al., 1974; and Kunaver, 1975). Still in the Pleistocene era, ice streams ventured out from Soča and Koritnica valleys to the Bovec basin while snow from the Northern Julian Alps accumulated along the smaller side valleys, such as Radovna, and along the slopes of the Bohinj and Sava Dolinka valleys.

The Bohinj glacier, one of the largest in Slovenia, covered Bled and certain areas of the Pokljuka plateau. (Figure 3) Today, the area between Lake Bled and the Sava Dolinka river is surrounded by Late Pleistocene till, with certain zones covered by fine-grained sediments that were deposited during the glacial retreat. When the glacier melted, its terminus split first into two and then into three tongues (Bavec, Verbič, 2011). One carved the hollow of the present Lake Bled, the other formed a depression at the village of Ribno, and the third stretched towards the village of Gorje (Melik, 1930). Most of the glaciers had melted towards the end of the Pleistocene period. This resulted in large amounts of poorly water-saturated till that had slid downhill along

`

the main glacial valley and slope sides. This till, mixed with non-glacial material, formed the large amounts of sediments we see today at glacially shaped clasts (Bavec, Verbič, 2011). Some have even been recorded on the floor of the Soča Valley around Tolmin and Most na Soči. This area is mainly covered with glaciofluvial, fluvial, and alluvial fan deposits, some of which were terraced. Alluvial fans associated with minor Soča River tributaries cover the terraces in a number of locations. Alongside this are lacustrine sediments, laminated and well-consolidated with muds, silts, and sands (Rupnik et al. 2020).

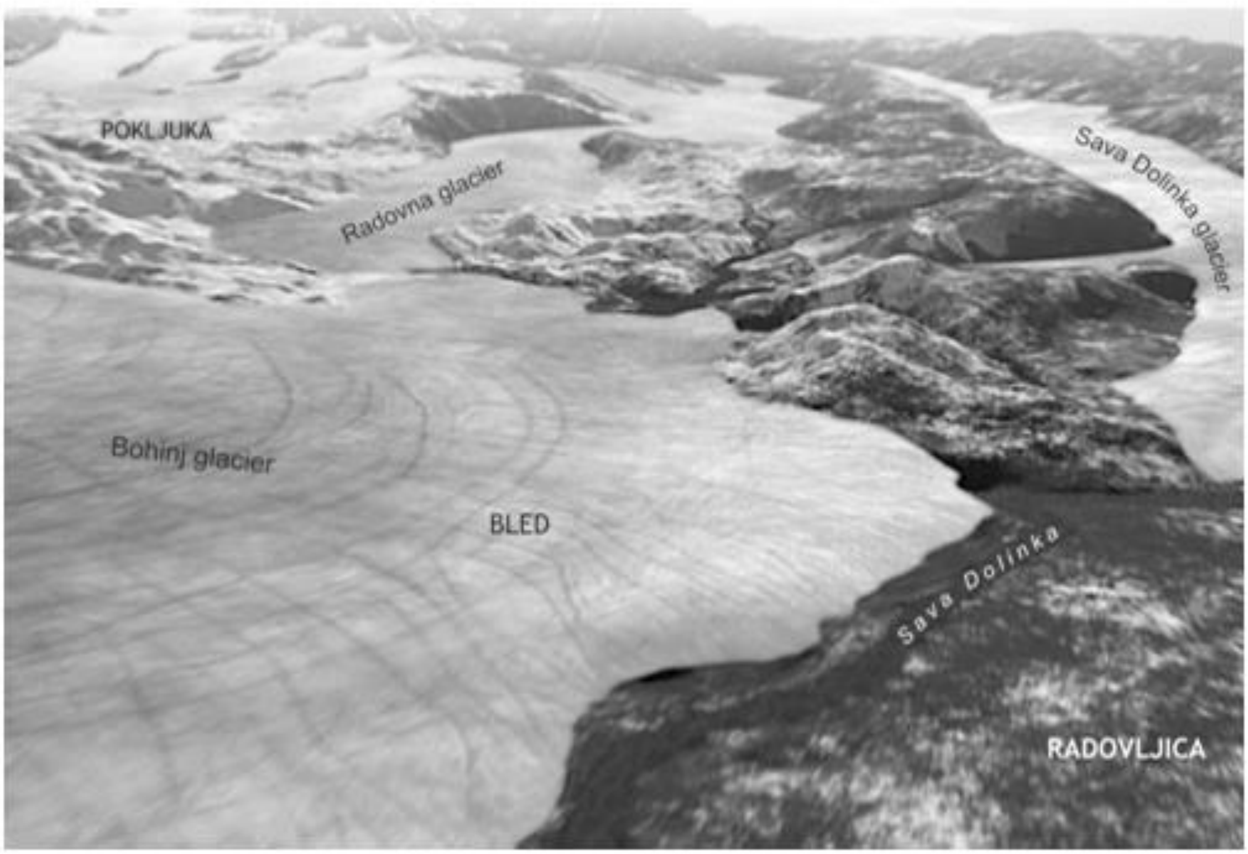


Figure 3: Reconstruction of maximal glacier extent during the Late Pleistocene in the surroundings of Bled and Radovljica. The Julian Alps are to the left (west) and the Karavanke Mountains to the right (east) (Ehlers, Gibbard, and Hughes, 2011).

`

Soča River and Trout Species

The Alpine karst is an important natural resource in Kobarid and holds large amounts of groundwater, supplying half the country through it. As a result of their geological evolution, these rocks are well karstified and are permeable aquifers. Along the high karst plateaus and mountain peaks, abundant precipitation with an average value of 3000 mm is recorded yearly. In these areas, vegetation and soils are hardly present, creating a high effective infiltration but rare surface streams. High mountain lakes collect surface waters on less permeable rocks while the infiltrated precipitation water (from recharge areas) flow underground along the easiest paths and towards the springs of these valleys. These spring waters recharge the Alpine rivers, an important one being the Soča River (Rivers 2004). Metka Petrič, who wrote 'The Alpine Karst waters in Slovenia', recorded that the Soča river springs with a capacity of 60 l/s and expands from its left affluent Krajcarica spring. Upstream of Soča river, there are several other tributaries, the biggest among them are the Glijun and Boka springs, the latter has a 140 m high waterfall. But it is the Tolminka, Zadlaščica, and Kneža (the southern edge of the alpine karst water) springs that flow into the Soča river (Petrič, 2004).

The Soča River is home to several native and non-native trout species, each with distinct characteristics. (Table 1) The Marble trout / Soča trout (*Salmo marmoratus*), an endemic species of the Adriatic river basin/watershed. This specific species grows significantly larger (min. size – 60 cm) than the other trout species and its main diet consists of aquatic insects, but mainly on other fish. The cold, fast-flowing waters of the main river are its preferred habitat but they are often found in areas with rocky substrates too (Soca Fly, "Rivers & Fish," 2025). They are recognized for its olive-green marbled pattern and can weigh up to 25kg (Berrebi et.al, 2000). The Rainbow trout (*Oncorhynchus mykiss*) is an allochthonous species and was introduced

`

sometime during the late 19th century due to their adaptability to grow and farm easily on both man-made and wild habitats. While it doesn't crossbreed, it does compete with other trout species for food and space. Due to their rainbow-colored flank and numerous black spots on their bodies, they are easy to spot. And can grow up to 80cm and weigh up to 8 kg, through feeding on both aquatic insects and other fish (Soca Fly, "Rivers & Fish," 2025).

FISH	DESCRIPTION AND SIZE	LOCATION	OPEN SEASON	MIN cm
Marble (Soča) trout (Salmo trutta marmoratus)	**Endemic** in the Adriatic river basin, this fish can grow to 140 cm and weighs up to 24 kg.	All waters.	**ZZRS** 1.4.–30.9. **RD Tolmin** no kill	60 cm
Grayling (*Thymallus thymallus*)	An **indigenous** salmonid, this fish can grow to 60 cm and weighs up to 2 kg.	The Soča (downstream from Mala korita), the Koritnica (downstream from Kluže), mouth of the Učja.	no kill (carch&release)	
Marble trout and brown trout **hybrids**	The appearance of these fish varies; they can grow to 1 m and weigh up to 10 kg.	Locations with the marble trout and brown trout.	**ZZRS** 1.4.–31.10. **RD Tolmin** no kill	/
Rainbow trout (*Oncorhynchus mykiss*)	This fish was released into rivers from fish farms; it can grow to 80 cm and weighs up to 8 kg.	The Soča (downstream from Mala korita), the Koritnica (downstream from Kluže), mouth of the Učja.	**ZZRS** 1.4.–31.10. **RD Tolmin** 23.3.–3.11.	**ZZRS** / **RD Tolmin** 24 cm

Table 1: Common Fish and Fishing in the Soča Valley (Soca Fly, "Rivers & Fish," 2025).

`

Chapter II: Materials and Methods

2.1 Study Area

Kobarid is a small town located in Western Slovenia, near the Italian border. (Figure 4) Situated within the Julian Alps and in the Upper Soča Valley (Kobarid, 2025), is composed of these formations: limestone, dolomite, and karst springs. Through the years of geological evolution, these landforms have built a favorable environment for cultivating a variety of crops and native trout populations. The region has a warm and temperate climate, but receives a significant amount of rainfall during the year. The average temperature in Kobarid is 36.6 °F | 20.3 °C, with around 1738 mm | 68.4 inches of rainfall annually (Climate Data, n.d.).

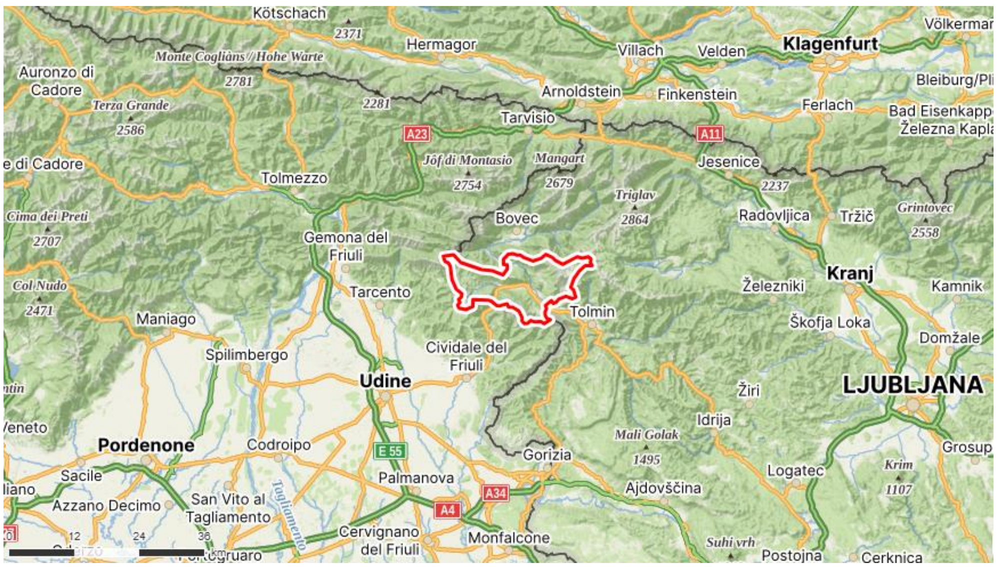


Figure 4: Map of Kobarid, highlighted in red. It is located near the Italian city, Udine (Mapy.com, 1998

Native marble trout populations have declined in previous years due to their crossbreeding with the non-indigenous brown trout. Both marble trout and brown trout come from the same ancestor, resulting in the ability to crossbreed and the quiet disappearance of the marble trout. During the 80s, the marble trout was placed on the Red List of endangered animal species.

`

Sprouted from a conservation plan, it was decided to try artificial breeding. Trout were caught in their natural habitats, and their eggs were taken to be artificially fertilized. The fingerlings were bred in hatcheries and later released back into rivers. Since then, the proportion of genes of the pure marble trout has increased in the population (About us, 2020).

All through Kobarid, restaurants and locals love to consume trout. The Soča trout, still a rare species, is an expensive delicacy to consume, so many opt for the rainbow and brown trout. The two prominent fish farms around the area are the Soča fish farm and the Tolmin fish farm. The area studied is the Soča River, starting from Čezsoča to Tolmin. One of the main focuses of the research (because it greatly affects trout populations) is using Google Earth Engine to calculate the water surface temperature along the Soča River, from January $1^{st,}$ 2021, to January $31^{st,}$ 2022. (Figure 5)

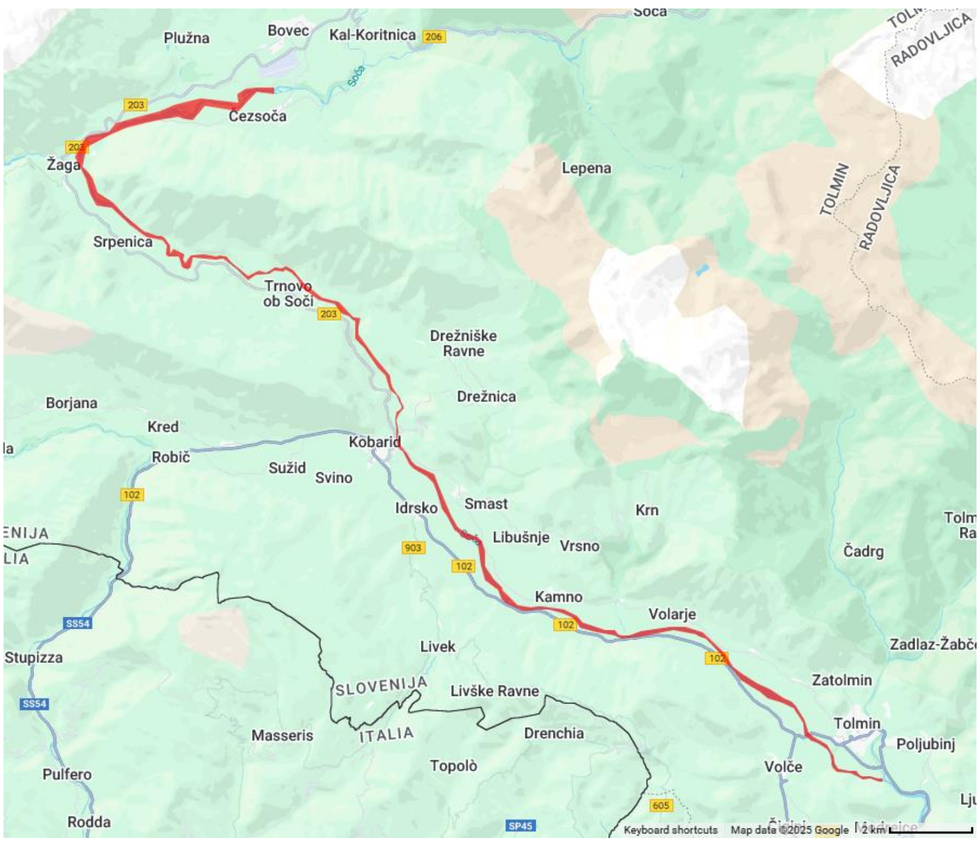


Figure 5: Marked in red is the area studied. It shows the Soča River, starting from Čezsoča to Tolmin. Image obtained using Google Earth Engine.

`

2.2 Google Earth Engine (GEE)

Remote sensing – an advanced process of detecting and monitoring the physical characteristics of an area through measuring its reflected and emitted radiation from a satellite. Cameras installed in satellites collect remotely sensed images to produce precise data about the Earth's landscapes (Remote Sensing, 2025). The Landsat program is a series of Earth-observing satellite missions, launched in 1972, to track land use and document land change due to climate change, urbanization, drought, wildfire, biomass changes, etc. It is a consistent provider of land change data and trending information that is not otherwise available (The Landsat satellite program, 2025). For this research, the datasets used are from the National Centers for Environmental Prediction (NCEP), the National Center for Atmospheric Research (NCAR), and the National Aeronautics and Space Administration's (NASA) Jet Propulsion Laboratory (JPL). Along with Landsat satellites 5 TM, 7 ETM+, 8, and 9 OLI/TIRS. (Table 2) All datasets are available on Google Earth Engine.

Satellite	*Dataset*	*Path/row*	*ECT*	*Available period*
Landsat 5 (TM)	T1-SR, T1-TOA	125/45	10:00–10:30 AM (16-day)	January 1, 1984–May 5, 2012
Landsat 7 (ETM+)	T1-SR, T1-TOA	125/45	10:00–10:30 AM (16-day)	January 1, 1999–present
Landsat 8 (OLI; TIRS)	T1-SR, T1-TOA	125/45	10:00–10:30 AM (16-day)	April 11, 2013–present
Landsat 9 (OLI-2; TIRS-2)	T1-SR, T1-TOA	125/45	10:00–10:30 AM (16-day)	October 31, 2021–present

Table 2: Satellite, Google Earth Engine dataset, path/row of the study area, equator crossing time (ECT), and available period for each Landsat satellite (Bui, 2024).

`

Landsat 5 carried the Multispectral Scanner (MSS) and the Thematic Mapper (TM) sensor that digitized raw and numeric pixel values (Landsat Missions, n.d.). Landsat 7 uses the Enhanced Thematic Mapper Plus (ETM+), a multispectral scanning radiometer that has the capabilities to provide high-resolution imaging information of the Earth's surface (Taylor, 2025). The images procured contain 4 visible and near-infrared (VNIR) bands and 2 short-wave infrared (SWIR) bands to process orthorectified surface reflectance, while the thermal infrared (TIR) band processes orthorectified surface temperature (USGS Landsat 7, n.d.). Each band uses the intensity of light reflected off a specific material to calculate surface temperature. Landsat 8 and 9 are installed with Operational Land Imager (OLI) and Thermal Infrared Sensor (TIRS) (Landsat 8 OLI and TIRS, n.d.). Both datasets contain atmospherically corrected surface reflectance and land surface temperature (USGS Landsat 8, n.d.).

The NCEP/NCAR Reanalysis Project processes new atmospheric analysis using historical data (NCEP/NCAR Reanalysis Data n.d.). The band used in this research is Total column water vapor (TCWV) to calculate the total amount of water vapor present in a vertical column of air over a specific area (Total column water vapor, 2022). The Advanced Spaceborne Thermal Emission and Reflection Radiometer Global Emissivity Database (ASTER-GED) was developed by NASA's JPL. It calculates the mean emissivity and mean land surface temperature (LST) (ASTER Global Emissivity, n.d.). The emissivity is crucial for accurately calculating the surface temperatures on Earth. Glynn Hulley's research letter on Mapping Earth's emissivity at a 100-meter spatial scale computes the range of emissivity to surfaces. Surfaces with emissivity less than 0.85 are typically found over deserts and semiarid areas due to the presence of quartz grains, which are ubiquitous in these types of environments. Vegetation, water, and ice have high

`

emissivity above 0.95 that is nearly constant over the TIR wavelength range (Hulley et al., 2015).

The satellite data and code used in this study were developed by Ermida et al. (2020). Professor Thuyet Bui utilized the code to then calculate water surface temperature (WST) at shrimp farms in Vietnam (Bui, 2024). For this study, similar data and code will be employed to calculate the water surface temperature along the specified area of the Soča River. The processing to derive the following code is structured as (Figure 6): load TOA brightness temperatures (BT) and SR data of all Landsat satellites; mask clouds by using the quality information bands; load total column water vapor (TCWV) values from NCEP/NCAR; using the SR data, compute the Normalized Difference Vegetation Index (NDVI) (Eq. 1) and the fraction of vegetation cover (FVC) (Eq. 2); load the ASTER-GED database; compute ASTER emissivity values for bare ground to obtain the corresponding Landsat's thermal infrared (TIR) emissivity (Eq. 3); compute L/WST based on the Statistical Mono-Window (SMW) algorithm (Eq. 4) (Bui, 2024). This dataset is then mapped on the region of study. Satellite data was retrieved using Google Earth Engine and analyzed via a JavaScript codebase.

Equation 1 (Eq. 1):

$$NDVI = \frac{NIR - R}{NIR + R}$$

NIR is the value of the near-infrared band, and R is the value of the red band (Bui, 2024).

`

Equation 2 (Eq. 2):

$$FVC = \left(\frac{NDVI - NDVI_{bare}}{NDVI_{veg} - NDVI_{bare}}\right)^2$$

$NDVI_{bare}$ and $NDVI_{veg}$ are the NDVI values of completely bare and fully vegetated pixels. The $NDVI_{bare}$ is set to 0.2 and the $NDVI_{veg}$ is set to 0.86 (Ermida et al. 2020).

Equation 3 (Eq. 3):

$$\varepsilon_b = FVC\varepsilon_{b,veg} + (1 - FVC)\, \varepsilon_{b,bare}$$

Where ε_b is the surface emissivity (Bui, 2024). $\varepsilon_{b,veg}$ and $\varepsilon_{b,bare}$ are the emissivity of vegetation and bare ground for a given spectral band b. Since emissivity of vegetated surfaces show small variations in the TIR region, the value prescribed to $\varepsilon_{b,veg}$ is 0.99 (Ermida et al. 2020).

Equation 4 (Eq. 4):

$$W/LST = A_i \frac{T_b}{\varepsilon} + B_i \frac{1}{\varepsilon} + C_i$$

This formula calculates the water/land surface temperature. Tb is the TOA brightness temperature in the TIR channel, and ε is the surface emissivity for the same channel (Ermida et al. 2020). A_i, B_i, and C_i are algorithm coefficients determined from TCWV (Bui, 2024).

`

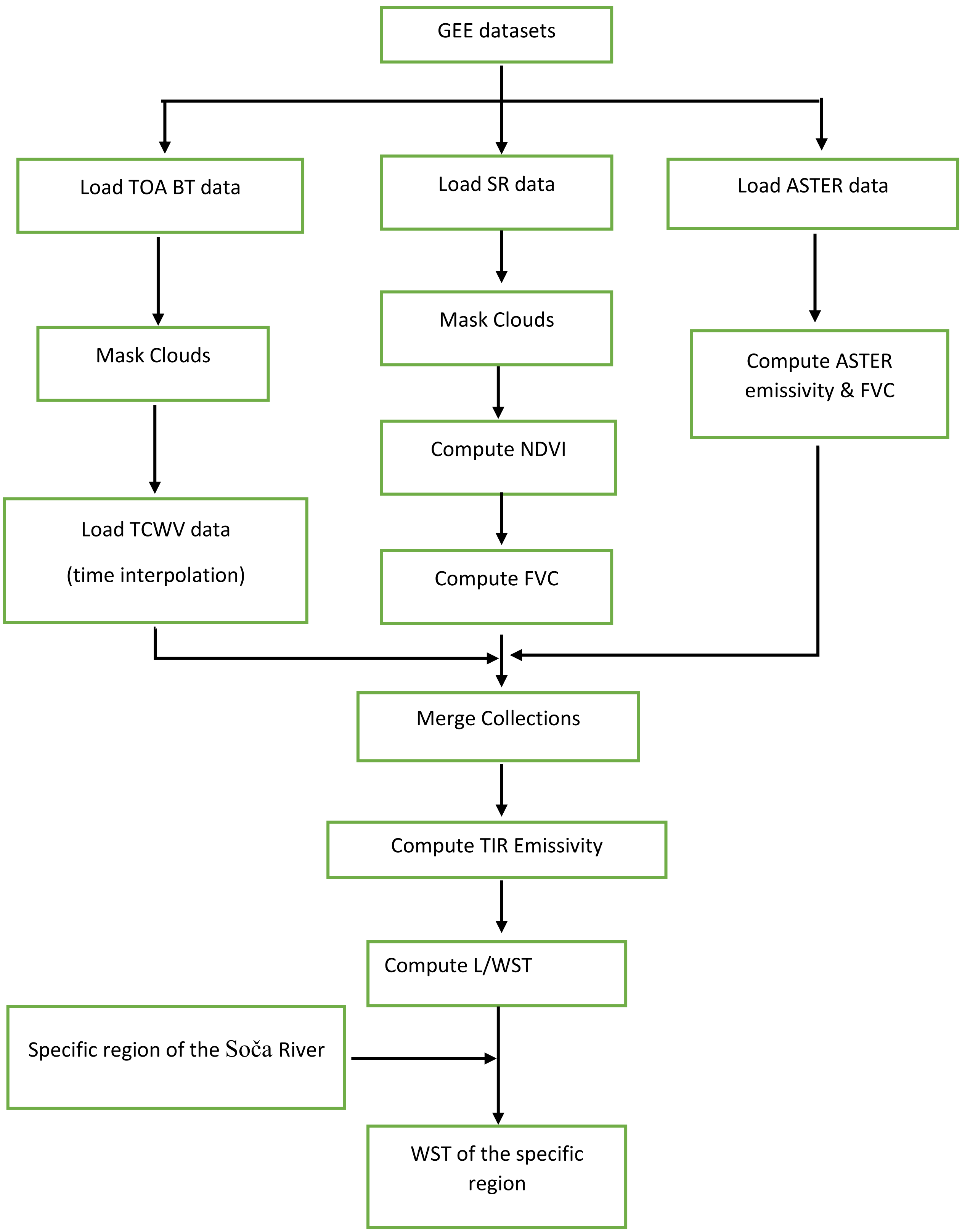


Figure 6: Google Earth Engine processing chain to calculate water surface temperature (WST) of the Soča River, starting from Čezsoča to Tolmin. The processing structure was taken from Ermida et al (2020), and Bui (2024).

`

2.3 Structured Interviews

The study draws on the use of semi-structured interviews. While it doesn’t follow a pre-set order of questions, it is designed to ensure the topic is being covered. The interview is done in the early stage of this study to structure the research background and formulate research questions. Hence, responses received form the basis for future investigation. These open-ended questions prompt participants to develop their thoughts and ideas in depth, and express their views on the subject matter using their own words. For this interview, there is a yes/no question, but it is followed by an open-ended question to obtain further clarifications, justifications, or illustrations (Karatsareas, 2022).

Four groups were interviewed for this study: The Fisheries Research Institute of Slovenia, Tolmin Angling Club, Soča Fish Farm, and the Faronika Fish Farm. Both the Fisheries Research Institute of Slovenia and the Tolmin Angling Club were interviewed in the beginning to set the framework for marking the region of interest along the Soča River. The Fisheries Research Institute of Slovenia was established in 1961 to create sustainable management of fish populations and the preservation of their diversity. The institute is divided into three departments: inland fisheries, marine fisheries, and fish farming (Institute Introduction, n.d.). Trout species in the Soča River fall under the department of freshwater species. Tomaž Modic, a researcher for 20 years at this institute, was interviewed. Tolmin Angling Club was built with the purpose of conservation and breeding of indigenous fish and protecting aquatic systems. It manages part of the Tolmin fishing district on Bovec, Kobarid, and Tolmin, which includes the Soča River (Tolmin Angling Club, n.d.). Blaž, a member of the Club and a fishing guide, was interviewed for this study. The Soča Farm was built in 1936 by the Italians, as compensation for the damage to fish life caused by the construction of hydroelectric power plants on the Soča

`

River. The fish farm is fed by the Korenov and Frandolič spring, and they grow around 20 tonnes of fish each year, although most are intended for stocking. They farm the marble trout, rainbow trout, and brown trout. In 1985, they received eggs of the marble trout from breeding farms, and now breed exclusively genetically pure marble trout and release them in the upper Soča River and its tributaries. On the other hand, they import eggs from the US to breed the Rainbow trout (Fish Farming SOČA, n.d.). Faronika Fish Farm, situated near the Tolminka River, which merges into the Soča River, is led by Tolmin fishermen. The farm is fed by the torrential Tolminka River, with temperatures ranging from 3–13 °C throughout the year, making it an ideal climate for the fish. The River flows into the farm through a pipeline, with a strong water flow (300 liters per second) during certain times, both to ensure similar ecological environments and to replicate the fast-flowing streams that are rich in oxygen. They breed up to 8,000 kg of commercial rainbow trout and 2,000 kg of Isonzo trout (Marble trout) (Fish farm Faronika, n.d.).

2.4 Specialized Maps

Maps can be an effective medium for communicating research. Systems to analyze geospatial data and prepare maps are now readily available and widely used in research (Coetzee, Carow, Snyman, 2021). With the study's primary focus being the ecological and geological connection to the trout species, it's necessary to involve the use of geological, and geomorphological maps. While aquaculture involves the cultivation of aquatic organisms, the underlying geology of a region profoundly influences the sustainability, and its potential environmental impact. In contrast, geology influences river base flow, which is sustained by groundwater, as well as natural minerals leaching into surface waters. For this study maps will be used to investigate the relationship between the geological landscape of the Soča Valley and the ecological health of its

`

trout species. Maps will be divided in two categories: one for geological purposes and the other for ecological understanding.

ArcGIS, a geographic information system (GIS) software developed by Esri, is a geospatial platform to integrate data through the context of geography (ArcGIS, n.d). One of its features is the ArcGIS Online platform, a cloud-based mapping system used to make maps and analyze data. For this study, two maps were created: A Topographic Map and a Vegetation Map of Čezsoča, Kobaird and Tolmin. Topographic maps are used to determine elevation, providing structural knowledge about the Earth's surface. A basic observation is the gradient or slope of the ground surface so it is vital to understand the pattern of the contour lines. Steep gradients are drawn in areas where there is a significant change in elevation over a short distance. But gentle gradients occur where there are diminutive changes in elevation over the same distance (Smith, 2005). The map used for this research provides both vector contour lines and vector hill shade for the regions in Slovenia (World Topographic Map, 2025). Vegetation maps are used to identify and classify diverse plant communities and land cover. The map used for this research provides data from the Corine Land Cover 2006 inventory (Végétation, n.d.). Riparian vegetation shading influences water surface temperature thereby impacting the climatic environment of the trout species. Both vegetation and topographic maps will be studied to evaluate and confirm their role in cultivating the perfect habitat for both the Rainbow and Marble trout. The Geological Survey of Slovenia (GeoZS) is an institute focused on geological and geoscience research. One of their platforms is the Glacial Landscape of the Alps-Dinarides, displaying glacial landforms in the northern Dinaric Mountains in Slovenia. For this study both the glacial database map and the geomorphologic ice extent map will be reviewed. The geomorphologic ice extent map will be used to create a baseline for understanding the contemporary landscape of the region that was

`

previously sculpted by glaciers. On the other hand, the glacial database map offers a comprehensive inventory of the various glacial landforms within the region, further emphasizing its influence on the current landscape. In addition, geological maps of the region, with structural units will be analyzed to correlate rock types and their influence on the Soča River's physical structure. Soil plays a crucial role in influencing water quantity, quality and the physical development of a habitat. A soil map of the region from ARSO Geoportal has been extracted to help determine its composition and mineralogy and better understand if there is a correlation between trout habitat and type of soil.

For the ecological part of the research, maps are procured from the Slovenian Fisheries Institute. A comprehensive published report, titled ‘Fish Farming Plan for Implementing Fisheries Management in the Tolmin Fisheries Institute,’ covering data from 2017 to 2022, was translated from Slovenian to English. To this day the report’s conclusive statistics remain valid and specific maps derived from it provide ecological insights for this study. These maps and graphs include: Assessment of the ecological status of surface water bodies, spawning grounds, areas in accordance with nature conservation regulations, distribution of Isonzo trout, distribution of rainbow trout, average annual catch of individual species in the period 2000-2014, catch (number of fish) of Isonzo trout in the period 1986-2014, and catch (number of fish) of Rainbow trout in the period 1986-2014.

An assessment of the ecological status of surface water bodies in Slovenia was studied, and rivers were marked to indicate their status. It will be used to understand the current environmental health of river ecosystems within the study area. The spawning ground maps highlight the hydro-morphological properties and geological foundations (Ramšak, 2022), and delineates trout habitat ecosystems. Its integration into the study will offer correlated insight

`

between geomorphological features and locations of breeding grounds. The Fisheries Institute manages and regulates nature conservation areas, many of which include riverine ecosystems. Reviewing this map will shed light on protected zones and areas of specific ecological sensitivity. Distribution maps of Marble and Rainbow trout are key to analyzing the distribution of trout populations. The last few graphs are accompanied with data on the average annual catch of all fish species and individual species such as the Marble and Rainbow trout. They are essential for understanding the current status of the trout population and habitat health.

Chapter III: Results

3.2 Geological Characterization

A necessity that is often overlooked are maps. Carrying out both geological history and terrestrial foundations, a map is an important instrument to advance the field of agriculture. From the sloped lush mountains to the emerald waters of Soča, glaciers have played a role in shaping these landforms. This erosional-depositional process has carved the mountain regions and valleys we see in Slovenia. The Bohinj glacier, one of the largest in Slovenia, covered Bled and certain areas of the Pokljuka plateau. The Geological Survey of Slovenia (GeoZS) reconstructed the vast ice extents of the glacier (Figure 7) during the Late Pleistocene period. It covers the Triglav National Park and sweeps into Bled. Modeling glacial ice sheets is done through the Parallel Ice Sheet Model (PISM) using horizontal resolutions of 2 and 1 km (Seguinot, et al., 2018). A modeled version (Figure 8) of ice extent shows that perhaps the glacier has stretched further out into Kobarid and all the way into Medvode. Landforms created through this come from three different time periods: the pre-Last Glacial Maximum, the Last Glacial Maximum (30,000 to

`

19,000 years ago) and the post-Last Glacial Maximum (Žebre, Gostinčar, 2023). An aftermath of this is the formation of alluvial landforms along Čezsoča (Figure 9), Kobarid (Figure 10), and Tolmin (Figure 11).

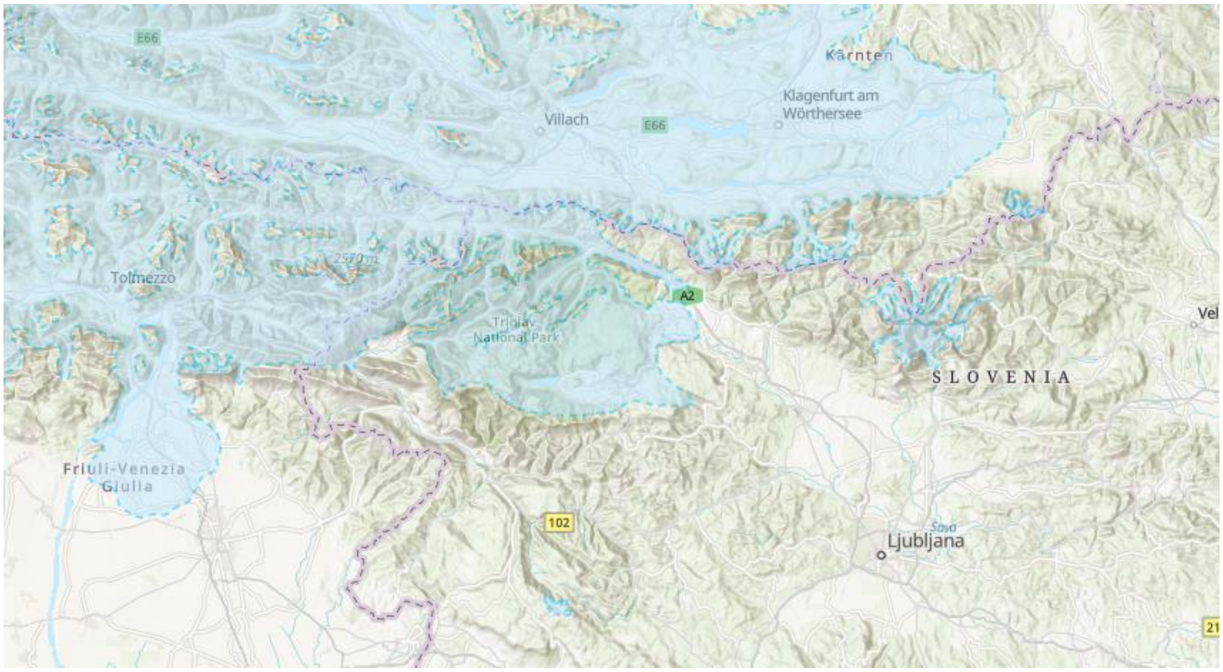


Figure 7: Historic geomorphological ice extent of the Alpine-Dinaric region. It is a reconstructed the vast ice extent of the glacier during the Late Pleistocene period.   (GeoZS, 2024).

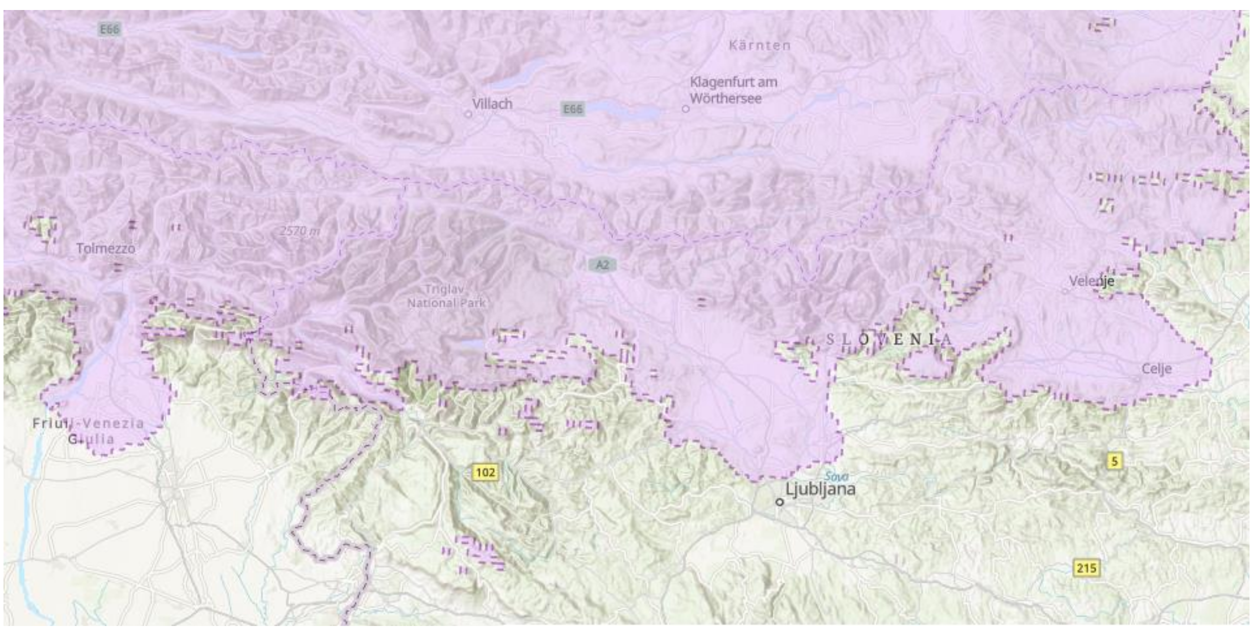


Figure 8: Modelled geomorphological ice extent of the Alpine-Dinaric region. This version shows that perhaps the glacier has stretched further out into Kobarid and all the way into Medvode (GeoZS, 2024

`

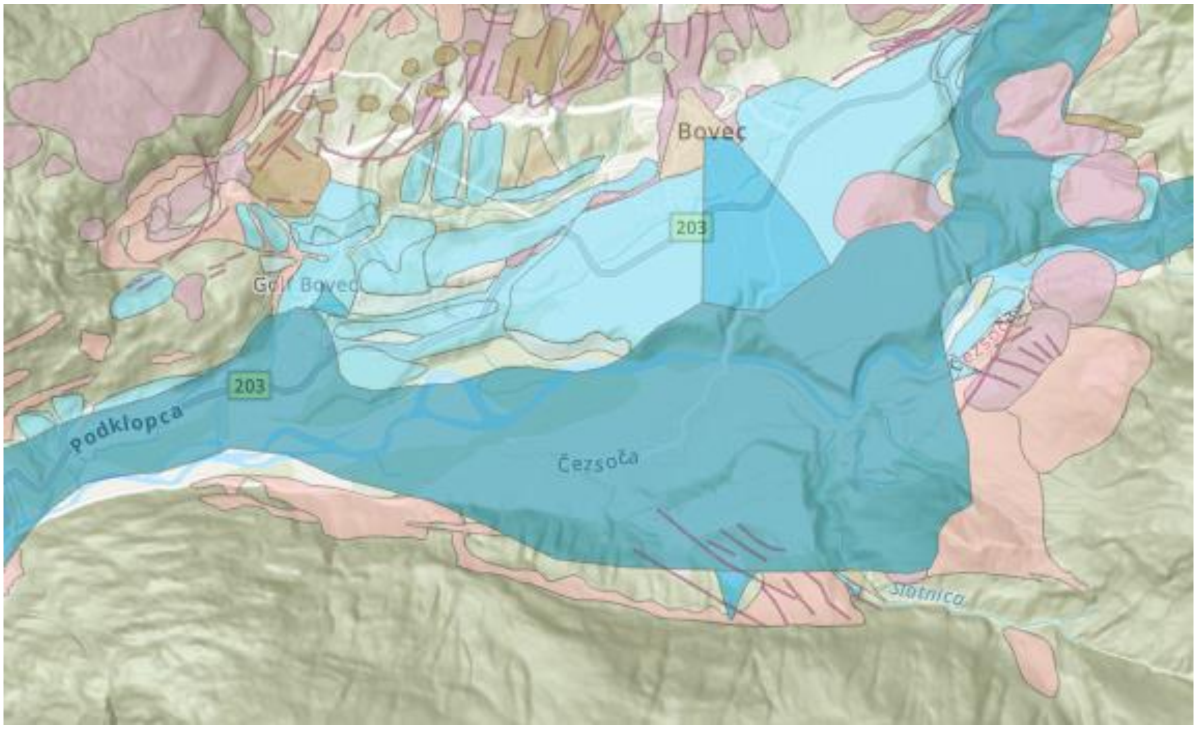


Figure 9: Glacial landform of Čezsoča with a legend (below Figure 11) that identifies key erosional and depositional features (GeoZS, 2023).

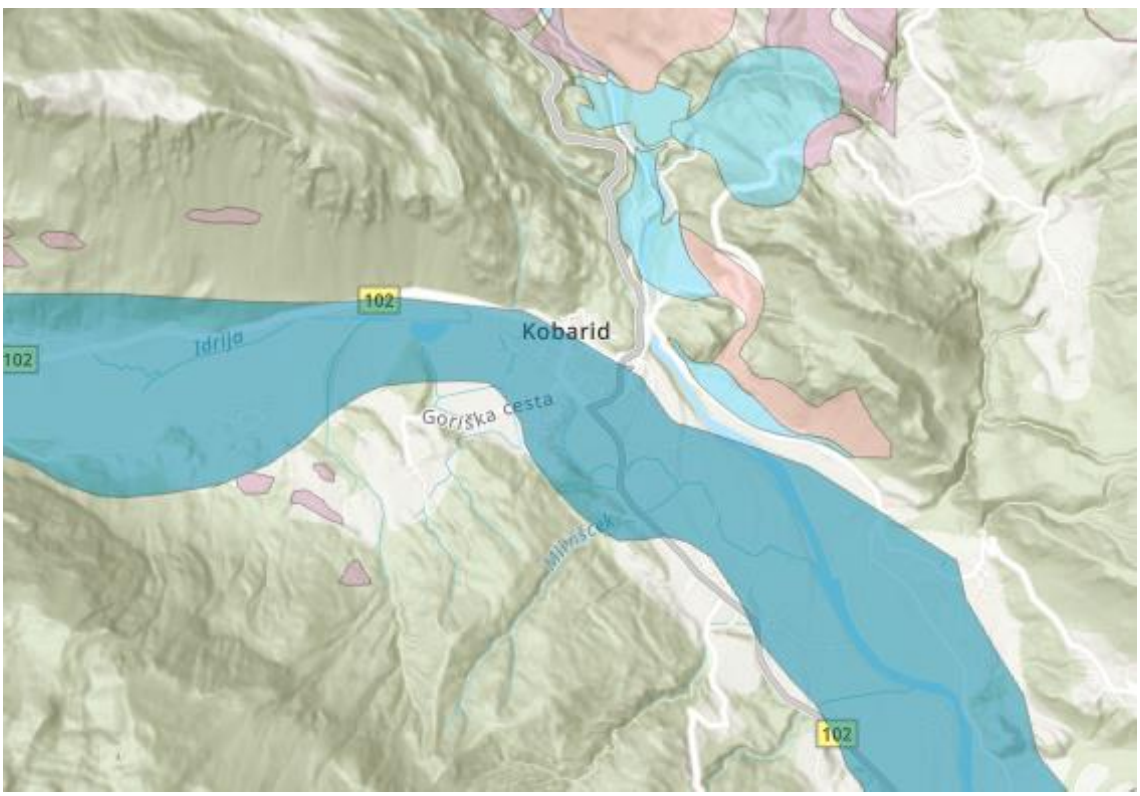


Figure 10: Glacial landform of Kobaird that identifies key erosional and depositional features, the legend is below

Figure 11 (GeoZS, 2023

`

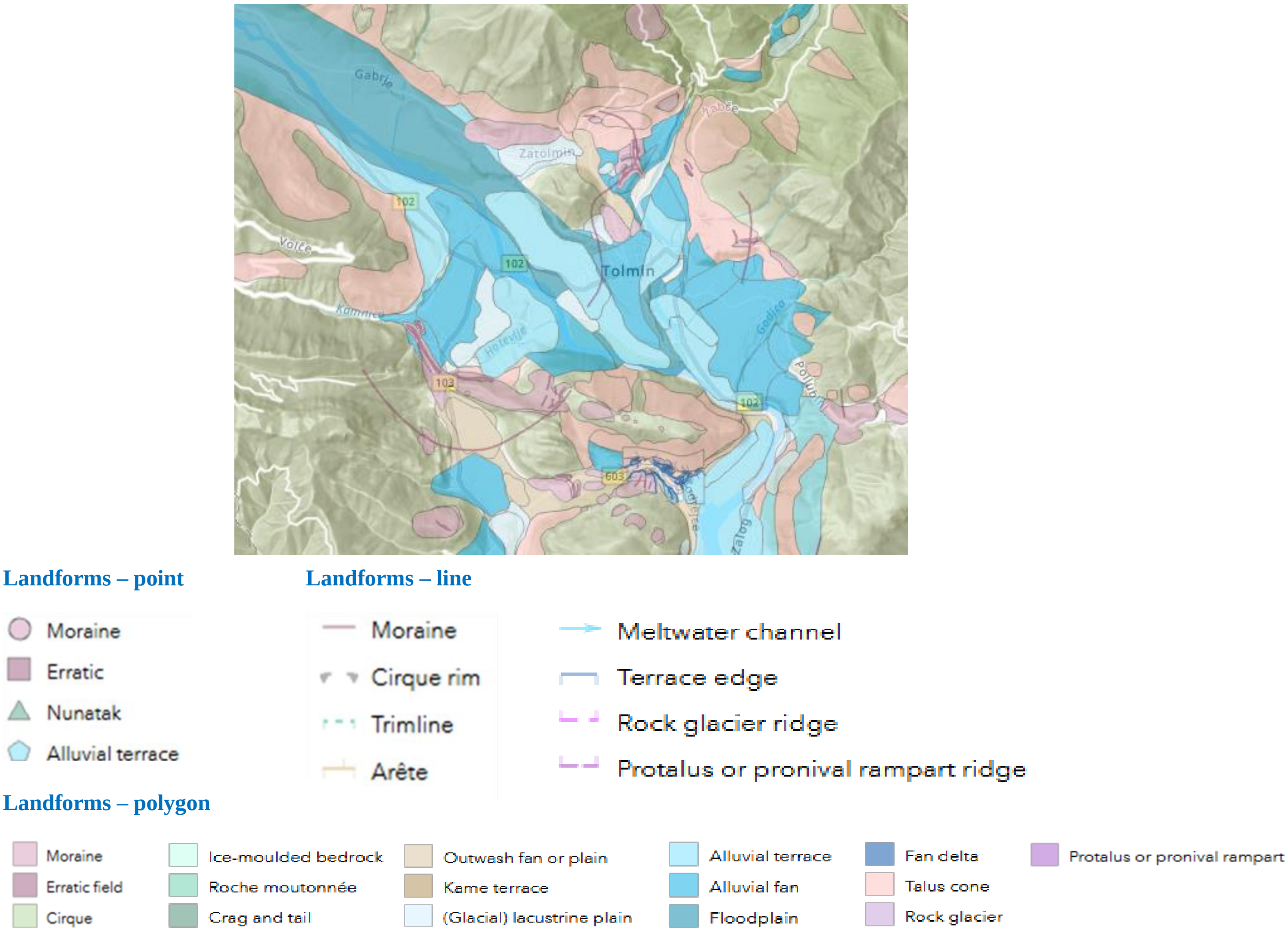


Figure 11: Glacial landform of Tolmin that identifies key erosional and depositional features, the legend is below (GeoZS, 2023).

These landforms are constructed by depositional features formed through water discharge and sediment transport. Geological maps stand as a testament to this. Looking into the geological map of Bovec – Kobarid (Figure 12), we can see Čezsoča is surrounded with gravel and sand but as you move further down Kobarid is covered by thick layers of limestone and river terraces. Surrounding Tolmin (Figure 13), are terrestrial deposits of flysch and other deep-marine rocks.

`

The structural unit map of Kobaird and Čezsoča (Figure 14) show similar flysch coverage but instead with alluvial and till that was deposited during the Upper Triassic and Jurassic periods.

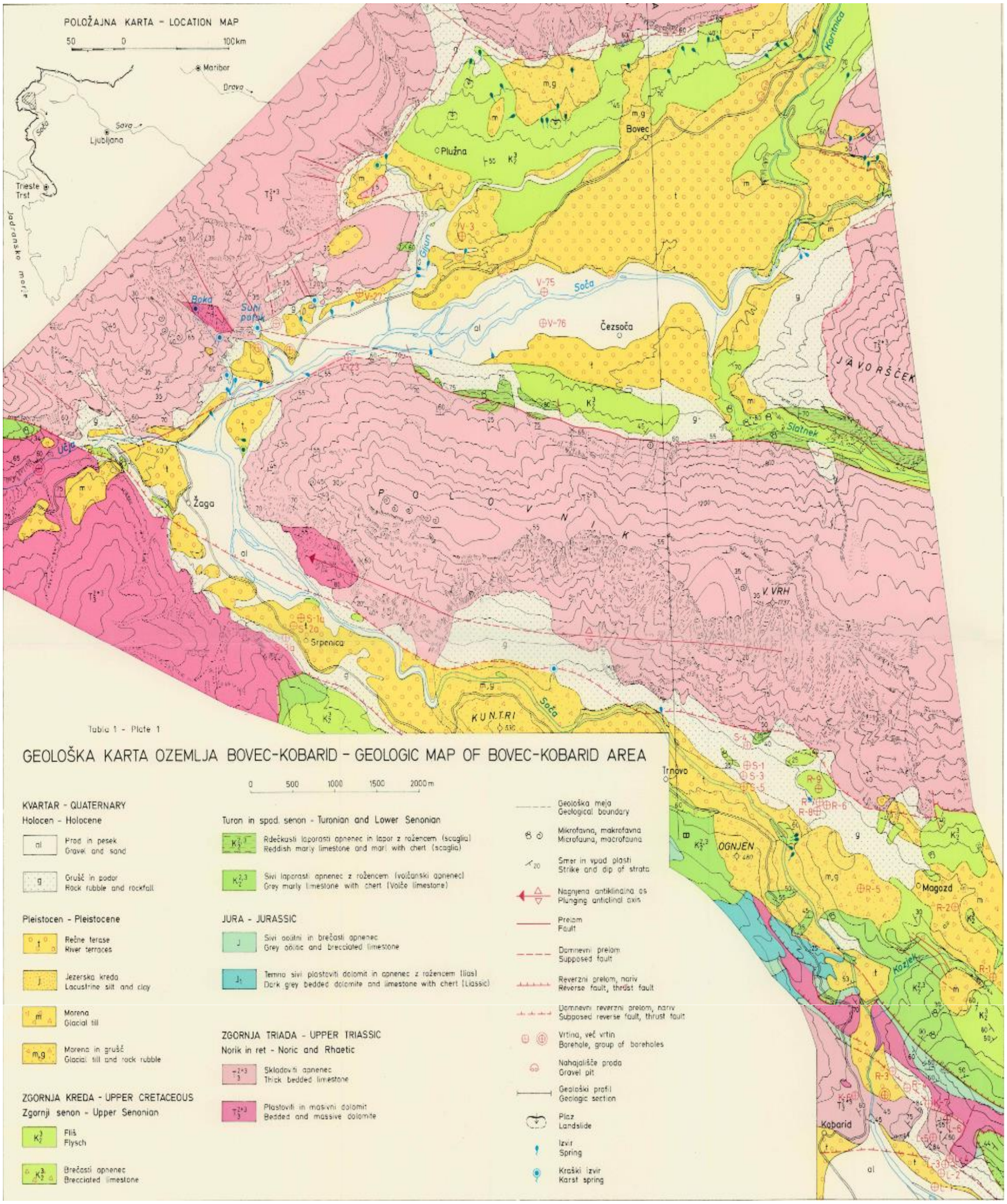


Figure 12: Geological map of Bovec – Kobarid area, to provide foundational data to analyze the region's geology (Kuščer, et. al, 1974).

`

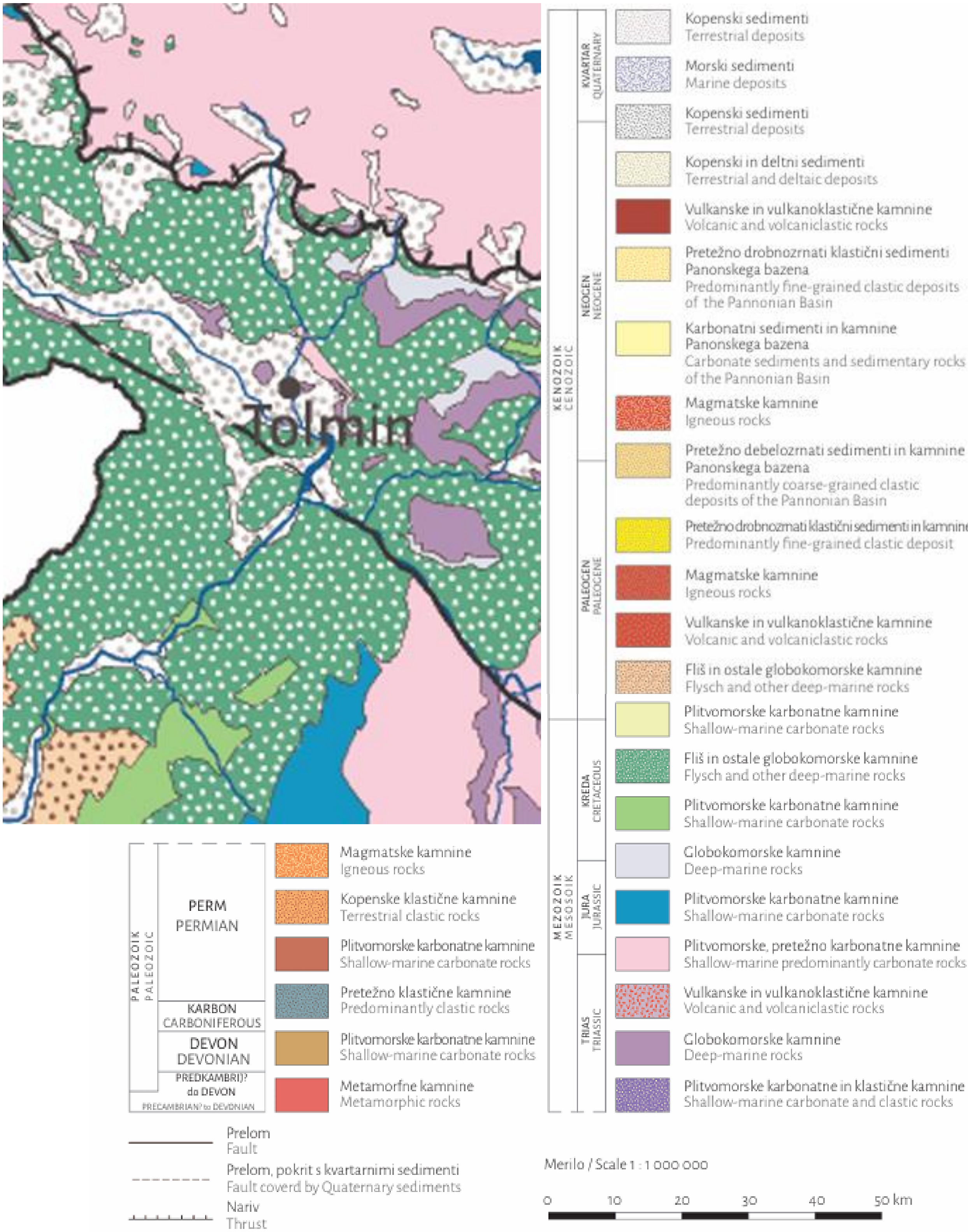


Figure 13: Geological map of Tolmin, displaying areas that are terrestrial deposits of flysch and other deep-marine rocks. (Bavec, Novak, Poljak, 2013).

`

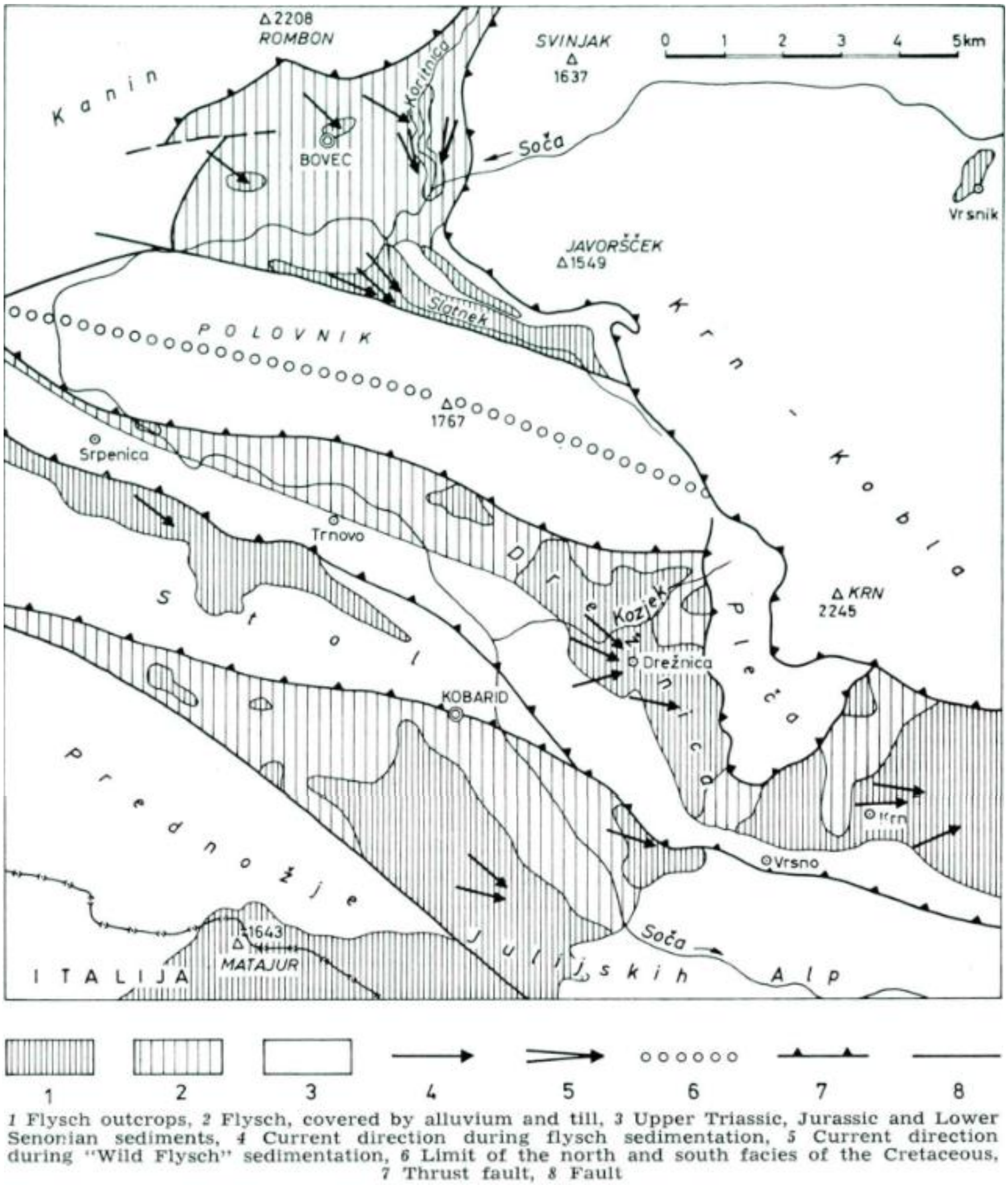


Figure 14: Map showing flysch areas and structural units between Bovec and Kobarid (Kuščer, et. al, 1974).

While geological maps show the distribution of rock types, topographic maps represent elevation changes that have occurred as a result of geological transformations. The Soča River located

`

throughout the regions (Čezsoča, Koabird, Tolmin) for this study has an elevation of 150m – 400m (Figure 15). Topography plays a role in soil structure, with varying sediment layers in confluence with erosional elevation. Soil maps of Čezsoča (Figure 16), Kobarid (Figure 17), and Tolmin (Figure 18) are displayed to study their relation to the Soča River and the types of vegetation that grow around it (Figure 19) (Figure 20).

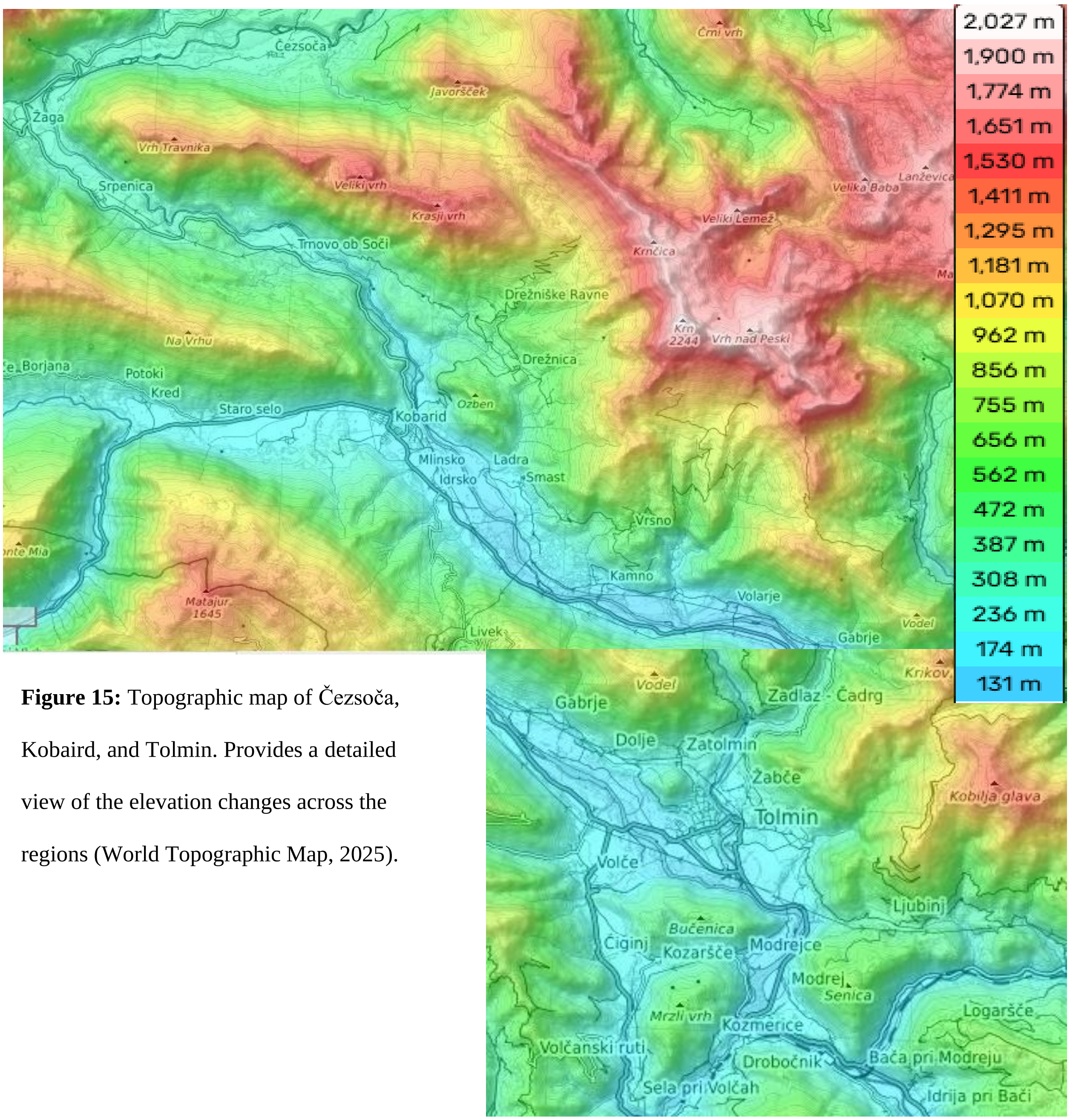
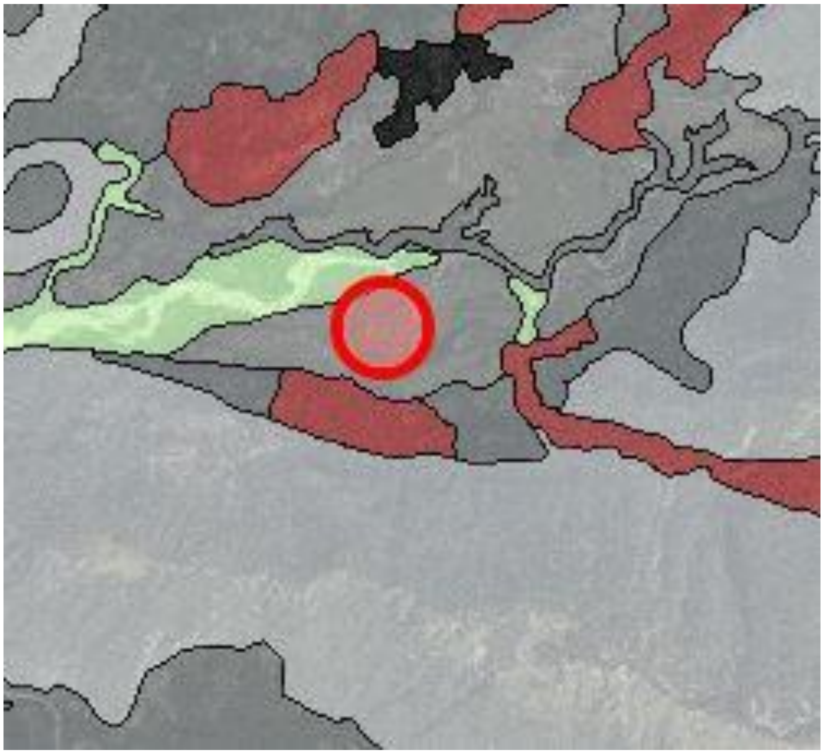


Figure 15: Topographic map of Čezsoča, Kobaird, and Tolmin. Provides a detailed view of the elevation changes across the regions (World Topographic Map, 2025).

`



- Soil type: Rendzina on carbonate gravel and sand
- Soil type: District brown soil on non-carbonate flysch and decalcified marl
- Soil type: Rendzina on moraine and slope gravel
- Soil type: Undeveloped riverine soil
- Soil type: Rendzina on limestone and dolomite
- Soil type: Urban, water and barren surfaces

Figure 16: Soil map of Čezsoča. The region is circled in red and the legend is on the right (ARSO Geoportal, 2006).

- Soil type: District brown soil on non-carbonate flysch and decalcified marl
- Soil type: Eutric brown soil on moraine and slope gravel
- Soil type: Rendzina on moraine and slope gravel
- Soil type: Rendzina on limestone and dolomite
- Soil type: Urban, water and barren surfaces
- Soil type: Undeveloped riverine soil
- Soil type: Washed floor on limestone, acrylic
- Soil type: Rendzina on limestone and dolomite and brown carbonate soil
- Soil type: Eutric brown soil on clastic rocks
- Soil type: Eutric brown soil on flysch
- Soil type: There is no floor

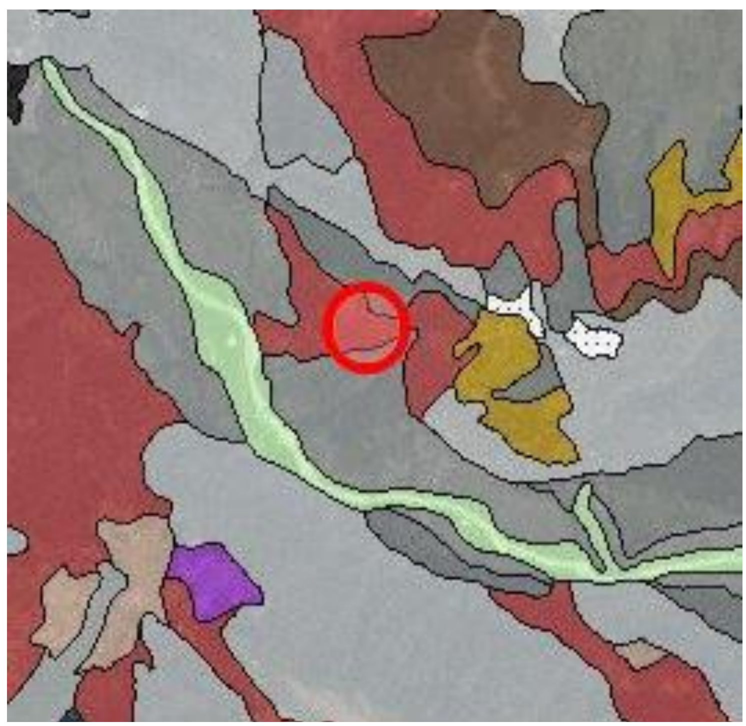
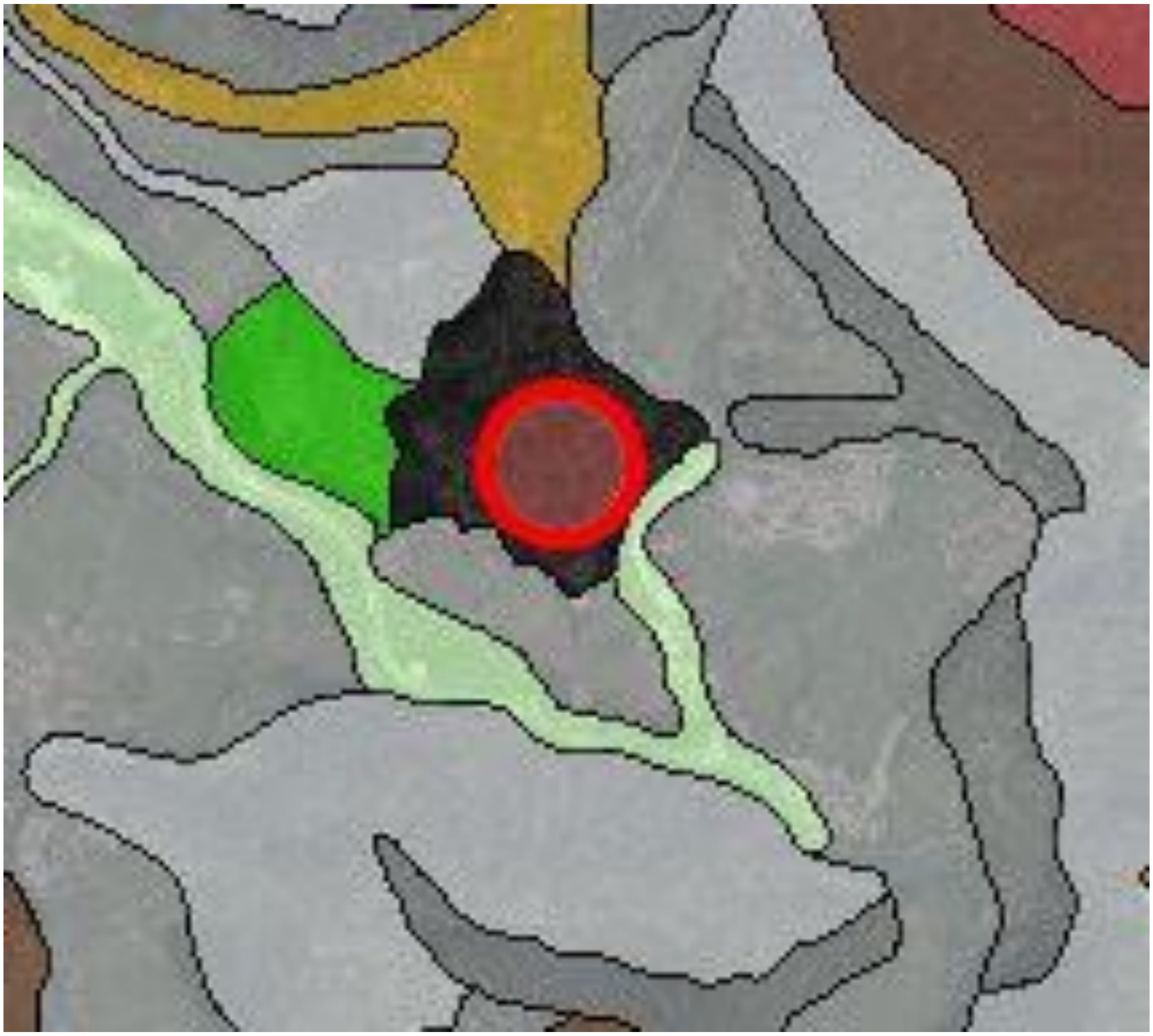


Figure 17: Soil map of Kobaird. The region is circled in red and the legend is on the right (ARSO Geoportal, 2006).

`



- Soil type: Urban, water and barren surfaces
- Soil type: Undeveloped riverine soil
- Soil type: Rendzina on carbonate gravel and sand
- Soil type: Alluvial soil, eutric
- Soil type: Rendzina on limestone and dolomite
- Soil type: Rendzina on moraine and slope gravel
- Soil type: Eutric brown soil on clastic rocks
- Soil type: Eutric brown soil on moraine and slope gravel
- Soil type: District brown soil on non-carbonate flysch and decalcified marl
- Soil type: Rocky surfaces without soil

Figure 18: Soil map of Tolmin. The region is circled in red and the legend is on the right (ARSO Geoportal, 2006).

`

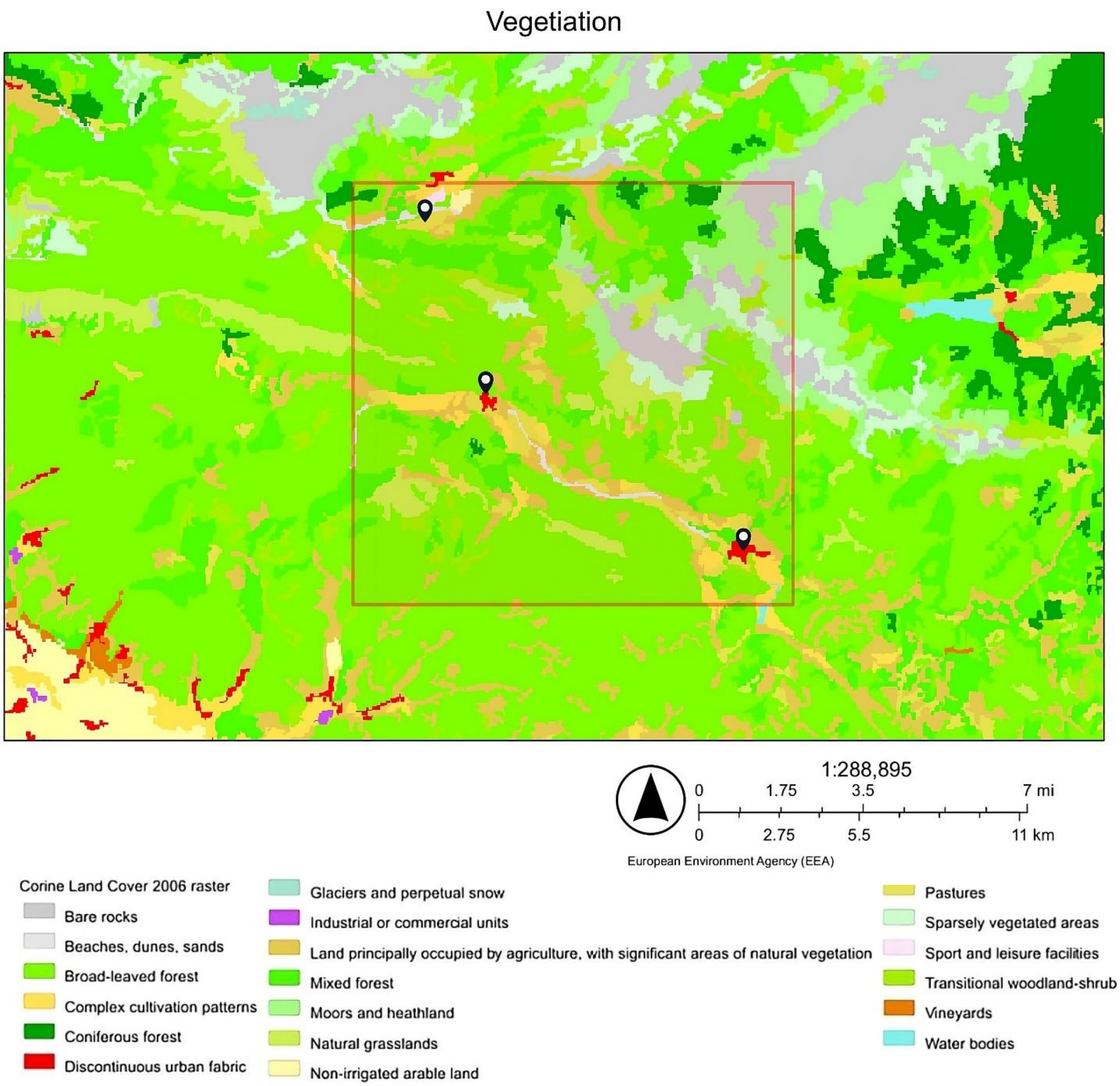


Figure 19: Vegetation map of Čezsoča, Kobarid and Tolmin are represented in pins inside the square. Identifying and classifying the diverse plant communities to analyze riparian vegetation and its impact on the environment. Red areas are urban cities and they are surrounded by lands that are principally occupied by agriculture with also significant areas of natural vegetation (yellowish brown). Most of the vegetation (light green) in the region are broad-leaved forests (ArcGIS, n.d).

`

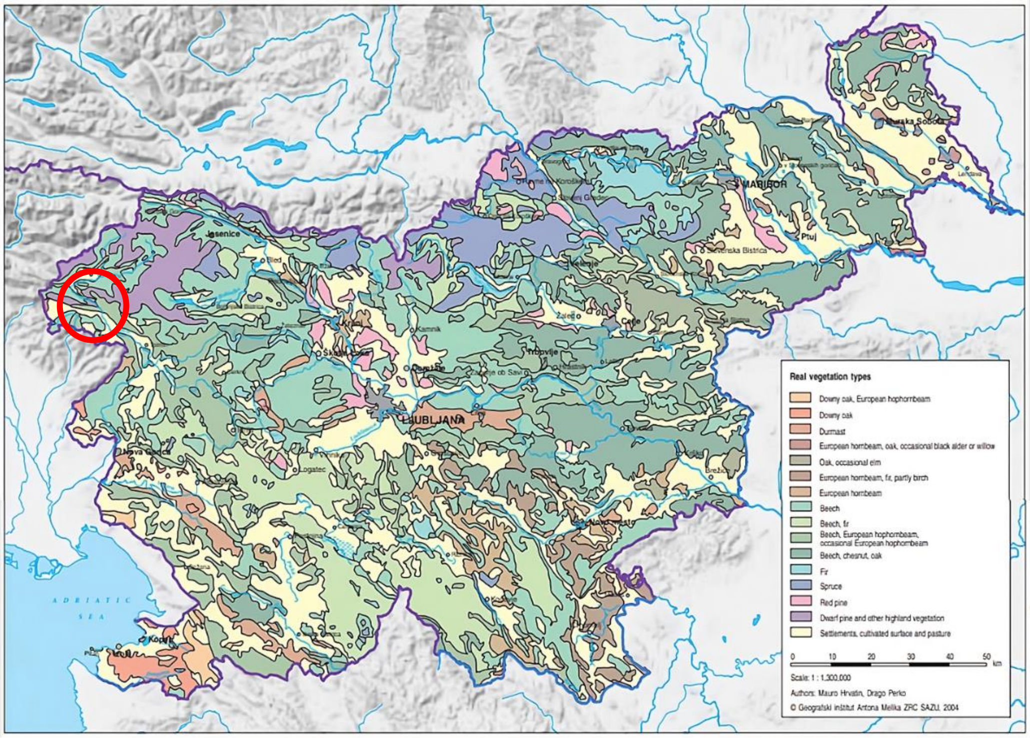


Figure 20: Vegetation map of Slovenia. Circled in red is the region of study (Repe, n.d.).

3.2 Ecological Status of Slovenian Rivers and tributaries

With relation to this, the Slovenian Fisheries Institute formed a map (Figure 21) displaying fishing areas that are both in accordance with nature conservation regulations and have ‘natural value’. According to their report, “Natural values are comprised of all-natural heritage in the territory of the Republic of Slovenia. Types of natural values are: surface geomorphological, subsurface geomorphological, geological, hydrological, botanical, zoological, ecosystem, tree and shaped natural value, landscape value, mineral and fossil.” Geological habitats can either build or destroy a region’s ecological status. An ecological assessment (Figure 22) was conducted on surface water bodies from 2009-2015. Reported data are still used by local

`

fishermen and the Angling Club. 97% of water bodies were assessed for the quality of the structure and the functioning of aquatic ecosystems (Ramšak, et al., 2022).

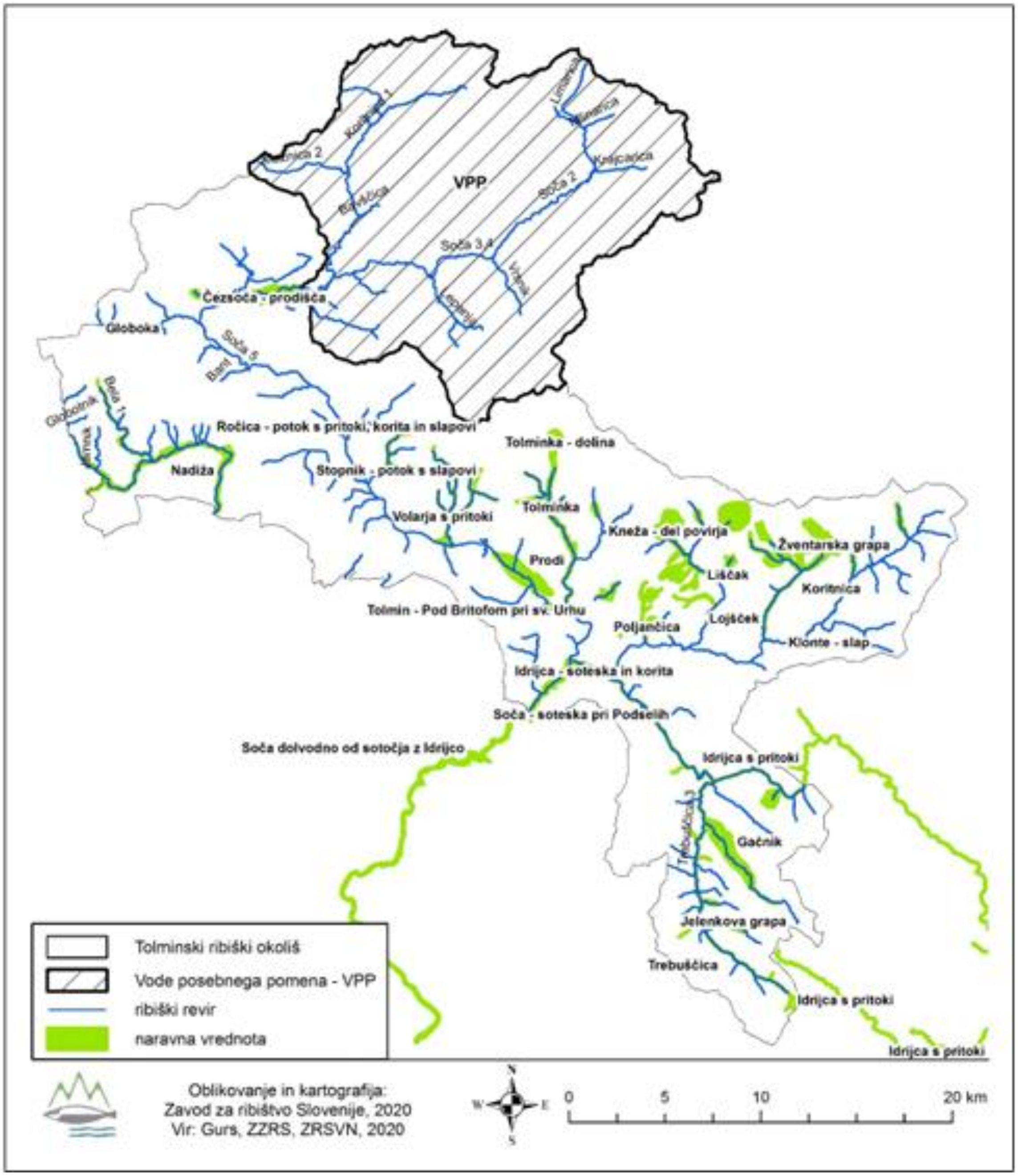


Figure 21: Overview map of the Tolmin fishing district showing areas that, in accordance with nature conservation regulations, have special status – natural values and are highlighted in green. These represent surface geomorphological, subsurface geomorphological and other ecosystems. Areas highlighted with diagonal lines have waters with special importance (Ramšak, et al., 2022).

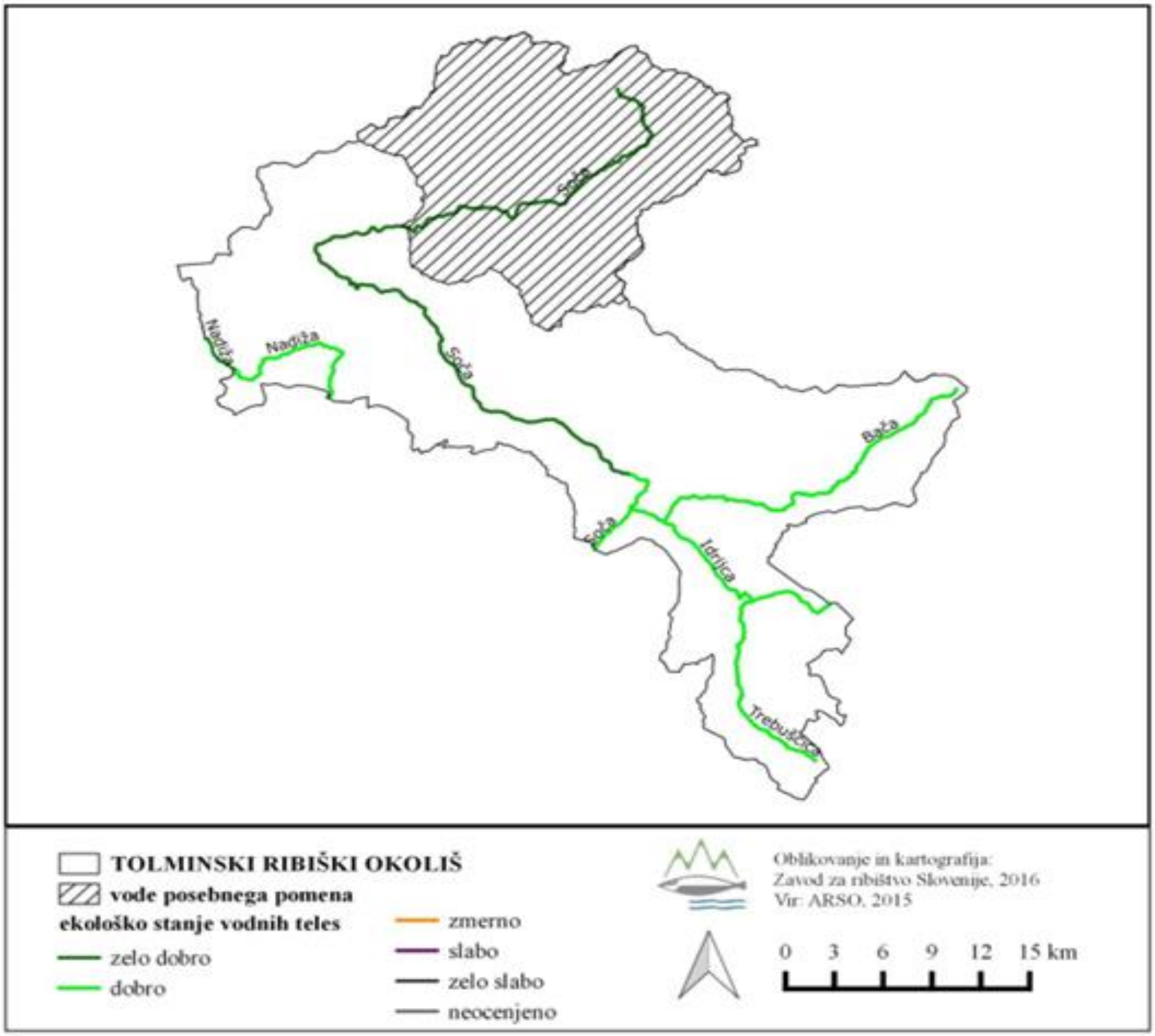


Figure 22: Assessment of the ecological status of surface water bodies in the Tolmin Fishing District (ARSO monitoring data, period 2009-2015). Rivers highlighted in dark green have very good ecological water status. While rivers highlighted with light green have a good ecological water status. Areas highlighted with diagonal lines have waters with special importance (Ramšak, et al., 2022).

With the drafting of the conservation plan, the growth of Marble trout had risen. After months of artificially breeding trout by local farms and its distribution along the Soča River, spawning

`

grounds (Figure 23) had begun to grow throughout the river. They stand as an important habitat for the reproduction of rainbow and marble trout. Local fish farms continue to breed the Marble and Rainbow trout to later pass it off to the Tolmin Angling Club to distribute them into the Soča River. Eric Sivec from the Kobarid Fish farm and Stas Ivancec from the Tolmin Fish Farm were interviewed. Both farms breed Rainbow and Marble trout for the purpose of conservation and fishing. The Rainbow trout eggs are female and sterile and are imported from Seattle, Oregon. This is because Oregon is home to numerous hatcheries that specialize in breeding trout. But these species are invasive to Soča River and while they adapt well, it is crucial they do not overpopulate. For this reason, they are sterile when imported. On the other hand, marble trout that are bred are exclusively genetically pure. Sperms from pure marble trout are extracted from the wild, and are bred only once and released back into the Soča River.

Both fish farms have around 15 pools that are kept within 10-11°C (283K-284K) and a 7½ and 8½ pH. The pools are built to hold 1½ m of water, if the pools are too deep it would be hard to catch the trout and if it is too shallow, water temperatures can rise, both negatively affecting the trout. Distribution of the trout population by the Tolmin Angling Club happens 1) at the beginning of trout season (March/April) 2) when they notice a decline in the species' population. The report written by the Slovenian Fisheries Institute presents a map view of the Marble (Figure 24) and rainbow trout (Figure 25) distribution along Slovenian Rivers. Though bred for conservation, marble trout can also be caught by fishermen, but many opt for the rainbow trout due to its easy visibility (Figure 6). Unfortunately, over the years, there has been a significant decline of the Marble trout catch (Figure 27), while the Rainbow trout (Figure 28) has had a steady gradient. A main cause of concern for the decline of the Marble trout catch is the irregularity of the food chain. Otters are expert hunters and love to catch the Marble trout. In the

`

Lepena and Vipava region, there is an overabundance of them that hunt the majority of the Marble trout. The Marble trout are also easily scared, and with the increase in water sports activities in the Soča Valley, they tend to hide near large boulders or close to fallen trees, making them harder to catch.

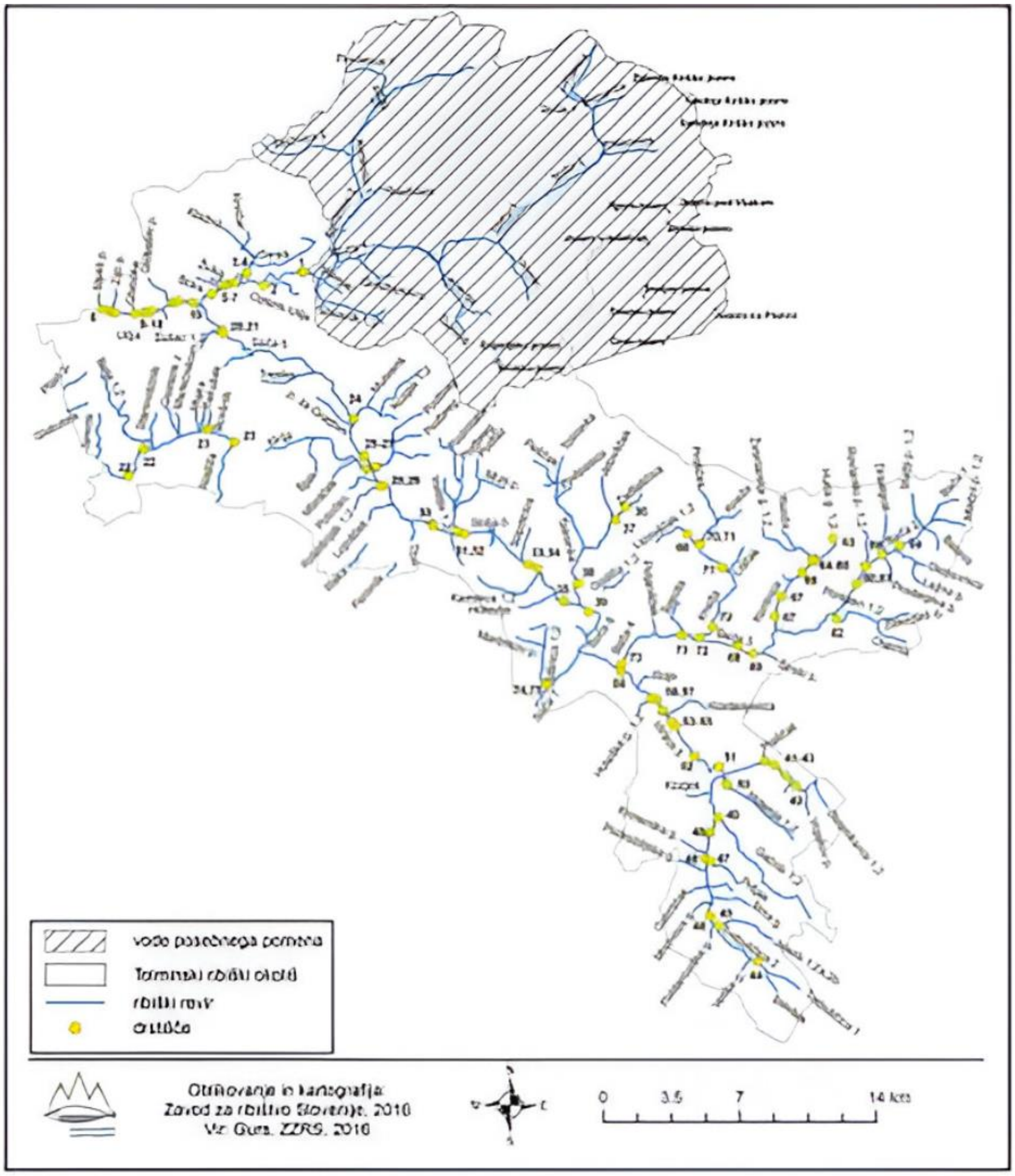


Figure 23: Spawning grounds of the Tolmin fishing district. These are important locations for the reproduction of trout. Areas highlighted with diagonal lines have waters with special importance (Ramšak, et al., 2022).

`

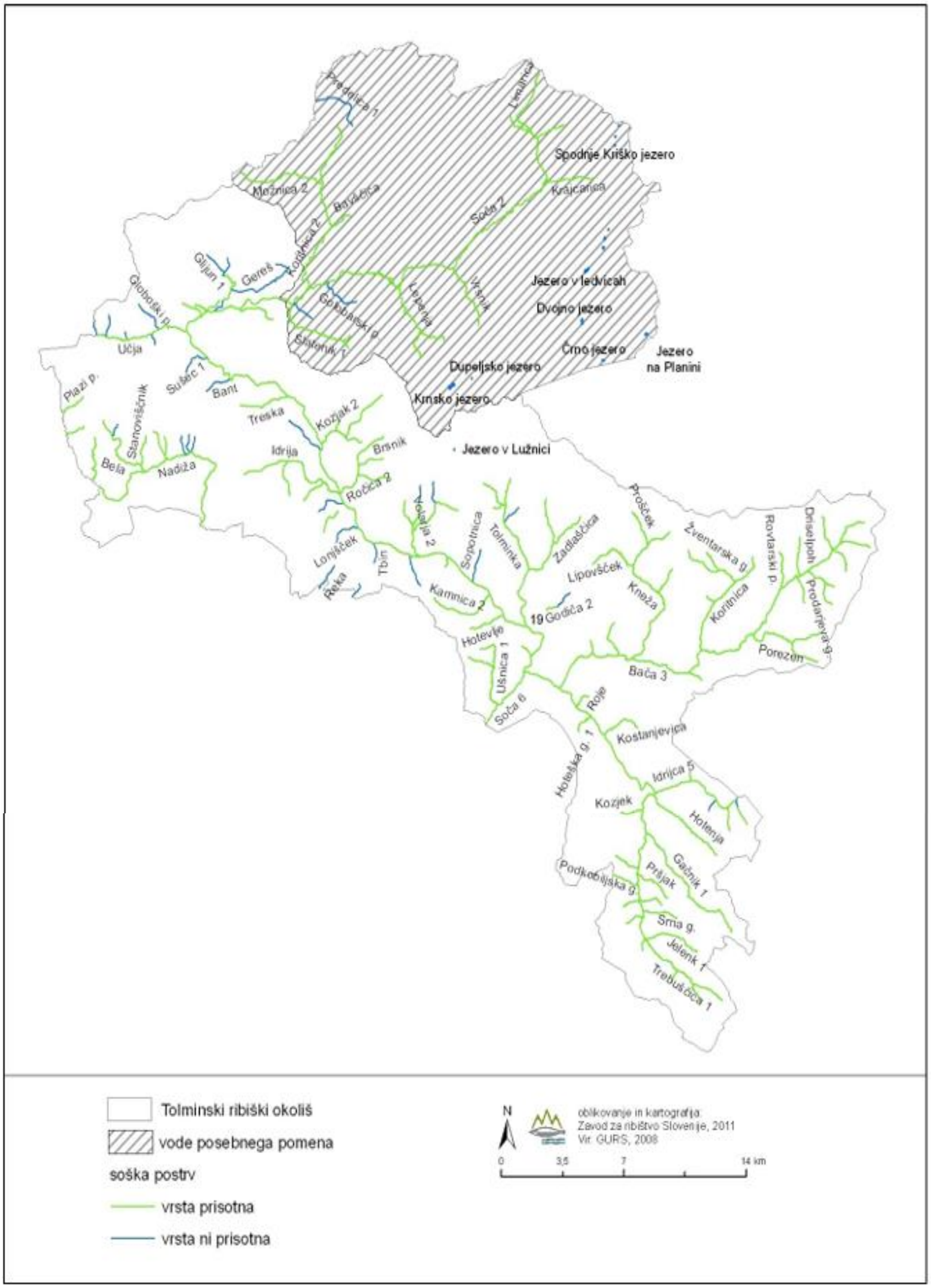


Figure 24: Distribution of Marble trout in the Tolmin fishing area. It lives in the Soča and Idrijca rivers and their tributaries. Green lines reveal where the trout species are present and blue lines reveal areas where they are not present. Areas highlighted with diagonal lines have waters with special importance (Ramšak, et al., 2022).

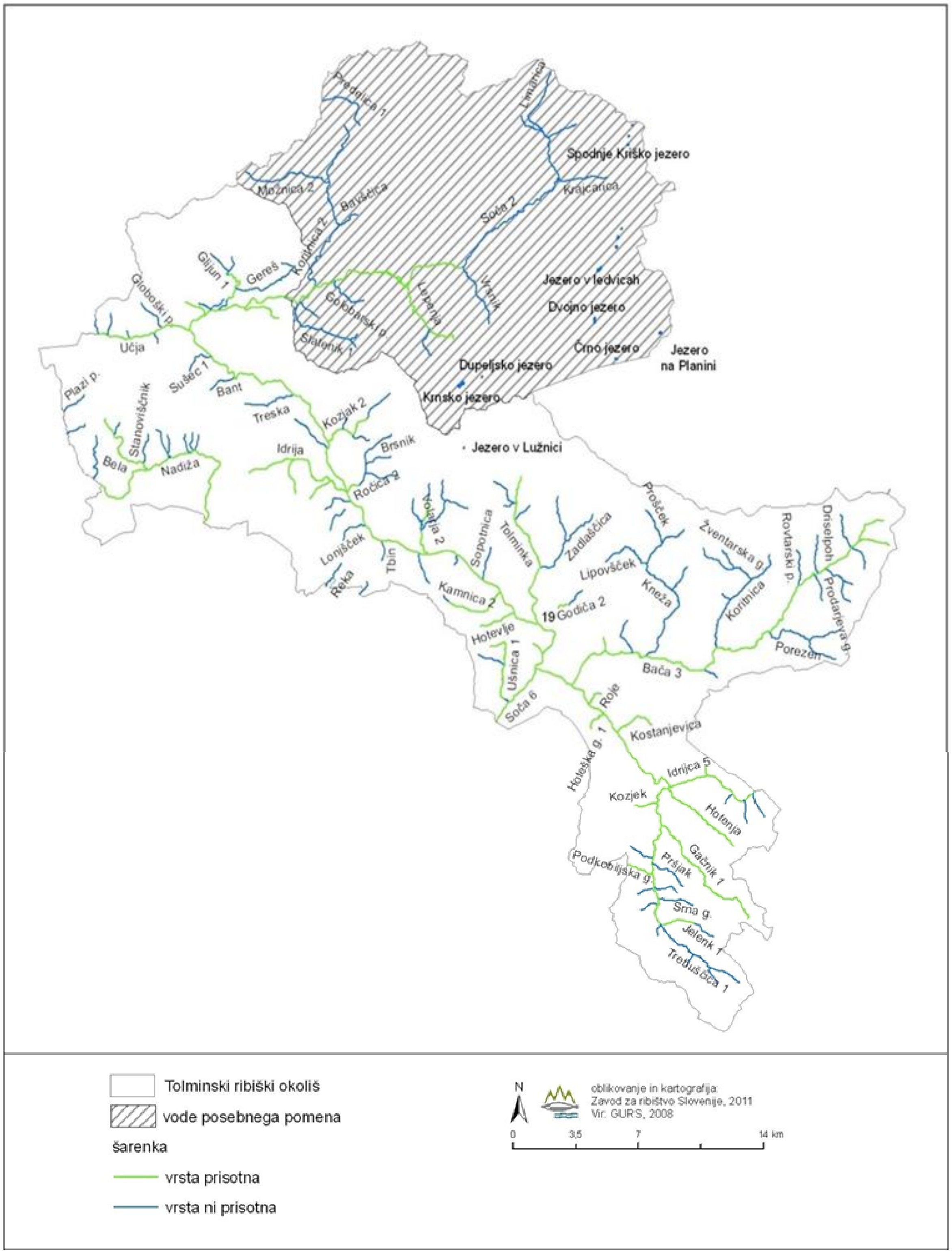


Figure 25: Distribution of rainbow trout in the Tolmin fishing area. It is spread throughout Soča, Učja, Nadiža, Idrijca rivers. Green lines reveal where the trout species are present and blue lines reveal areas where they are not present. Areas highlighted with diagonal lines have waters with special importance (Ramšak, et al., 2022).

`

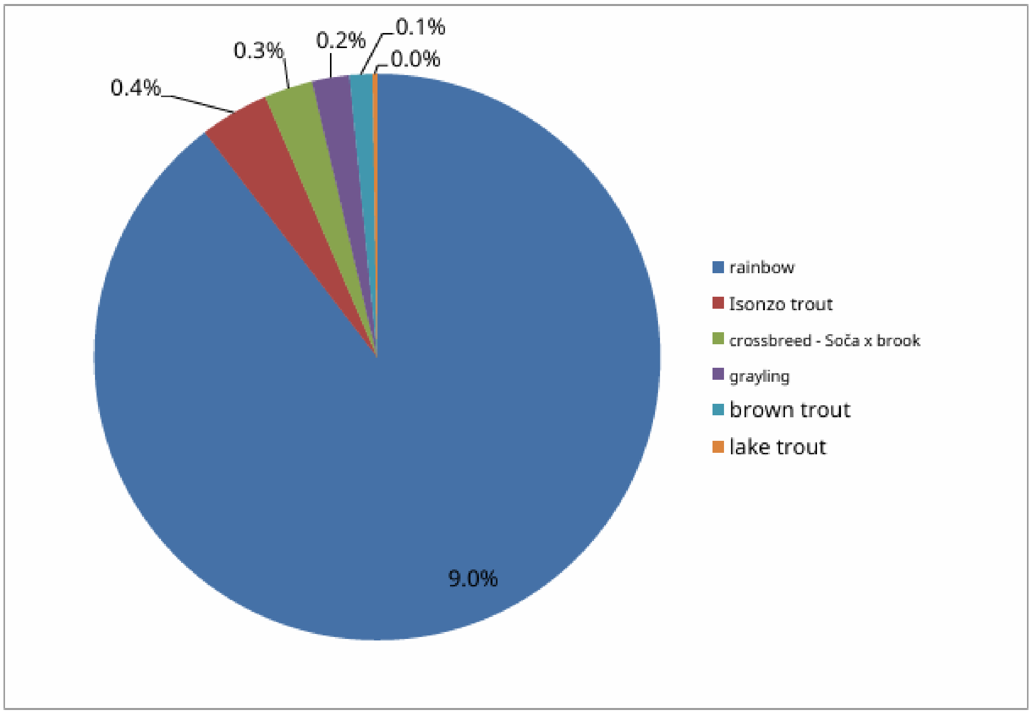


Figure 26: Shares of individual species in the average annual catch (kg) of salmonids in the period 2000-2014 along Slovenian rivers. 89.9% of the fish caught were Rainbow trout and only 3.9% of it was the Marble trout (Ramšak, et al., 2022).

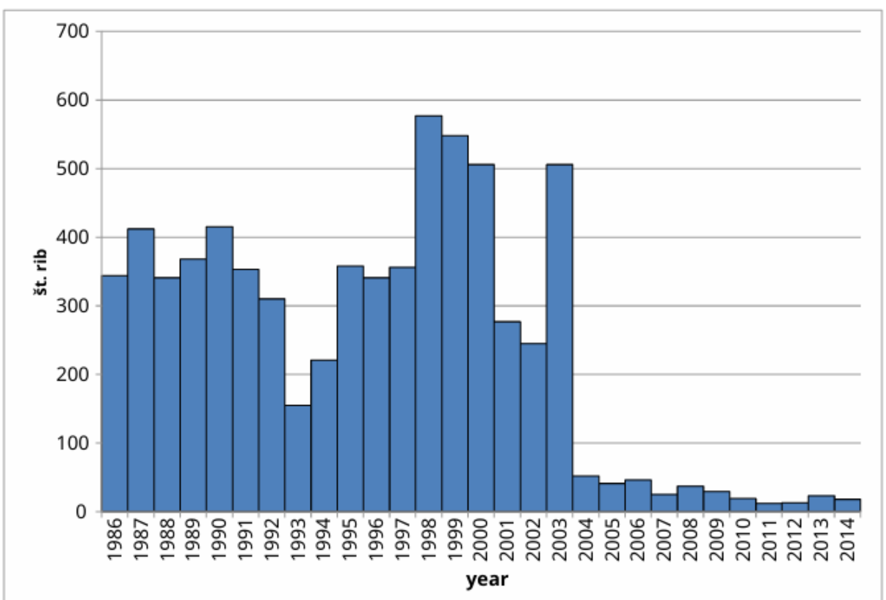


Figure 27: Catch (number of fish) of Isonzo (marble) trout in the period 1986-2014 along Slovenian rivers. After 2003, the catch decreased significantly, and the average annual catch from 2004-2011 was only 32 fish (Ramšak, et al., 2022).

`

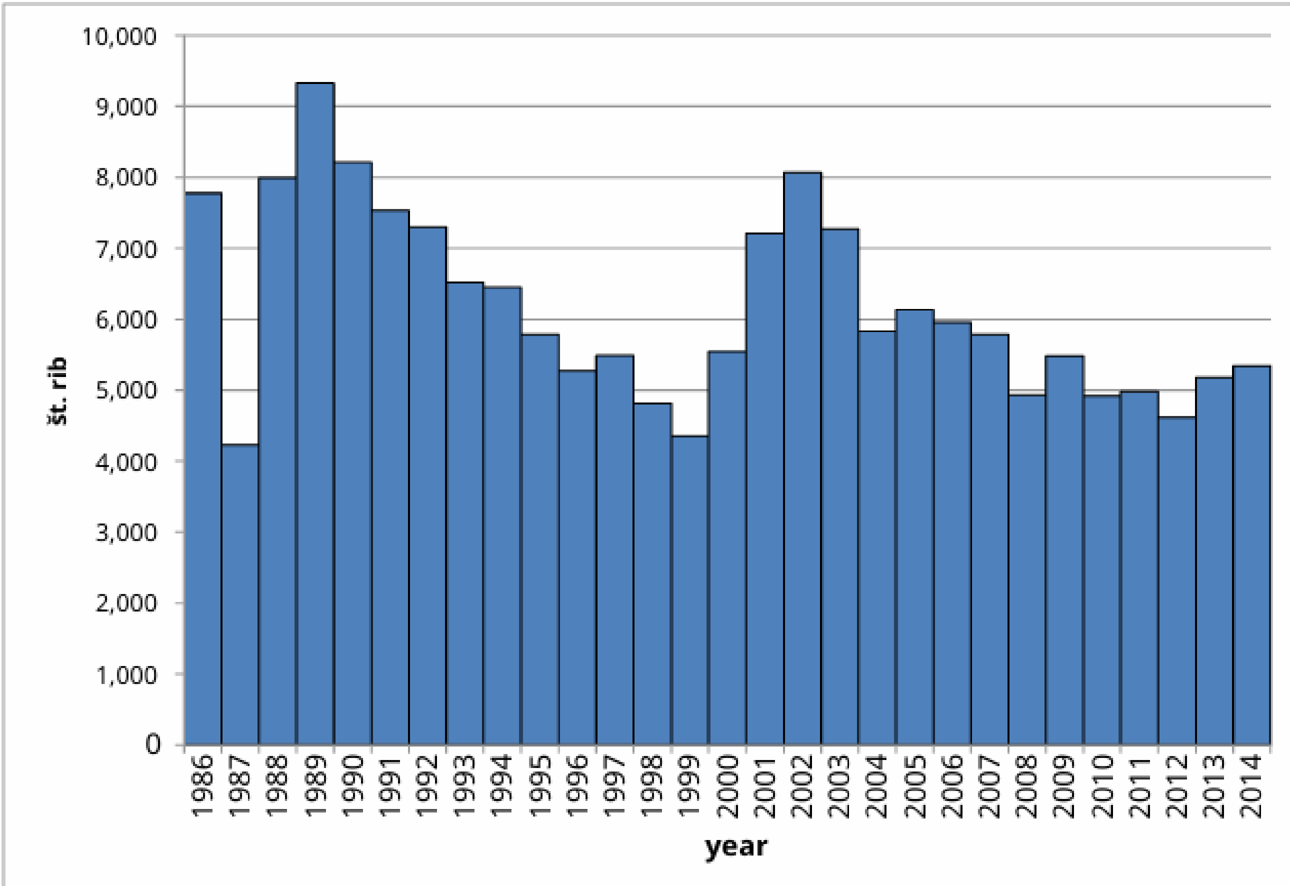


Figure 28: Rainbow trout catch (number of fish) in the period 1986-2014 along Slovenian rivers. From all the salmonid species in Slovenia, the Rainbow trout is caught most often (Ramšak, et al., 2022).

Integrating the interview answers, a section of the Soča River was highlighted as the region of study (Figure 5) in Google Earth Engine. Trout populations are closely linked to water temperatures, and thrive in cold waters. Using satellite imaging, land/water surface temperatures of the region throughout the year (Figure 29) and during harvest months were obtained (Figure 30).

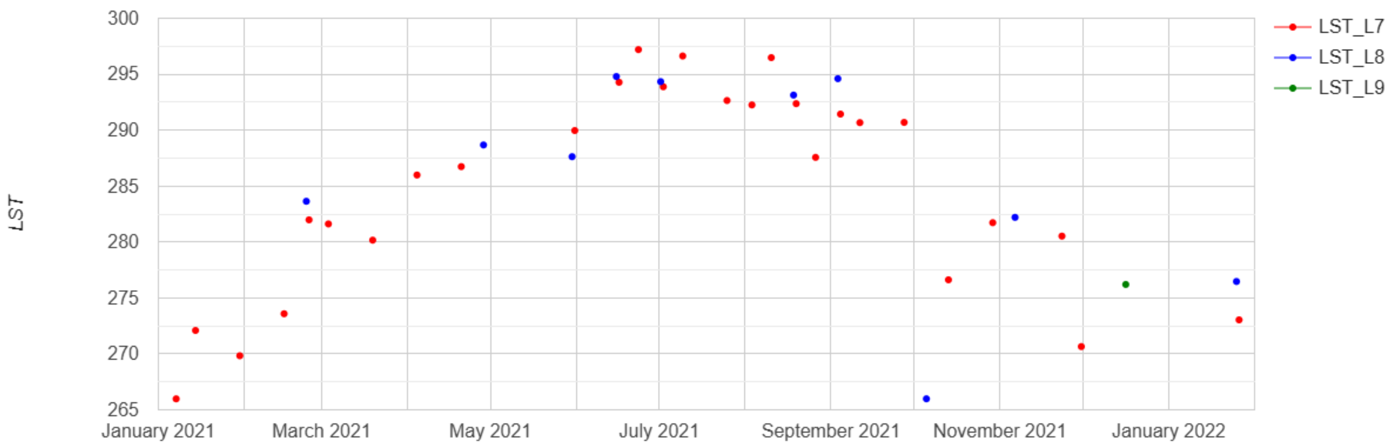


Figure 29: Above is the land Surface temperature (LST) of Soča River from Čezsoča to Tolmin from January 2021 to January 2022 using Google Earth Engine.

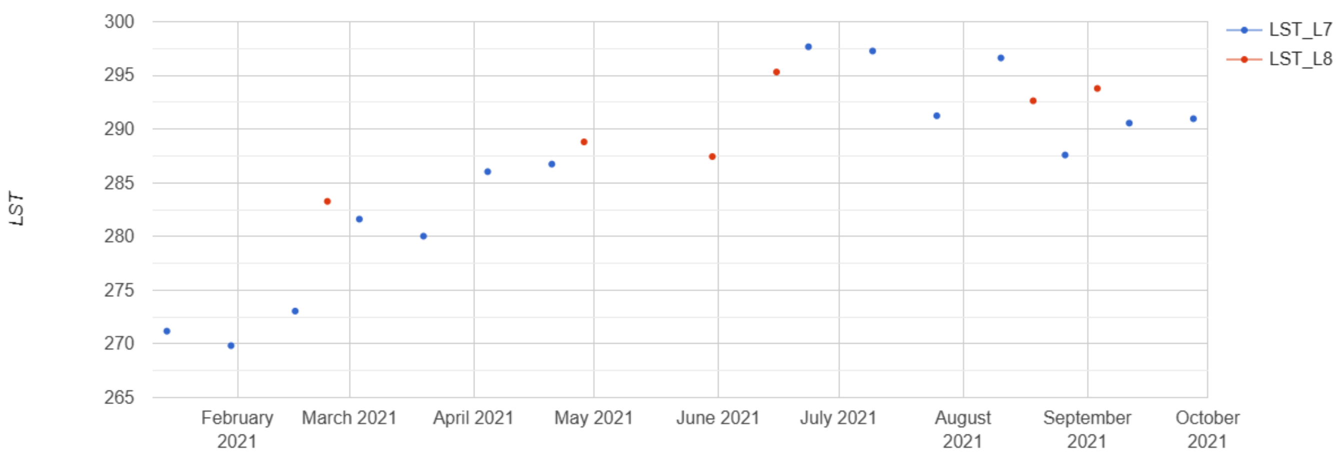


Figure 30: Above is the land Surface temperature (LST) of Soča River from Čezsoča to Tolmin during harvest months using Google Earth Engine

`

Chapter IV: Discussion

4. 1 Interpreting geological findings

The results of this study demonstrate correlation between glacial geomorphology on the formation of the Soča River valley and its ecosystems. The glacial activity that took place during the Late Pleistocene period, is evidenced by both the reconstructed historic (Figure 7) and modeled ice extents (Figure 8) that shaped the mountain regions and valleys of Slovenia. In addition to this, these geological features such as alluvial terraces and moraines have produced distinct soils and vegetation. The connection between geological history and present-day ecological structures provide a critical understanding for the distribution and conservation of the Rainbow and Marble trout.

During the late Pleistocene period, glaciers formed an ice cap over parts of the Julian Alps and extended beyond the Triglav national park. Figure 7 reconstructs this ice extent, with certain limitations. During the Quaternary tectonic activity, fluvial erosion and mass movements of sediments eroded away most of the glacial sedimentary successions in some areas, so the maximum extent of the glacial ice (Figure 7) was reconstructed from limited geomorphological evidence (Bavec, Verbič, 2011). The modelled ice extent (Figure 8) displays excessive ice cover in the Eastern Alps, with glaciers extending tens of kilometers beyond the mapped ice limits (Seguinot et al. 2018b). With much of the landscape being influenced by glaciers, landforms such as moraines and alluvial terraces cover the regions. Most of Čezsoča is an alluvial Terrace (Figure 9), that is assumed to have appeared during the Holocene period. According to the GeoZS software, this region is a valley- contained surface consisting of a long, narrow and gently inclined landform bounded along the lower edge by a steeper descending slope or tread, and along the higher edge by a steeper ascending slope. There are a couple of moraines that have

`

been preserved fairly well, which appeared during the last glacial maximum period (GeoZS, 2023). On the other hand, Kobarid is situated on a floodplain (Figure 10). Though the sediments that build this landform are alluvial, the landform itself is constructed largely by the flow regime of the present river thereby subject to flooding. Few geologists have predicted that the Soča glacier reached as far as the town of Tolmin during earlier Pleistocene glaciations (Bavec, Verbič, 2011), thereby strongly influencing its glacial landscape (Figure 11). Tolmin is located on an alluvial fan, built on both alluvial and glaciofluvial sediments, that was deposited during the late glacial period. Northwest of Tolmin is a moraine that shows signs of degradation, but its morphology can still be recognized (GeoZS, 2023).

Following the interpretation of glacial maps, the analysis shifts towards geological structures that further define the landscape of the region. In response to this, geological maps provide a crucial layer of information on the earth's composition that have contributed to these landforms. Diving into the geological maps of Bovec – Kobarid (Figure 12), Čezsoča consists of gravel and sand (Figure 16) that were deposited during the Holocene period. Alluvial terraces are formed by river erosion, so they vary in grain size, composition, and thickness. Both they mostly contain outwash or glacially derived sand and gravel. Areas like this form some of the most productive water-bearing units in the world (Cheremisinoff 1997). Moving south of map (Figure 12), Kobarid is surrounded with thick bedded limestone that was deposited during the Upper Triassic period and river terraces that opened during the Pleistocene period. There are also areas of gravel and sand that were deposited during the Holocene period. River terraces are formed when a floodplain is abandoned due to channel incision or downward erosion (Gkouma 2023). It would also explain the presence of gravel and sand. Looking back to the regional geology section, Slovenia is not only categorized by glacial activity but also as a result of tectonic movement and sea-level

`

changes. Towards the end of the Oligocene Epoch, thick layers of bedded limestone were folded and partly overthrust due to crustal compression from the subduction of the African plate under the Eurasian plate. The geological map of Tolmin (Figure 13) shows that the region is surrounded with flysch and deep marine rocks that were deposited during the Mesozoic period. There are few areas with terrestrial deposits that were accumulated during the Quaternary period. The upper Tithonian and Berriasian of the Tolmin Basin are categorized by uniform sedimentation of limestone, a calcareous deposit typical in a deep-marine environment (Rožič and Reháková 2024). Sediments such as, calcareous breccia, calciturbidites, marl, shale, and chert were carried by erosional waters and deposited into the Tolmin Basin forming a Flyschoid Formation (Rožič, 2005). These sedimented layers formed on land are terrestrial deposits (Lancaster & Mountney, 2020), which would indicate why the soil type are rocky surfaces without soil (Figure 18). We see similar geological settings in the structural unit map of between Bovec and Kobarid (Figure 14). Kobaird is located on a thrust fault, with half the area covered by alluvial and till flysch and the other half with Upper Triassic Jurassic and Lower Senonian sediments. There is a strong presence of Cretaceous sediments, which are more pronounced, attributing to the stronger tectonic deformations of the seabed on which they were deposited (Kuščer, 1974). After the Last Glacial Maximum, much of the alluvial and till debris were deposited. And it has left a district brown soil on non-carbonate flysch and decalcified marl (Figure 17). Taking all this into account, the pH of the Soča River is neutral and, in some place, slightly alkaline. The region around Čezsoča, Kobaird, and Tolmin (that is close to the Soča River) is surrounded by limestone and calcite sediments. This creates the slightly alkaline environment in the Soča River and its tributaries.

`

The topography of study regions is relatively low with an elevation of 150m – 400m (Figure 15). Glaciers strongly impact relief production and relief reduction (topographic changes) in landscapes (Brocklehurst et al., 2007). The Pleistocene glaciers that covered central parts of the Julian Alps, Kamnik Savinja Alps and Karavanke Mountains drained into foreland along the glacial/fluvial valleys. In result, the relief in Slovenia is low compared to other parts of the Alps. Only few mountains in Slovenia exceed 2800 m but the valleys and basins are situated as low as 200 m (Bavec, Verbič, 2011). Forests are the dominant landscape in Slovenia, with around 58% of it covering the country (Tend, n.d.). A good indication of this can be seen on the vegetation map (Figure 19). Čezsoča is currently primarily pastoral land but surrounded by broad-leaved forest. There are also some dwarf pines and other highland vegetation (Figure 20). Kobaird is a small urban town but also holds lands that are principally occupied by agriculture with also significant areas of natural vegetation (Figure 19) and pastoral land (Figure 20). Tolmin, though very similar to Kobaird, also has few hectares of beech, chestnut and oak. Beech forests are common in Slovenia and they are the most frequent naturally occurring tree. According to Blaž Repe's and Matej Blatnik report on the vegetation of Slovenia, "beech trees in various forms are absolutely dominant. On non-carbonate bedrock, mostly in central and northeastern Slovenia, these are acidophilic beech groves with deer fern (Blechnum spicant) and sweet chestnut (Castanea sativa), often mixed with Scotch pine (Pinus Sylvestris). On carbonate bedrock, the lowest lying is submontane beech forests with hop hornbeam (Ostrya carpiniflolia)." Along the Soča river, it is heavily vegetated with these beech trees (Figure 20), which would in turn provide shade for the aquatic species flowing through the waters.

`

4.2 Interpreting ecological findings

Just as geological maps uncover the deep history that shaped the landscape, ecological maps provide a complementary view of the region's rivers and tributaries. The Tolmin Angling Club operates on the banks on the Soča River (*V Osrčju Divje Soče - Tolmin*, n.d.). They are a community of dedicated fisherman, and river rangers. Using their expert knowledge, the Slovenian Institute of Fisheries published a report to guide fishermen and fish farmers. Various maps about the rivers and tributaries are presented in this report. Figure 21 displays an overview map, showing areas that, in accordance with nature conservation regulations, have special status – natural values. The term 'natural values' "encompasses geological phenomena, minerals, fossils and their deposits, surface and underground karst phenomena, underground caves, gorges and narrow and other geomorphological phenomena, glaciers and forms of glacial activity, springs, waterfalls, rapids, lakes, bogs, streams and rivers with banks, the sea coast, plant and animal species, their exceptional specimens and their habitats, ecosystems, landscapes and formed nature" (Ramšak, et al., 2022). Unfortunately, there aren't a lot of places within the region of study that have these natural values. One way to interpret this, is that the whole region could be considered as a natural phenomenon, so perhaps, smaller, specific areas may not be singled out for special status. Another assessment was done to scale the ecological status of surface water bodies. Looking at Figure 22, Soča Bovec – Tolmin show a very good ecological status for the period 2009-2015. And according to the hydro morphological elements, the river also has a really good status. But this "assessment does not include a biological element -fish, because an evaluation methodology was not developed for it" (Ramšak, et al., 2022).

Spawning areas refer to geomorphologic areas in marine environments where aquatic animals aggregate to spawn (Heyman & Kobara, 2011). Examining Figure 23, there are around 12

`

spawning grounds within the region of study. These areas are dependent on the geological base, relief, precipitation and water flows. And trout adapt to this and locate micro locations for spawning that are suitable for laying eggs (Ramšak, et al., 2022). Marble trout are lithophilous spawners. According to the Slovenian Institute of Fisheries report, "the spawning grounds of lithophilous spawners, fish species that lay their eggs on rocky or gravel substrates, are located under different heights of natural or constructed levels, where a suitable structure of the bottom substrate is formed and the speed and depth of the water are suitable for laying eggs. Such spawning grounds are more or less permanent (translated from Slovenian)," There are locations with permanent spawning grounds, in narrower areas of river dunes, where the width of the riverbed and an inclined slope causes a decrease in water velocity and transport capacity of the watercourse, thus causing river sediments to deposit and form river dunes. In tributaries and smaller watercourses, the marble trout spawn there in pairs. An ideal environment are areas with suitable substrate, speed and water depth, though none of the areas are a permanent spot due to the changing dynamics of the hydrological conditions during the spawning period (Ramšak, et al., 2022). It is imperative to know that Rainbow trout do not spawn naturally. Since the Rainbow trout are an invasive species to the Soča River, fisherman and the Angling Club only introduce them if they are sterile. Establishing the spawning grounds, we can move towards the distribution of the Marble (Figure 24) and Rainbow trout (Figure 25) along the region of study. The Marble trout are widespread throughout the Slovenian waters. It is located both in Soča and Idrijca rivers as well as their larger and smaller tributaries. On the other hand, the Rainbow trout is only located in the fishing grounds of the Soča, Učja, Nadiža, Idrijca rivers and their larger tributaries such as the Trebuščica and Bača (Ramšak, et al., 2022).

`

With the spawning grounds established, we now analyze the data on trout species caught to understand the population dynamics. The catch records provide crucial insight on the success or failures of the conservation methods taken for the Marble and Rainbow trout. Figure 26 shows the average annual catch (kg) of salmonids in the period 2000-2014. Data collected from the report tells us, “that largest share in terms of the mass of fish caught in the catch of salmonid fish species in the period 2000-2014 was rainbow trout (89.6%), followed by Isonzo trout (Marble trout) (3.9%), a cross between Isonzo and brown trout (2.8%), grayling (2.1%), brown trout (1.3%) and lake trout (0.3%).” The Marble trout are considered to be difficult to catch, which could be one of the reasons why the number of Marble trout caught (Figure 27), has significantly decreased over the years. According to the report, from the period 1986-2003, the average annual catch of Isonzo trout was 369 fish but after 2003 the catch decreased the average annual catch from 2004-2011 was only 32 fish. Figure 27 shows that the largest catch was recorded in 1998 (577 fish), and the smallest in 2011 (12 fish). On the other hand, there is a steady gradient of the Rainbow trout catch in the period 1986-2014 (Figure 28). Of all the trout species caught, the rainbow trout is the highest, where the average annual catch was 6,147 fish weighing 3.4 t. And the largest annual catch was recorded in 1989, with around 9,323 fish weighing 3.6 t, and the smallest in 1987, with 4,228 fish weighing 1.4 t (Ramšak, et al., 2022).

Beyond the static geological and ecologic maps, it is also imperative to understand the physical conditions of the Soča river. To answer the second research question, an analysis of the Land Surface Temperature (LST) of the Soča River was conducted from January 2021 to January 2022 using Google Earth Engine. The data provides insight into the temperate conditions of the river, which directly impacts the health and growth of trout populations. The results reveal that the trout species thrive in cold waters. Data from Figure 29 show a drop with the lowest temperature

`

in January (266K/-7.2°C) and the highest temperature in July (297K/23.9°C). Throughout the year, the temperature gradually increases and decreases. In an interview with Tomaž Modic (a member of the Fisheries Research Institute of Slovenia), an ideal temperature would be around 283.2K (10.0 °C) to 288.2K (15.0 °C), so 297.1K (23°C) is pretty high for the trout. A lot of factors could be the issue: loss of riparian vegetation, introduction of dams and the fluctuating climatic temperatures.

Both the Tolmin Fish farm and the Kobaird Fish farm, keeps their pools around 10.0 °C - 11°C. Waters are supplied through springs for the Kobarid Fish Farm and from melted snow and rainfall 15kms away for the Tolmin Fish Farm. Both these water sources provide the ideal temperature and pH (7 ½ - 8 ½) for the Marble and Rainbow trout breed and grow. Harvest or fishing season falls February till the end of October, though many opt to do it from April to September, when the waters are not too cold. Figure 30 projects the surface temperature of Soča River from Čezsoča to Tolmin during harvest months using Google Earth Engine. Since the data is collected on a more selective period, the numbers are more precise compared to Figure 29. Based on the ideal fishing/harvest period, water temperatures are around 286K (12.9°C) in April and go as high as 297K (23.9°C) in July and a small drop to 287K (13.9°C) in September. But there are concerns of temperatures gradually rising. When the temperature is high, it exhausts the fish which could make it easier to catch but it can also reduce their feeding activity. The trout are less active and instead of feeding, they attempt to conserve their energy, thereby hindering their growth rates (Ncfga, 2025).

4.3 Implications of the research

Based on the findings, a strong correlation between the geological history of the Soča River valley in shaping the ecological habitat of trout species, can be drawn. The glacial period that

`

took place many years ago carved the landscape and provided the diverse landforms for the trout to thrive. These geological foundations directly influence the river's physical characteristics, in specific, the mineral composition, pH and water temperature of the Soča River. By integrating data on nature conservation regulations, spawning grounds, species distribution, and catch records, it will provide concrete evidence of the trout populations' reliance of the geological landscape. The following discussion will interpret these integrated findings to answer the two research questions.

In a fieldwork expedition with Nejc (a local fisherman from the Tomin Angling Club), areas where the Marble trout spawn, where both the Rainbow and Marble trout are being reintroduced, and where local fishermen fish were examined along the Soča River. The Rainbow trout don’t spawn and are sterile when they are introduced into the Soča River. Four areas were visited, where the Marble and Rainbow trout are introduced in the Soča River. In these locations (Figure 31) (Figure 32), the water flows in a laminar current, and the width of the river is much larger, giving more room for the trout to swim. These areas also have good access for the van to reach as close to the banks of the river to introduce the trout. And the fishermen usually stock the

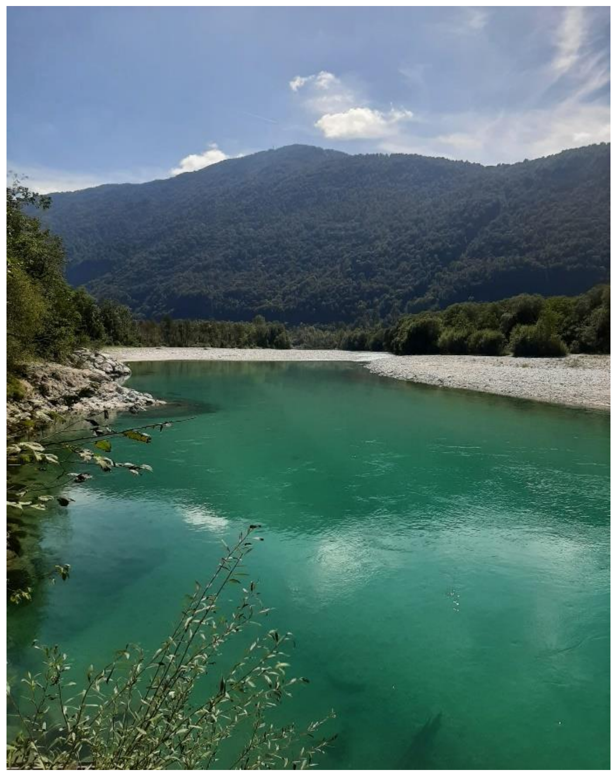


Figure 31: River located in Bečje. The Tolmin Angling Club along with the local fishermen introduce around 200-300kgs of Rainbow trout and couple kilos of Marble trout here.

`

trout when water levels are high so that the trout, especially the Rainbow, can swim easily downhill. But areas inside the Triglav National Park are only reserved for the introduction of the Marble trout. These areas are located in gorges, with water coming from karst aquifers.

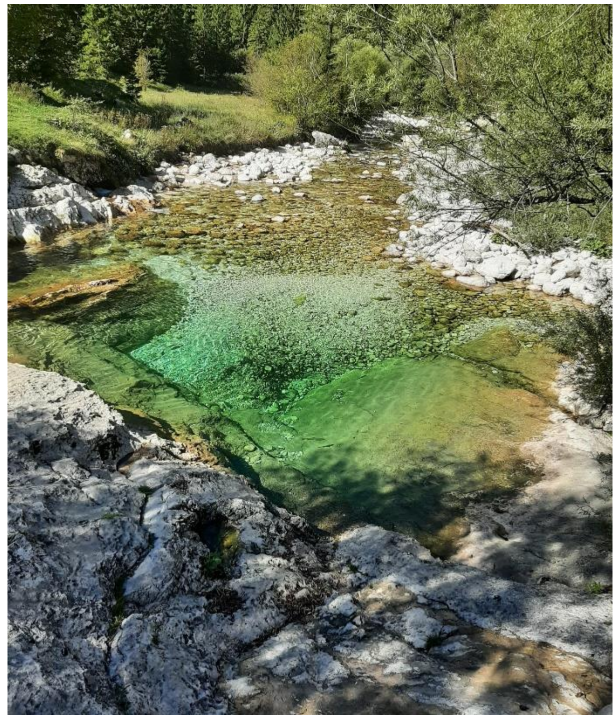


Figure 32: River located in Lipina. The Tolmin Angling Club along with the local fishermen introduce both the Rainbow trout and the Marble trout here.

The Marble trout spawn after the fishing period (in the beginning of November) and generally last for about a month (Claudio et al., 2018). The Marble trout spawn in shallow waters with laminar current. A lot of the spawning areas had similar characteristics. They were surrounded with large boulders and on the banks of the river there were Black Willow trees *(črna vrba)* and other vegetation (Figures 33) (Figure 34). The river beds were covered with pebbles and with little to no sand between them so that the trout can move more easily. "Strong currents may limit embryonic survival by damaging or displacing eggs" (Fitzsimons & Marsden, 2014). "The deposition sites are located in shallow water (60 - 80 cm), with a substrate characterized by pebbles and gravels and with a stream of about 0.4 - 0.5 m / s. Each female lays an average of 1,700 - 2,800 eggs per kg of weight, with a diameter of about 5 - 6 mm and an orange or yellowish color" (Claudio et al., 2018). "Embryonic development requires a relatively long period depending on the temperature of the water (about 40 days at 10 ° C)" (Claudio et al., 2018). Looking at the analysis of Land Surface Temperature (LST), water surface temperatures

`

during the first couple of days of the month of November can range from 286.6 K (13.45 ° C) to 279.9 K (6.75° C). Fishing season starts from the first week of January to the end of October, with temperatures ranging from 273.0 K (-0.15 ° C) to 305.0 K (31.9° C). Local fishermen also fish in spawning areas. Looking into Figure 23, it shows the numerous spawning grounds along the Soča River. Since both the Marble and Rainbow trout migrate in small distances, they are distributed (Figure 24) (Figure 25) quite close to their spawning grounds. After the spawning period, the spawning beds, or redds, become the prime location for the trout to hunt for food. Leftover eggs that have been displaced or not buried properly become a readily available protein food source (Swentosky, 2024).

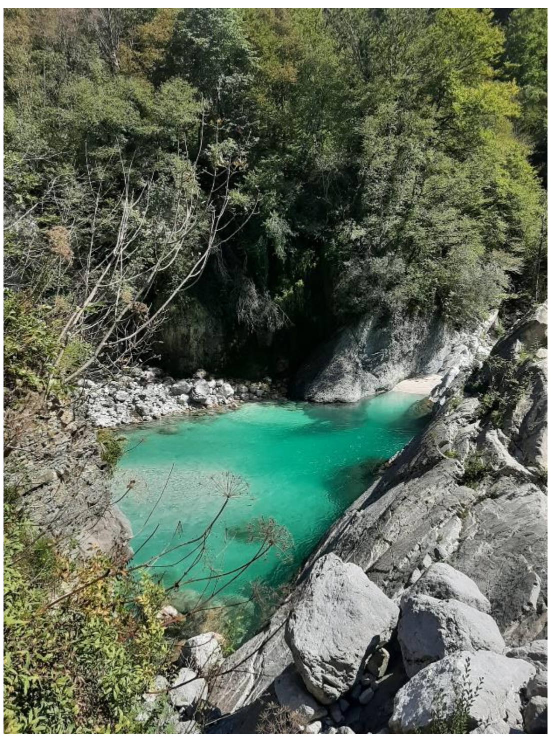


Figure 33: River located in Otona. A lot of the Marble trout come here to spawn during the season. The area is surrounded with vegetation and large boulders and the river floor is covered with pebble substrate.

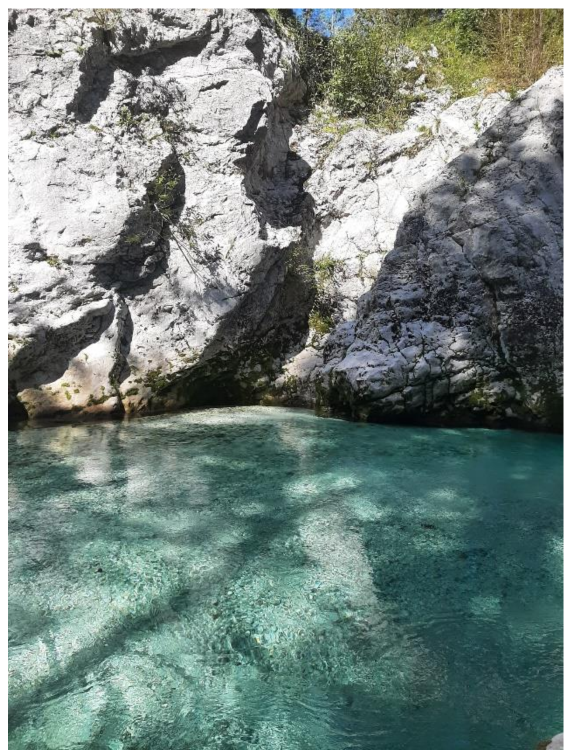


Figure 34: River located in Velica Korita. This area is surrounded by gorges. Marble trout are found spawning here during season.

`

Analyzing the geological characteristics of the regions around the Soča Valley, we confer that the valley's landscape is influenced by the product of glacial activity during the Late Pleistocene period. A large section of glacial till was found about 300 m above the modern Soča river, 3 km north of Tolmin (Bavec & Verbič, 2011). Landforms such as alluvial terraces and moraines, that cover regions like Čezsoča and Tolmin, are deposited by both river erosion and glacial melt wash. These landforms are now described as, "some of the most productive water-bearing units in the world." These self-sustaining natural wells and springs provide the perfect water environment for the Marble and Rainbow trout to grow. We see evidence of the direct impact of meltwater from retreating glaciers, from the glaciofluvial sediments surrounding Tolmin. These sediments are also prone to build floodplains (as seen around Kobaird) due to the flow regime of the present river. But in an interview with Eric, it was mentioned that the roots from the riparian vegetation is also useful in protecting the soil from erosion at the Soča Valley (Figure 35). The roots form a web that physically binds soil particles making it harder to erode away (Smith et al., 2020).

Figure 35: Located in Otona, the picture shows a cross-section view of the soil. Medium -sized rocks and small rocks are accumulated within the soil. Thin, long strands of the plant's roots are visible.

The Flyschoid Formation (surrounding Tolmin), that is composed of calcareous breccia, calciturbidites, marl, shale, and chert, create to the rocky surfaces without soil in the area. This is both a key physical feature of the riverbed where the Marble trout spawn. One of the downsides of this landscape is that it is also prone to heavy rockfalls. Doctor Klemen Teran had stated that this is a common occurrence in the Soča Valley, as a result of its steep slopes and intense seismic activity. Examples of it are seen in Figure 36 and Figure 37. Land sliding not only changes morphology of the terrain but quite often produces sediments that reach the fluvial network (Mikos et al., 2005). The sediments moved by the landslide are often deposited directly into nearby rivers, and tributaries. In essence the Soča Valley's landscape is a direct reflection of its glacial and tectonic history, still living.

Figure 36: Kekec rockfall that occurred in 2007.

Figure 37: Polog rockfall in the Tolminka valley that occurred in 2004.

The widespread presence of limestone and calcite sediments in the Soča Valley produces slightly neutral/ alkaline ph. This chemical environment is a direct result of the valley's rock

`

composition. In an interview with Blaž, we interpret that this mineral composition and pH could definitely provide a stable and supportive environment for trout growth, reproduction, and survival. In his words, "trout in mineral-balanced rivers show better growth rates, stronger bones, and more efficient metabolic functions. This partly explains why marble trout can reach very large sizes (recorded over 20 kg), which is exceptional compared to trout in more mineral-poor alpine waters." Another important factor of rich-mineralized waters is its influence on primary producers. Single-celled algae, called diatom, are affected and in fact thrive in hard, mineral-rich waters with high calcium concentrations (Ouyang et al., 2018). Vegetation riparian areas act as a buffer between waterways and agricultural land (Kobaird) that can intercept nutrients (O'Toole et al., 2018). Their roots are deep enough to absorb nutrients like nitrogen and phosphorus, thus balancing the mineral composition of the Soča River. In the interview with Eric, it was mentioned that too much nitrogen dissolved in the waters can affect the trout. So, having riparian vegetation helps regulate the amount of nitrogen in the river by converting it from a dissolved form into organic matter (Zhao et al., 2024). Primary producers such as algae, diatoms, and macroinvertebrates (mayflies, caddisflies, stoneflies) are the food for both the Rainbow and Marble trout. While there isn't any concrete scientific proof, it is possible to confer that in the Soča, the combination of clear, oxygen-rich water and balanced minerals support abundant benthic invertebrates, allowing trout to grow relatively large compared to populations in poorer streams (Močnik, n.d). Oxygen-rich water is also important for the development of trout eggs. The Marble trout uses its tail to create small holes in areas of pebble substrate to lay its eggs. Even though they are covered to protect them from predators, the waters are well oxygenated, so the eggs can grow and not suffocate.

`

In relation to temperature, the water accumulated in the Soča River flows from a cave with a small subterranean lake, through a narrow gorge (DOO, n.d.). Unlike surface lakes, subterranean lakes are located deep enough so they are continually insulated by soil and rocks and not open to solar heat (Milena, 2025b). The glacial history of the Soča Valley created low-relief landscapes that help moderate water temperature via groundwater discharge from lowland deposits (O'Sullivan et al., 2019). This combined with the vast forest cover and the riparian vegetation, creates a shaded environment for the trout to travel and hiding spots from their prey. Riparian vegetation helps regulate water surface temperature. Incoming solar radiation decreases by up to 95% due to riparian vegetation (Kalny et al., 2017). This keeps the surface water temperatures cool, which is crucial for the Marble and Rainbow trout that thrive in cold waters. Looking back at the analysis of Land Surface Temperature (LST), temperatures in the Soča River can reach 23.9°C, which is considered high for trout, which ideally prefer temperatures between 10.0°C and 15.0°C. A lot of factors could play a role in this change of temperature, like: loss of riparian vegetation, straightening of rivers and even dam constructions.

`

4.4 Further research

In an interview with Eric Sivec (a fisherman from the Kobarid Fish Farm), a question was addressed. Apart from climate change, have there been any issues with the conservation practice of these trout species? Several reasons were listed: -

- temperature of the water have risen and it exhausts the trout
- tourists illegally fish and exploit the habitat
- we find more trash in river banks
- during the summer the Soča River is overcrowded so trout spend most their time hiding or swimming away in exhaustion
- trout spawn in the winter where the gentle snow aids their habitat but now it rains and destroys the spawning grounds.

While there are, in fact, both technological and regulated solutions for these problems, a deep concern that Eric had was the straightening of Slovenian rivers.

The Stržen watercourse had been altered many years ago. Locals within that region struggle to grow and provide food, so instead of having water in the lake, they altered Stržen's meanders into a straight channel to open up more land for agriculture (Urednik, n.d.). In Eric’s words, “Soča is one of them, but there are other rivers too that are affected. People everywhere want the water to disappear as soon as possible. One of the main reasons is flooding, which erodes land and agriculture. A few years ago, in Carsic Lake Cerknica, a project to repair the river started, and soon they were able to create back meanders again. But unfortunately, people ruined it, and then the government had to use a lot of money to repair the damage. Straight current is bad for everyone except humans.” Channelization or river straightening destroys the natural landscape of

`

a river system. Rivers with straight channels can deposit silt and other materials evenly on river beds, thus causing changes in invertebrate life and suffocation of trout eggs in spawning gravel. Moreover, the lack of variation in habitat negatively affects the different life stages for the trout - gravels for spawning, shallow areas for juveniles, and cover to hide from predators (Trust, 2020). Marble trout are known to be easily spooked, so they hide under rocks or fallen tree trunks. This trout species is also known to exhibit cryptic coloration, which helps it hide from its predators. When it swims in shallow river beds, it camouflages to a light pale limestone color, and when they are near large boulders, it camouflages to a brown color. This keeps them well hidden from local fishermen as well. But with the instance of river straightening, much of the vegetation and large boulders are removed, leaving vast areas of the water open and vulnerable to the Marble trout.

Based on these findings, a future study would concentrate on reintroducing natural channel design for the Soča River. The research would shift towards river engineering, which relies on natural processes and materials. River engineering falls under hydraulic engineering and combines subjects such as hydrology, hydraulics, and geomorphology. With river engineering, we can better understand that river beds can be eroded by the river flow or suspended sediment can be deposited onto the river bed (Hrissanthou et al., 2025), thus altering river channels. The question that will be tackled is: How can we naturally restore meandering river channels in a way that is resilient and engages the local community? And the objective will be to develop a practical solution for the Soča River restoration. The methodology will focus on these aspects:

- Historical Topographical Maps

`

This is an important source for understanding the topography of the river, vegetation cover and land use in the past centuries at a detailed scale and their changes (Cevasco, n.d.).

- Structured interviews

Interviews with local fishermen, members of the Tolmin Angling Club, and the Slovenian Institute of Fisheries will be conducted. Knowledge and locations about the river's changes will be recorded. The answers will help design a structured restoration plan that would help the local ecosystem and habitat.

- Vegetation and Soil Analysis

Riparian vegetation will be sampled and studied to evaluate riverbank stability. This vegetation (with roots) has profound effects on channel morphology, thus impacting total channel width, braiding index, and relative mobility of channels (Yu et al., 2018). In-site measurement and root samples will be recorded along the meandering channels of the Soča River.

- River Modeling

Stimulated river modeling systems such as Scalgo will be utilized for the restoration project. This software company provided detailed data and analysis to work with surface water challenges (*Let's Enter a Digital World Like No Other*, n.d.-b). By observing stimulated water flow patterns, we can predict how rivers evolve and then design a structured plan for the ecological restoration.

`

- Geological Maps

  According to a NASA report, sharp bends in rivers result in meanders. Research that was led by the UT Jackson School of Geosciences Bureau of Economic Geology found that the rate of river migration is directly linked to how sharp its bends are (Mtaylor, 2022). With the use of geological maps, we can directly link rock types with their rates of erosion. Many geological maps depict erosional features, though they usually focus on the solid geology beneath the surface (*Using Our Geological Maps | Earth Sciences New Zealand | GNS Science | Te Pū Ao*, n.d.).

This proposed research would provide a data-driven approach to a problem observed by local fishermen. Though issues like water temperature and policy management for tourism are important, Eric's concern for the straightening of rivers highlights a significant problem. Ecological principles strongly proclaim that channelization destroys essential habitats for all stages of a trout's life cycle, from spawning gravels to pools that provide cover from predators. With evidence at Carsic Lake Cerknica, the failure of a previous restoration effort highlights the need for a different approach- one that is both scientifically and communally driven. The research will show that restoring a river's natural meanders is not just an act of conservation but a long-term solution for the prosperity of the landscape and the community that lives within it. It will ensure that the Soča River continues to support its trout species for the years to come.

`

Chapter V: Conclusion

5.1 Summary

Taken together, these findings suggest the importance geology has played in creating the ideal environment for Marble and Rainbow trout to thrive. The geological formation of the Soča Valley, from the Late Pleistocene period, have formed the river beds where the Marble and Rainbow trout swim. The pebble substrate, created through years of weathering and erosion have become the perfect environment for the Marble trout to spawn and grow. Due to the abundant presence of limestone and calcite sediments in the valley, the Soča River is recorded to hold a neutral to slightly alkaline pH thereby allowing oxygen to be retained and utilized effectively (*pH And Water*, 2019) for the trout's survival. And according to Blaž, it is this mineral-rich water that also help support the growth rates of the trout, especially the Marble trout, which is seen to be exceptionally large in size. Due to its glacial history the valley's low-relief landscape help moderate water surface temperatures via aquifers. This combined with the densely populated trees and riparian vegetation provide shade that is both crucial to regulating water surface temperatures. It also acts as a natural barrier against floods and erosion.

Alongside the favorable conditions, few challenges were also identified. It is recorded that both the Marble and Rainbow trout prefer temperate waters ranging from 283.2K (10°C) to 288.2K (15°C). But based on the analysis of Land Surface Temperature (LST), the temperature of the Soča River can reach as high as 297.1K (23.9°C). When water surface temperatures increase, the water holds less dissolved oxygen (United States Department of Agriculture, 2012). Trout are cold blooded species, so their metabolic rates increase as water temperature increases, thereby reducing their ability to survive (Licea, 2021). Moreover, since much of the soil is loosely

`

packed and certain geological landscapes are alluvial terraces, many areas are prone to flooding. To prevent this, many introduce river straightening. Albeit, one of the side effects is the slow destruction of aquatic species such as the trout through the elimination of varied habitats. In essence, the Soča Valley's landscape is a direct reflection on its glacial and tectonic activity. But while this geological diversity has created the ideal environment for the Marble and Rainbow trout, it is important to also highlight the challenges the Soča Valley faces today. It is imperative that conservation strategies be taken in, to create natural foundations for the future of these trout species. Afterall, we are all stewards for earth, and it is a God-given responsibility to take care of it.

`

References

———. 2018b. “Modelling Last Glacial Cycle Ice Dynamics in the Alps.” *˜the œCryosphere* 12 (10): 3265–85. https://doi.org/10.5194/tc-12-3265-2018.

———. 2024b. “Kobarid: Itinerary Through History and Nature.” Miry Giramondo - Blog Di Viaggi in Italiano. December 28, 2024. https://www.mirygiramondo.com/en/kobarid-itinerary-through-history-and-nature/.

“———.” n.d. https://doc.arcgis.com/en/arcgis-online/get-started/what-is-agol.htm.

“———.” n.d. RD Tolmin [EN]. https://rdtolmin.si/en/.

“AG100: ASTER Global Emissivity Dataset 100-meter V003.” n.d. Google for Developers. https://developers.google.com/earth-engine/datasets/catalog/NASA_ASTER_GED_AG100_003#description.

“eGeologija - Geološki Zavod Slovenije.” n.d. https://egeologija.si/geonetwork/srv/eng/catalog.search#/metadata/05d134d6-086d-471c-8152-aa25ef30441f.

“Fish Farming OBRH | Fisheries Research Institute of Slovenia.” n.d. https://www.zzrs.si/en/page/ribogojstvo-obrh/.

“Fish Farming SOČA | Fisheries Research Institute of Slovenia.” n.d. https://www.zzrs.si/en/page/ribogojnica-soca/.

“Geospatial Platform | ArcGIS GIS Software for Business &Amp; Government.” n.d. Esri. https://www.esri.com/en-us/arcgis/geospatial-platform/overview.

“Global Monthly and Daily High-spatial Resolution of Total Column Water Vapour From 2002 to 2017 Derived From Satellite Observations.” 2025. July 1, 2025.

`

https://cds.climate.copernicus.eu/datasets/satellite-total-column-water-vapour-land-ocean?tab=quality_assurance_tab.

"In The Heart of the Wild Soča - RD Tolmin [EN]." n.d. RD Tolmin [EN]. https://www.rdtolmin.si/en/.

"Institute Introduction | Fisheries Research Institute of Slovenia." n.d. https://www.zzrs.si/en/page/predstavitev-zavoda-za-ribistvo-slovenije/.

"Landsat 5." 1984. USGS. March 6, 1984. https://www.usgs.gov/landsat-missions/landsat-5#web-tools.

"Landsat 8 OLI and TIRS and Their Uses." n.d. USGS. https://www.usgs.gov/media/images/landsat-8-oli-and-tirs-and-their-uses.

"Maars and Tuff Rings (U.S. National Park Service)." n.d. https://www.nps.gov/articles/000/maars-and-tuff-rings.htm.

"NCEP/NCAR Reanalysis Data, Water Vapor." n.d. Google for Developers. https://developers.google.com/earth-engine/datasets/catalog/NCEP_RE_surface_wv#bands.

"Ribogojnica | Faronika." n.d. https://www.faronika.si/ribogojnica/.

"Rivers & Fish - Soca Fly." 2025. Soca Fly. May 7, 2025. https://www.socafly.com/rivers-and-fish/

"USGS Landsat 8 Level 2, Collection 2, Tier 1." n.d. Google for Developers. https://developers.google.com/earth-engine/datasets/catalog/LANDSAT_LC08_C02_T1_L2#description.

"What Is Remote Sensing and What Is It Used For?" 2024. USGS. August 28, 2024. https://www.usgs.gov/faqs/what-remote-sensing-and-what-it-used.

"What Is the Landsat Satellite Program and Why Is It Important?" 2024. USGS. December 23, 2024. https://www.usgs.gov/faqs/what-landsat-satellite-program-and-why-it-important.

ArcGIS." n.d. https://www.arcgis.com/home/item.html?id=0751355514f64bcaa1c874d2e4308c05.

Authors, P. (n.d.). *PISM*. PISM. https://www.pism.io/

`

Bavec, Miloš and Verbič, Tomaž, “Glacial History of Slovenia,” In Developments in Quaternary Science, Volume 15, Pages 385-392. https://doi.org/10.1016/b978-0-444-53447-7.00029-5.

Bavec, Miloš, and Tomaž Verbič. 2004. “The Extent of Quaternary Glaciations in Slovenia.” In *Developments in Quaternary Science,* 385–88. https://doi.org/10.1016/s1571-0866(04)80088-5.

Bavec, Miloš, Slawek M Tulaczyk, Shannon A Mahan, and Gregory M Stock. 2004. “Late Quaternary Glaciation of the Upper Soča River Region (Southern Julian Alps, NW Slovenia).” *Sedimentary Geology* 165 (3–4): 265–83. https://doi.org/10.1016/j.sedgeo.2003.11.011.

Bendle, Jacob. 2020. “Moraine Types - AntarcticGlaciers.org.” AntarcticGlaciers.Org. June 22, 2020. https://www.antarcticglaciers.org/glacial-geology/glacial-landforms/glacial-depositional-landforms/moraine-types/.

Berrebi, P, M Povz, D Jesensek, G Cattaneo-Berrebi, and A J Crivelli. 2000. “The Genetic Diversity of Native, Stocked and Hybrid Populations of Marble Trout in the Soca River, Slovenia.” *Heredity* 85 (3): 277–87. https://doi.org/10.1046/j.1365-2540.2000.00753.x.

Blatnik, M., & Repe, B. (2012). Vegetacijski pasovi na meliščih v slovenskih Alpah. *Dela, 37,* 45–63. https://doi.org/10.4312/dela.37.3.45-63

Brocklehurst, S. H., Whipple, K. X., & Foster, D. (2007). Ice thickness and topographic relief in glaciated landscapes of the western USA. *Geomorphology*, *97*(1–2), 35–51. https://doi.org/10.1016/j.geomorph.2007.02.037

Bui, Thuyet D. 2024. “Using Remotely Sensed Data in Google Earth Engine to Investigate Water Surface Temperature at Shrimp Farms in the Climate Change Context: A Case Study at Mong Cai City, Quang Ninh Province, Vietnam.” *Aquaculture International* 32 (5): 6273–86. https://doi.org/10.1007/s10499-024-01465-9.

`

Buser, Stanko, and Marko Komac. 2002. “Geologic Map of Slovenia 1:250.000.” *Geologija* 45 (2): 335–40. https://doi.org/10.5474/geologija.2002.029.

Cambridge Dictionary | English Dictionary, Translations & Thesaurus. (2025). https://dictionary.cambridge.org/

Chambers, J. E., Wilkinson, P. B., Uhlemann, S., Sorensen, J. P. R., Roberts, C., Newell, A. J., Ward, W. O. C., Binley, A., Williams, P. J., Gooddy, D. C., Old, G., & Bai, L. (2014). Derivation of lowland riparian wetland deposit architecture using geophysical image analysis and interface detection. *Water Resources Research*, *50*(7), 5886–5905. https://doi.org/10.1002/2014wr015643

Cheremisinoff, Nicholas P. 1997. “Principles of Geology.” In *Elsevier eBooks*, 1–37. https://doi.org/10.1016/b978-081551411-4.50003-x.

Coetzee, Serena, Sanet Carow, and Lourens Snyman. 2021. “How Are Maps Used in Research? An Exploratory Review of PhD Dissertations.” *Advances in Cartography and GIScience of the ICA* 3 (November): 1–8. https://doi.org/10.5194/ica-adv-3-3-2021.

CORINE Land Cover 2006 (vector/raster 100 m), Europe, 6-yearly. (n.d.). https://land.copernicus.eu/en/products/corine-land-cover/clc-2006

d.o.o., Arctur. “Fishing.” Soča Valley - Slovenia. Accessed May 12, 2025. https://www.soca-valley.com/en/in-search-of-adventure/activities/2021010510461140/fishing/.

D2 Non-indigenous species. (2016, November 7). https://mcc.jrc.ec.europa.eu/main/dev.py?N=20&O=119&titre_chap=D2%20Non-indigenous%20species

Davies, B. (2020, June 22). *Ice streams*. AntarcticGlaciers.org. https://www.antarcticglaciers.org/glacier-processes/glacier-types/ice-streams/

`

Davies, B. (2020, June 22). *Ice streams*. AntarcticGlaciers.org. https://www.antarcticglaciers.org/glacier-processes/glacier-types/ice-streams/

DOO, A. (n.d.). *The source of the Soča River | Soča Valley - Slovenia*. Soca Valley. https://www.soca-valley.com/en/in-search-of-adventure/nature/2020122214205455/the-source-of-the-soca-river/

Edmund Optics. (n.d.). *What is SWIR?* https://www.edmundoptics.co.uk/knowledge-center/application-notes/imaging/what-is-swir/

Ehlers, Jürgen, Philip L. Gibbard, and Philip D. Hughes. 2004. *Quaternary Glaciations: Extent and Chronology*. *Elsevier eBooks*. http://ci.nii.ac.jp/ncid/BA74515612.

Ermida, Sofia L., Patrícia Soares, Vasco Mantas, Frank-M. Göttsche, and Isabel F. Trigo. 2020. "Google Earth Engine Open-Source Code for Land Surface Temperature Estimation From the Landsat Series." *Remote Sensing* 12 (9): 1471. https://doi.org/10.3390/rs12091471.

Ferrarin, Miriam, Miriam Ferrarin, and Miriam Ferrarin. 2024. "Kobarid: Itinerary Through History and Nature." Miry Giramondo - Blog Di Viaggi in Italiano. December 28, 2024. https://www.mirygiramondo.com/en/kobarid-itinerary-through-history-and-nature/.

Fitzsimons, J. D., & Marsden, J. E. (2014). Relationship between lake trout spawning, embryonic survival, and currents: A case of bet hedging in the face of environmental stochasticity? *Journal of Great Lakes Research*, *40*(1), 92–101. https://doi.org/10.1016/j.jglr.2013.12.014

Fluvial erosion. (n.d.). https://www.geo.fu-berlin.de/en/v/iwm-network/learning_content/environmental-background/fluvial_processes/fluvial_erosion/

Foglini, Claudio, Paolo Sala, Carolina Zellino, and Pietro Volta. "Autoecology of the bullhead Cottus gobio in the Province of Verbano Cusio Ossola." *IdroLIFE Project* 1 (2018).

`

Gale, Eva, et al., 2025, *"QUATERNARY LANDSCAPE DYNAMICS OF THE BOVEC BASIN, SOČA VALLEY AND CLASSICAL KARST REGION (WESTERN SLOVENIA)."* DOVE & AGAQ meeting, Bovec (Slovenia).

Gkouma, Myrsini. 2023. "Geomorphology." In *Elsevier eBooks*, 620–30. https://doi.org/10.1016/b978-0-323-90799-6.00119-1.

Glacier Power: How do Glaciers Move? | NASA Earthdata. (2025, February 27). NASA Earthdata. https://www.earthdata.nasa.gov/topics/cryosphere/glaciers/glacier-power/how-do-glaciers-move

Global monthly and daily high-spatial resolution of total column water vapour from 2002 to 2017 derived from satellite observations. (2025, July 1). https://cds.climate.copernicus.eu/datasets/satellite-total-column-water-vapour-land-ocean?tab=overview

Gostinčar, Petra. 2016. "Geomorphological Characteristics of Karst on Contact Between Limestone and Dolomite in Slovenia." https://repozitorij.ung.si/IzpisGradiva.php?id=2828.

Grunwald, Sabine, 2016. *Environmental soil-landscape modeling: Geographic information technologies and pedometrics*. CRC Press.

Hajna, Nadja Zupan, Pavel Bosák, Petr Pruner, Andrej Mihevc, Helena Hercman, and Ivan Horáček. 2019. "Karst Sediments in Slovenia: Plio-Quaternary Multi-proxy Records." *Quaternary International* 546 (November): 4–19. https://doi.org/10.1016/j.quaint.2019.11.010.

Heyman, W. D., & Kobara, S. (2011). Geomorphology of reef fish spawning aggregations in Belize and the Cayman Islands (Caribbean). In *Elsevier eBooks* (pp. 387–396). https://doi.org/10.1016/b978-0-12-385140-6.00026-8

House, & R, M. (2025, August 14). *Devonian Period | Definition, Climate, Animals, Plants, Timeline, Map, & Facts*. Encyclopedia Britannica. https://www.britannica.com/science/Devonian-Period

`

How does present glacier extent and sea level compare to the extent of glaciers and global sea level during the Last Glacial Maximum (LGM)? (2024, September 1). USGS. https://www.usgs.gov/faqs/how-does-present-glacier-extent-and-sea-level-compare-extent-glaciers-and-global-sea-level

Hrissanthou, V., Spiliotis, M., & Kaffas, K. (2025). Research on river engineering. *Water*, *17*(11), 1605. https://doi.org/10.3390/w17111605

Hrvatin, M., Tičar, J., Zorn, M. (2020). Rocks and Tectonic Structure of Slovenia. In: Perko, D., Ciglič, R., Zorn, M. (eds) The Geography of Slovenia. World Regional Geography Book Series. Springer, Cham. https://doi.org/10.1007/978-3-030-14066-3_2

Hughes, P. D., Allard, J. L., & Woodward, J. C. (2021). The Balkans: glacial landforms from the Last Glacial Maximum. In *Elsevier eBooks* (pp. 487–495). https://doi.org/10.1016/b978-0-12-823498-3.00058-3

Hulley, G. C., Hook, S. J., Abbott, E., Malakar, N., Islam, T., & Abrams, M. (2015). The ASTER Global Emissivity Dataset (ASTER GED): Mapping Earth's emissivity at 100 meter spatial scale. *Geophysical Research Letters*, *42*(19), 7966–7976. https://doi.org/10.1002/2015gl065564

Hulley, Glynn C., Simon J. Hook, Elsa Abbott, Nabin Malakar, Tanvir Islam, and Michael Abrams. 2015. "The ASTER Global Emissivity Dataset (ASTER GED): Mapping Earth's Emissivity at 100 Meter Spatial Scale." *Geophysical Research Letters* 42 (19): 7966–76. https://doi.org/10.1002/2015gl065564.

Ivy-Ochs, S., Monegato, G., & Reitner, J. M. (2021). The Alps: glacial landforms prior to the Last Glacial Maximum. In *Elsevier eBooks* (pp. 283–294). https://doi.org/10.1016/b978-0-12-823498-3.00008-x

`

Izadi, S., & Sohrabi, H. (2021). Using Bayesian kriging and satellite images to estimate above-ground biomass of Zagros mountainous forests. In *Elsevier eBooks* (pp. 193–201). https://doi.org/10.1016/b978-0-12-822931-6.00014-9

Jemec Auflič, M., M. Komac, and J. Šinigoj. "Modern Remote Sensing Techniques for Monitoring Pipeline Displacements in Relation to Landslides and Other Slope Mass Movements." In *Environmental Security of the European Cross-Border Energy Supply Infrastructure*, pp. 31-48. Dordrecht: Springer Netherlands, 2014.

Jet Propulsion Laboratory - NASA. (n.d.). NASA. https://www.nasa.gov/jpl/

Kalny, G., Laaha, G., Melcher, A., Trimmel, H., Weihs, P., & Rauch, H. P. (2017). The influence of riparian vegetation shading on water temperature during low flow conditions in a medium sized river. *Knowledge and Management of Aquatic Ecosystems*, *418*, 5. https://doi.org/10.1051/kmae/2016037

Karatsareas, Petros. 2022. "Semi-Structured Interviews." In *Cambridge University Press eBooks,* 99–113. https://doi.org/10.1017/9781108867788.010.

Kazlev, M. (n.d.). *Palaeos cenozoic: Oligocene: The Oligocene Epoch*. http://palaeos.com/cenozoic/oligocene/oligocene.html

Khan, N., Jhariya, M. K., Banerjee, A., Meena, R. S., Raj, A., & Yadav, S. K. (2022). Riparian conservation and restoration for ecological sustainability. In *Elsevier eBooks* (pp. 195–216). https://doi.org/10.1016/b978-0-12-822976-7.00003-x

Kuščer, Dušan, Grad, Karel, Nosan, Anton, Ogorelec, Bojan, 1974. "Geological research of the Isonzo valley between Bovec and Kobarid." Geology, volume 17, issue 10. http://www.dlib.si/?URN=URN:NBN:SI:DOC-32U57C6G "

`

Kuščer, Dušan, Karel Grad, Anton Nosan, and Bojan Ogorelec. 1974. "Geology of the Soča Valley Between Bovec and Kobarid". *Geologija* 17 (1):425-76. https://www.geologija-revija.si/index.php/geologija/article/view/330.

Lancaster, N., & Mountney, N. P. (2020). Eolian processes and sediments. In *Elsevier eBooks* (pp. 809–829). https://doi.org/10.1016/b978-0-08-102908-4.00031-x

Landsat NASA. (2024, April 4). *Thermal Infrared Sensor | Landsat Science*. Landsat Science | a Joint NASA/USGS Earth Observation Program. https://landsat.gsfc.nasa.gov/satellites/landsat-8/spacecraft-instruments/thermal-infrared-sensor/

Landsat NASA. (2024b, June 7). *Multispectral Scanner (MSS) | Landsat Science*. Landsat Science | a Joint NASA/USGS Earth Observation Program. https://landsat.gsfc.nasa.gov/multispectral-scanner/

Landsat NASA. (2025, July 31). *Operational Land Imager | Landsat Science*. Landsat Science | a Joint NASA/USGS Earth Observation Program. http://landsat.gsfc.nasa.gov/satellites/landsat-8/spacecraft-instruments/operational-land-imager/

Landsat NASA. 2023. "Enhanced Thematic Mapper Plus (ETM+) | Landsat Science." Landsat Science | a Joint NASA/USGS Earth Observation Program. June 22, 2023. https://landsat.gsfc.nasa.gov/etm-plus/.

Let's enter a digital world like no other. (n.d.). https://scalgo.com/en-US/products

Li, Z., Wu, H., Wang, N., Qiu, S., Sobrino, J. A., Wan, Z., Tang, B., & Yan, G. (2012). Land surface emissivity retrieval from satellite data. *International Journal of Remote Sensing*, *34*(9–10), 3084–3127. https://doi.org/10.1080/01431161.2012.716540

Licea, E. (2021, September 1). How do warm temperatures affect trout? *Moonshine Rod Company*. https://moonshinerods.com/blogs/the-moonshine-journal/how-do-warm-temperatures-affect-trout

`

Mapy.com. Accessed August 11, 2025. https://mapy.com/en/zakladni?source=osm&id=85148&x=13.6376522&y=46.3361025&z=9.

Mesozoic. (n.d.). USGS. https://www.usgs.gov/youth-and-education-in-science/mesozoic

Mihevc, A., Gabrovšek, F., Knez, M., Kozel, P., Mulec, J., Otoničar, B., Petrič, M., Pipan, T., Prelovšek, M., Slabe, T., Šebela, S. and Zupan Hajna, N., 2016. Karst in Slovenia. Boletín Geológico y Minero, 127 (1): 79-97ISSN: 0366-0176

Miko. (2025, July 1). *What is VNIR hyperspectral imaging? - Specim*. Specim. https://www.specim.com/technology/what-is-vnir-hyperspectral-imaging/

Mikos, M. "Estimation of increasing sediment transport rates along watercourses in the upper Soca river valley after recent strong earthquakes and large landslides." In *Geophysical Research Abstracts*, vol. 7, p. 06861. 2005.

Milena. (2025b, January 27). *Why is it cold inside caves? - Lipa cave*. Lipa Cave. https://lipa-cave.me/why-is-it-cold-inside-caves/

Mioč, Pero. 2003. "Outline of the Geology of Slovenia." *Acta Geologica Hungarica* 46 (1): 3–27. https://doi.org/10.1556/ageol.46.2003.1.2.

Mtaylor. (2022, April 19). Sharp bends make rivers meander, as Landsat attests | Landsat Science. *Landsat Science | A joint NASA/USGS Earth observation program.* https://landsat.gsfc.nasa.gov/article/sharp-bends-make-rivers-wander-as-landsat-attests/

Ncfga. (2025, June 23). *Summer water temperatures and how they affect trout. - Noontootla Creek Farms*. Noontootla Creek Farms. https://ncfga.com/summer-water-temperatures-and-how-they-affect-trout/

Nealson, K., & Berelson, W. (2009). Sediment habitats, including watery. In *Elsevier eBooks* (pp. 350–360). https://doi.org/10.1016/b978-012373944-5.00288-1

`

NOAA’s National Weather Service. (n.d.). *National Centers for Environmental Prediction*. https://www.weather.gov/organization/ncep

NSF National Center for Atmospheric Research | National Center for Atmospheric Research. (2025, September 1). NCAR. https://ncar.ucar.edu/

O’Sullivan, A. M., Devito, K. J., & Curry, R. A. (2019). The influence of landscape characteristics on the spatial variability of river temperatures. *CATENA*, *177*, 70–83. https://doi.org/10.1016/j.catena.2019.02.006

O’Toole, P., Chambers, J., & Bell, R. (2018). Understanding the characteristics of riparian zones in low relief, sandy catchments that affect their nutrient removal potential. *Agriculture Ecosystems & Environment*, *258*, 182–196. https://doi.org/10.1016/j.agee.2018.02.020

Ouyang, Z., Chen, R., Liu, Q., He, L., Cai, W., & Yin, K. (2018). Biological regulation of carbonate chemistry during diatom growth under different concentrations of Ca2+ and Mg2+. *Marine Chemistry*, *203*, 38–48. https://doi.org/10.1016/j.marchem.2018.04.002

Oxford English Dictionary. (n.d.). https://www.oed.com/?tl=true

Petrič, Metka. 2016. “Alpine Karst Waters in Slovenia.” *Acta Carsologica* 33 (1). https://doi.org/10.3986/ac.v33i1.312

Petrič, Metka. 2016. “Alpine Karst Waters in Slovenia”. *Acta Carsologica* 33 (1). Ljubljana, Slovenija. https://doi.org/10.3986/ac.v33i1.312

pH and Water. (2019, October 22). USGS. https://www.usgs.gov/water-science-school/science/ph-and-water

Ramšak, Lucija, Bertok, Marko, Jenič, Aljaž, Ivenčnik, Matej, and Hamzić, Rok, 2022 *“FISH FARMING PLAN FOR IMPLEMENTING FISHERIES MANAGEMENT IN THE TOLMIN FISHERIES ENVIRONMENT FOR THE PERIOD 2017 – 2022”*

`

Reitner, J. M., & Menzies, J. (2024). Subglacial deformation and till formation in a stratigraphic complex Late Pleistocene sequence (Einödgraben/Aurach, Kitzbühel Alps, Austria). *E&G Quaternary Science Journal*, *73*(1), 101–116. https://doi.org/10.5194/egqsj-73-101-2024

Remote sensing systems. (n.d.). https://www.remss.com/measurements/brightness-temperature/

Rhee, H. H., Lee, M. K., Seong, Y. B., Lee, J. I., Yoo, K., & Yu, B. Y. (2020). Post-LGM dynamic deglaciation along the Victoria Land coast, Antarctica. *Quaternary Science Reviews*, *247*, 106595. https://doi.org/10.1016/j.quascirev.2020.106595

Rožič, B. (2005). Albian - Cenomanian resedimented limestone in the Lower flyschoid Formation of the Mt. Mrzli Vrh Area (Tolmin region, NW Slovenia). *Geologija*, *48*(2), 193–210. https://doi.org/10.5474/geologija.2005.017

Rožič, Boštjan, and Daniela Reháková. 2024. “Sedimentology and Biostratigraphy of the Biancone Limestone Formation of the Tolmin Basin (Southern Alps, NW Slovenia).” *Cretaceous Research* 163 (June): 105958. https://doi.org/10.1016/j.cretres.2024.105958.

Rupnik, Petra Jamšek, Manja Žebre, and Giovanni Monegato. 2020. “Late Quaternary Evolution of the Sedimentary Environment in Modrejce Near Most Na Soči (Soča Valley, Julian Alps).” *Geologija* 63 (2): 295–309. https://doi.org/10.5474/geologija.2020.022.

Seguinot, Julien, Susan Ivy-Ochs, Guillaume Jouvet, Matthias Huss, Martin Funk, and Frank Preusser. 2018. “Modelling Last Glacial Cycle Ice Dynamics in the Alps.” *˜the œCryosphere* 12 (10): 3265–85. https://doi.org/10.5194/tc-12-3265-2018.

Smith, D. J., Wynn-Thompson, T. M., Williams, M. A., & Seiler, J. R. (2020). Do roots bind soil? Comparing the physical and biological role of plant roots in fluvial streambank erosion: A mini-JET study. *Geomorphology*, *375*, 107523. https://doi.org/10.1016/j.geomorph.2020.107523

`

Smith, Scot E, 2005. "Topographic mapping." *Environmental soil-landscape modeling: geographic information technologies and pedometrics* 1:155-182.

Swentosky, D. (2024, May 14). *Redd Fish — Should we fish for trout through the spawn or stay home?* Troutbitten. https://troutbitten.com/2018/11/07/redd-fish-should-we-fish-for-trout-through-the-spawn-or-stay-home/

Tend, O. (n.d.). *Forest cover - Slovenia Forest Service*. Slovenia Forest Service. https://www.zgs.si/en/slovenian-forests/forest-cover

The Precambrian (U.S. National Park Service). (n.d.). https://www.nps.gov/articles/000/the-precambrian.htm

The Triassic Period: the rise of the dinosaurs | Natural History Museum. (2019, August 27). https://www.nhm.ac.uk/discover/the-triassic-period-the-rise-of-the-dinosaurs.html

Tielidze, Levan G. 2017. “Late Pleistocene and Holocene Glacier Extent in the Georgian Caucasus.” *Open Journal of Geology* 07 (04): 517–32. https://doi.org/10.4236/ojg.2017.74036.

Trust, W. T. (2020, November 1). *water quality, water quantity, abstraction, pollution*. Wild Trout Trust. https://www.wildtrout.org/content/about-trout-challenges

United States Department of Agriculture. (2012). Elevated water temperature. In *WATER* [Report]. Natural Resources Conservation Service. https://efotg.sc.egov.usda.gov/references/public/AR/Water_Quality_Degradation_Elevated_Water_Temperature.pdf

Urednik. (n.d.). *Novice in dogodki*. https://life.notranjski-park.si/en/everything-you-wanted-to-know-about-the-strzen-watercourse-restoration/

Urska.Solc. 2025. “Domov - GeoZS.” GeoZS. April 8, 2025. https://www.geo-zs.si/.

`

Using our geological maps | Earth Sciences New Zealand | GNS Science | Te Pū Ao. (n.d.). Earth Sciences New Zealand | GNS Science | Te Pū Ao. https://www.gns.cri.nz/our-science/land-and-marine-geoscience/geology-of-new-zealand/geological-maps/using-our-geological-maps/

V osrčju divje Soče - Tolmin. (n.d.). Tolmin. https://rdtolmin.si/#

Vrabec, M., Šmuc, A., Pleničar, M. & Buser, S. (2009): Geological evolution of Slovenia – An overview. – In: Pleničar, M., Bojan, O., Novak, M. & Pirc, S. (eds): The Geology of Slovenia. – p. 23–40, 17 fig.; Ljubljana (Geološki zavod Slovenije).

What is Geospatial Data? - Geospatial Data - AWS. (n.d.). Amazon Web Services, Inc. https://aws.amazon.com/what-is/geospatial-data/

What is orthorectified imagery? (2022, August 30). Esri. https://www.esri.com/about/newsroom/insider/what-is-orthorectified-imagery

Wikipedia contributors. (2025, July 6). *River engineering*. Wikipedia. https://en.wikipedia.org/wiki/River_engineering

Wikipedia contributors. (2025b, July 21). *Laminar flow*. Wikipedia. https://en.wikipedia.org/wiki/Laminar_flow

Wikipedia contributors. (2025c, August 14). *Miocene*. Wikipedia. https://en.wikipedia.org/wiki/Miocene

Wikipedia contributors. (2025c, August 26). *Triassic*. Wikipedia. https://en.wikipedia.org/wiki/Triassic

Wikipedia contributors. (2025c, August 31). *Aquifer*. Wikipedia. https://en.wikipedia.org/wiki/Aquifer

Wikipedia contributors. (2025d, September 5). *Cretaceous*. Wikipedia. https://en.wikipedia.org/wiki/Cretaceous

Wikipedia contributors. (2025e, September 1). *Pleistocene*. Wikipedia. https://en.wikipedia.org/wiki/Pleistocene

`

Wikipedia contributors. (2025e, September 4). *Holocene*. Wikipedia. https://en.wikipedia.org/wiki/Holocene

Wikipedia contributors. 2025. “Kobarid.” Wikipedia. July 24, 2025. https://en.wikipedia.org/wiki/Kobarid.

Yu, G., Li, Z., Huang, H. Q., & Yao, W. (2018). Effect of riparian vegetation roots on development of meander bends in Tarim River, Northwest China. *E3S Web of Conferences*, *40*, 02029. https://doi.org/10.1051/e3sconf/20184002029

Zhao, X., Xu, H., Kang, L., Zhu, G., Paerl, H. W., Li, H., Liu, M., Zhu, M., Zou, W., Qin, B., & Zhang, Y. (2024). Nitrate sources and transformations in a river-reservoir system: Response to extreme flooding and various land use. *Journal of Hydrology*, *638*, 131491. https://doi.org/10.1016/j.jhydrol.2024.131491

Žlebnik, Ljubo. 1971. “Pleistocene Deposits of the Kranj, Sora and Ljubljana Fields”. Geologija 14 (1):5-51. https://www.geologija-revija.si/index.php/geologija/article/view/286.

Zorn, Matija, and Drago Perko, 2018. "The Historical overview of Geografski vestnik (Geographical Bulletin)." *Geografski vestnik* 90, no. 2.

Zorn, Matija, Mateja Ferk, Matej Lipar, Blaž Komac, Jure Tičar, and Mauro Hrvatin. 2019. “Landforms of Slovenia.” In *World Regional Geography Book Series*, 35–57. https://doi.org/10.1007/978-3-030-14066-3_3.