# Fryingpan River Anchor Ice Report 2020-2021

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## Executive Summary

Stationary ice formation, a natural occurrence in northern hemisphere streams during winter, has significant impacts on the hydrology and ecology of a stream. From December 2020 through March 2021, Roaring Fork Conservancy researchers conducted a pilot study on the Lower Fryingpan River to better understand the parameters affecting anchor ice formation in the river. Anchor ice presence was observed 13 out of the 32 survey days. A decrease in anchor ice presence started in the second half of January 2021 and continued through the end of the study period. This decrease in anchor ice aligned with observed increases in water temperature, air temperature, and stream flow rate. Logistic regression modeling substantiated these observations with statistically significant results showing a negative correlation between those three independent variables and anchor ice presence. While the results from this initial period of anchor ice monitoring provides a strong basis for future studies, improvements can be made to protocol and methodology to strengthen the integrity of the data moving forward. Additionally, continuing the study for at least five more years will provide more evidence necessary to make definitive conclusions about the influence of water temperature, air temperature, and stream flow rate on anchor ice formation in the Lower Fryingpan River.

## Introduction

Ice formation in rivers occurs when water becomes supercooled, meaning it cools to below 0°C. Conditions for supercooling are sub-zero air temperatures, little to no surface ice, and turbulent water flow (Brown et al. 2011). Under these conditions tiny ice particles on the surface of the water can become suspended in the water column, forming frazil ice. From there, frazil ice grows and is transported to the streambed in turbulent water. Frazil ice attached to the channel bottom is called anchor ice, a form of stationary ice attached to the streambed (Brown et al. 2011).

Left: Anchor ice at Site 1 (in Basalt). Right: Anchor ice on boulders at Site 2 (near Mile Marker 1). Cover Page Photo: Anchor ice and border ice at Site 5 (near confluence of Fryingpan and Seven Castles Creek).

Anchor ice formation, a natural occurrence in northern hemisphere streams in the winter, has significant impacts on the hydrology and ecology of a stream. Anchor ice dams can obstruct water flow, as well as increase and decrease water levels, upstream and downstream, respectively. Additionally, anchor ice can occupy fish and macroinvertebrate habitat, forcing them to make energetically costly movements, and anchor ice release events or ice jam releases can carry sediments and invertebrates down river (Brown et al. 2011).

Ice jam releases also have implications for human safety and the integrity of infrastructure nearby the stream. Large ice jams can cause flooding upriver. Moreover, release of these large ice jams at high stream velocity can damage bridges or similar structures as well as severely harm anyone recreating in the river (Huokuna et al. 2017).

In winter, discharges from Reudi Dam have a noticeable effect on the thermal regime of the river, water level, and temporal and spatial characteristics of the stream flow. All of these are factors in anchor ice formation. In a study of North American rivers, Huokuna et al. (2017) found that greater discharges of warm water from reservoirs in the winter increased open water areas, therefore creating more area for frazil ice formation and subsequently more anchor ice formation in downstream river reaches (Huokuna et al. 2017). Ultimately, local river conditions, year-to-year weather conditions, and dam structure and operation determine the impact that reservoirs have on stream flow and ice formation.

It is important to understand the processes underlying anchor ice formation to better predict how the management of rivers will impact anchor ice formation and, subsequently, the hydrology and ecology of the river. These factors are especially pertinent to the Lower Fryingpan River as a Gold Medal Fishery. This report addresses how stream flow regulation by Ruedi Dam may be affecting ice formation within the Lower Fryingpan River in Basalt, CO. Findings from this study could help inform management decisions regarding future winter flow discharge out of Ruedi Dam.

## Research Goals

The goal of the Fryingpan River Anchor Ice Study 2020-2021 was firstly to establish and execute an objective-driven protocol for assessing anchor ice formation within the Lower Fryingpan River. Secondly, we hoped to better understand the factors that affect anchor ice formation within the river, as well as establish a temperature gradient for the study area.

## Predictions

It was hypothesized that anchor ice abundance would increase with distance from Reudi Dam, and be negatively correlated with water temperature, air temperature, and stream flow rate.

## Methods

*Study Area*

Surveys were conducted at six sites along the Lower Fryingpan River in Basalt, CO. The Lower Fryingpan River is the approximately 14 mile stretch of river downstream of Ruedi Dam that flows into the Roaring Fork River. Site 1 was chosen at a location directly above the Roaring Fork River confluence. The other five sites were chosen at approximately one-mile intervals leading upstream with Site 6 at the Taylor Creek confluence. Convenience of access was prioritized.

| Site | Latitude (N) | Longitude (W) | Elevation (ft.) |
|---|---|---|---|
| Site 1 | 39.36827 ° | 107.03179° | 6657 |
| Site 2 | 39.37517 ° | 107.01622° | 6730 |
| Site 3 | 39.37444° | 107.00636° | 6772 |

| | | | |
|---|---|---|---|
| Site 4 | 39.37507° | 106.98652° | 6875 |
| Site 5 | 39.37949° | 106.96993° | 6930 |
| Site 6 | 39.37617° | 106.94305° | 7040 |

**Table 1** Fryingpan River Anchor Ice Study survey sites. Sites are numbered from downstream to upstream.

Surveying took place over the course of four months, December 3, 2020 through March 31, 2021. Surveyors assessed ice characteristics at each site at least once per week on days following at least two consecutive nights of below 20°F air temperature. In order to ensure frequent surveying, seven survey events were conducted on days without two prior consecutive nights of sub 20°F, predominately later in the study period. A total of 32 surveys were conducted: nine in December, eight in January, eight in February, and seven in March.

*Physical Parameters*

The latitude, longitude, and elevation were recorded for each survey site. Additionally, water temperature and air temperature were recorded at each site for every survey event using a digital thermometer. Stream flow rate data for each survey event was collected from the USGS Gauge below Ruedi Reservoir. Previous weather history was collected from the NCDC weather history database using the Aspen Pitkin County Airport Sardy Field weather station.

*Observational Parameters*

Notes were taken on specific stream characteristics at each site that could affect ice formation, including relative stream velocity, water depth, exposure to sun, and any drastic changes in ice presence between surveys, among other observed characteristics

*Ice Surveying*

The percent coverage and thickness of anchor ice was visually estimated for each site. The type of anchor ice formation was recorded, including the relative size of the clumps and the density of distribution among them. When opportune, an anchor ice sample was taken from the riverbed by pulling off an intact piece the size of at least one fist, while wearing rubber gloves. The sample was then photographed, individual crystal length was measured using a ruler, and any sediment lodged within the sample was recorded. Additional ice formation types were also recorded. Border ice width, the distance of border ice from the river bank to the outer edge of the ice, was estimated at each site, as well as whether or not the border ice had been flooded. Presence of slush ice, or ice floating down the stream of the river, was also recorded. The

Anchor ice sample from Site 1 (in Basalt).

presence of anchor ice dams and anchor ice weirs were recorded at each site. If present, heights of anchor ice dams were estimated. Photographs and videos were taken at each site. Lastly, the time and location of any witnessed anchor ice release event was recorded using photographs, videos and written descriptions of the event.

## Results

*Overall Anchor Ice Presence and Coverage*

Anchor ice surveying took place 32 times from December 3, 2020 to March 31, 2021, resulting in 192 unique site visits. Out of the 32 survey days, anchor ice was observed 13 out of the 32 days, and out of the 192 unique site visits, anchor ice was observed 54 times. Site-specific observations by month are depicted in **Table 2**. There was a decrease in anchor ice presence in January, and anchor ice remained largely absent for the rest of the survey period. Throughout the season, anchor ice presence was observed most frequently at Site 2 (11 times) and least frequently at Site 1 (7 times).

| | Site | | | | | | |
|---|---|---|---|---|---|---|---|
| **Month** | **Site 1** | **Site 2** | **Site 3** | **Site 4** | **Site 5** | **Site 6** | *Total* |
| **December** | 4 | 5 | 5 | 6 | 5 | 4 | *29* |
| **January** | 0 | 4 | 2 | 2 | 4 | 4 | *16* |
| **February** | 1 | 0 | 0 | 0 | 0 | 0 | *1* |
| **March** | 2 | 2 | 1 | 1 | 1 | 1 | *8* |
| *Total* | *7* | *11* | *8* | *9* | *10* | *9* | *54* |

**Table 2.** Number of times anchor ice presence was recorded at each site and for each month throughout the survey period (December 3, 2020 through March 21, 2021).

Anchor ice was absent the majority of the survey days. Anchor ice was not observed at 138 out of the 198 unique site visits. When excluding recordings of 0% coverage, the average estimated anchor ice coverage for each month was as follows: 61% in December, 42% in January, 10% in February, and 39% in March. Specific estimated coverages for each site visit are shown in **Table 3**.

| | **Site 1** | **Site 2** | **Site 3** | **Site 4** | **Site 5** | **Site 6** |
|---|---|---|---|---|---|---|
| **December** | | | | | | |
| 12/3/20 | 50 | 75 | 75 | 75 | 90 | 50 |
| 12/4/20 | 25 | 75 | 90 | 75 | 50 | 75 |
| 12/8/20 | 10 | 80 | 25 | 95 | | |
| 12/11/20 | | | | | | |
| 12/15/20 | | | | 75 | 90 | |
| 12/16/20 | | | | | | |
| 12/21/20 | | | | | | |
| 12/24/20 | 40 | 70 | 90 | 40 | 50 | 75 |
| 12/30/20 | | 10 | 50 | 25 | 70 | 75 |
| **January** | | | | | | |
| 1/1/21 | | 90 | 5 | | 60 | 30 |

| | | | | | | |
|---|---|---|---|---|---|---|
| 1/5/21 | | | | | | |
| 1/7/21 | | 70 | 20 | 40 | 50 | 75 |
| 1/11/21 | | 75 | | 5 | 35 | 40 |
| 1/15/21 | | 10 | | | 45 | 45 |
| 1/18/21 | | | | | | |
| 1/21/21 | | | | | | |
| 1/28/21 | | | | | | |
| **February** | | | | | | |
| 2/1/21 | 10 | | | | | |
| 2/5/21 | | | | | | |
| 2/8/21 | | | | | | |
| 2/12/21 | | | | | | |
| 2/17/21 | | | | | | |
| 2/19/21 | | | | | | |
| 2/22/21 | | | | | | |
| 2/26/21 | | | | | | |
| **March** | | | | | | |
| 3/1/21 | 75 | 60 | 45 | 30 | 45 | 45 |
| 3/3/21 | 5 | 5 | | | | |
| 3/12/21 | | | | | | |
| 3/15/21 | | | | | | |
| 3/24/21 | | | | | | |
| 3/25/21 | | | | | | |
| 3/31/21 | | | | | | |

**Table 3.** Estimated anchor ice coverage recordings for every anchor ice presence observed throughout the 4-month survey period. Blanks correspond with 0% estimated coverage of anchor ice.

**Physical Parameters**

Air and water temperature data were not collected prior to December 12, 2021 because a digital thermometer was not yet attained. Absences in water temperature data after that date were due to unsafe river access conditions.

Average recorded air temperatures for December, January, February, and March were -12.3°C, -2.9°C, 1.5°C, and 4.4°C, respectively (**Figure 1**). There was a noticeable shift in air temperatures starting after January 15$^{th}$. Prior to January 15$^{th}$, air temperatures were all below freezing. Following that date, temperatures remained consistently above freezing, falling to an average of below freezing across the six sites only on February 5$^{th}$, February 19$^{th}$, and March 1$^{st}$.

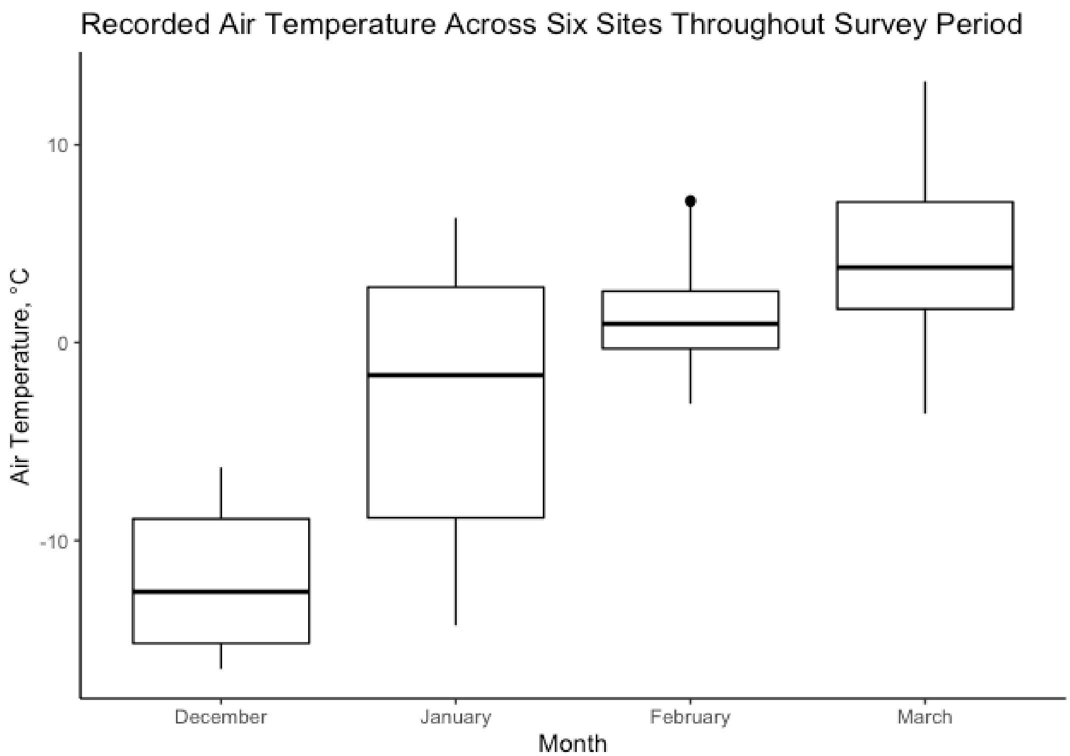
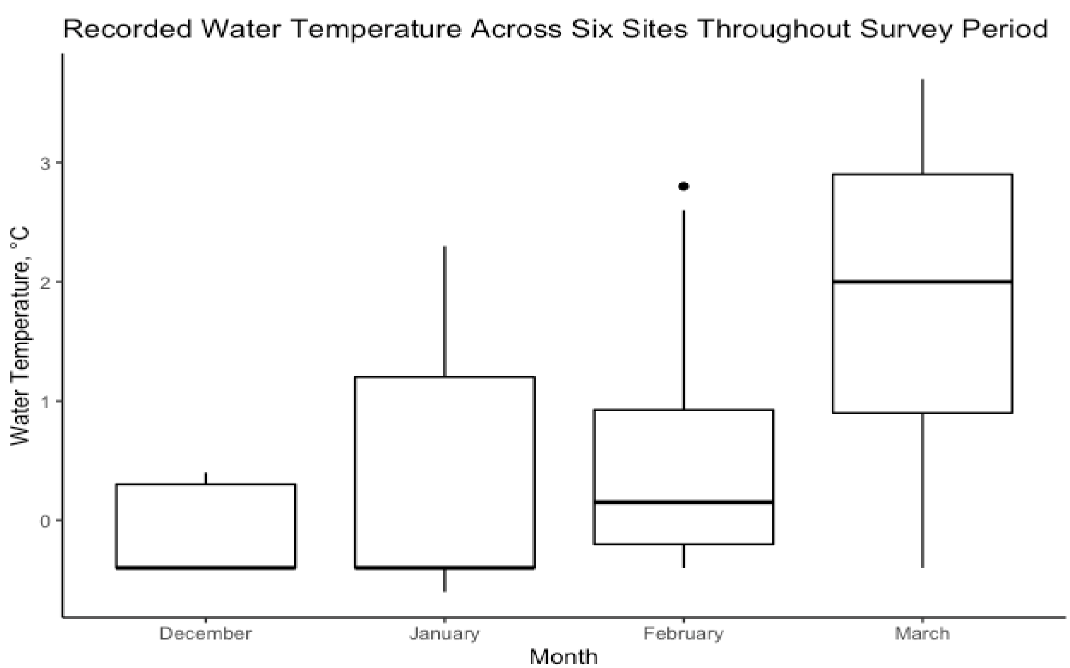



**Figure 1 (above).** Recorded air temperatures at each site by month throughout the survey period (December 3, 2020 through March 31, 2021). A general increasing trend is observed. **Figure 2 (below)**. Recorded water temperatures at each site by month throughout the survey period (December 3, 2020 through March 31, 2021). A general increasing trend is observed.



Average water temperatures for December, January, February, and March were -0.17°C, 0.25°C, 0.54°C, and 2.8°C, respectively (**Figure 2**). After Water temperatures began to be consistently above freezing starting January 18th. There was a notable increase in water temperature starting February 12th, when temperatures above 2°C were recorded for the first time in the season. One of the survey goals was to establish a temperature gradient of anchor ice formation leading up the stream. We were unable to detect significant differences in recorded water temperatures amongst the sites.

Three noticeable changes in stream flow rate occurred within the survey period at the beginning of January, the end of February, and mid-March (**Figure 3**). Throughout December, the stream flow remained between 46 and 48 cubic square feet (cfs). The stream flow rate then increased in January, consistently staying between 58.9 and 61.7csf for all of January. Stream flow remained about 60csf in February, between 61.3 and 63.9csf. Then on February 27th it decreased to around 4csf, and in the evening of February 28th it decreased again to 35csf. For the next few weeks, stream flow remained at an average of 35csf and, then increased slightly the last week of March to about 45csf.

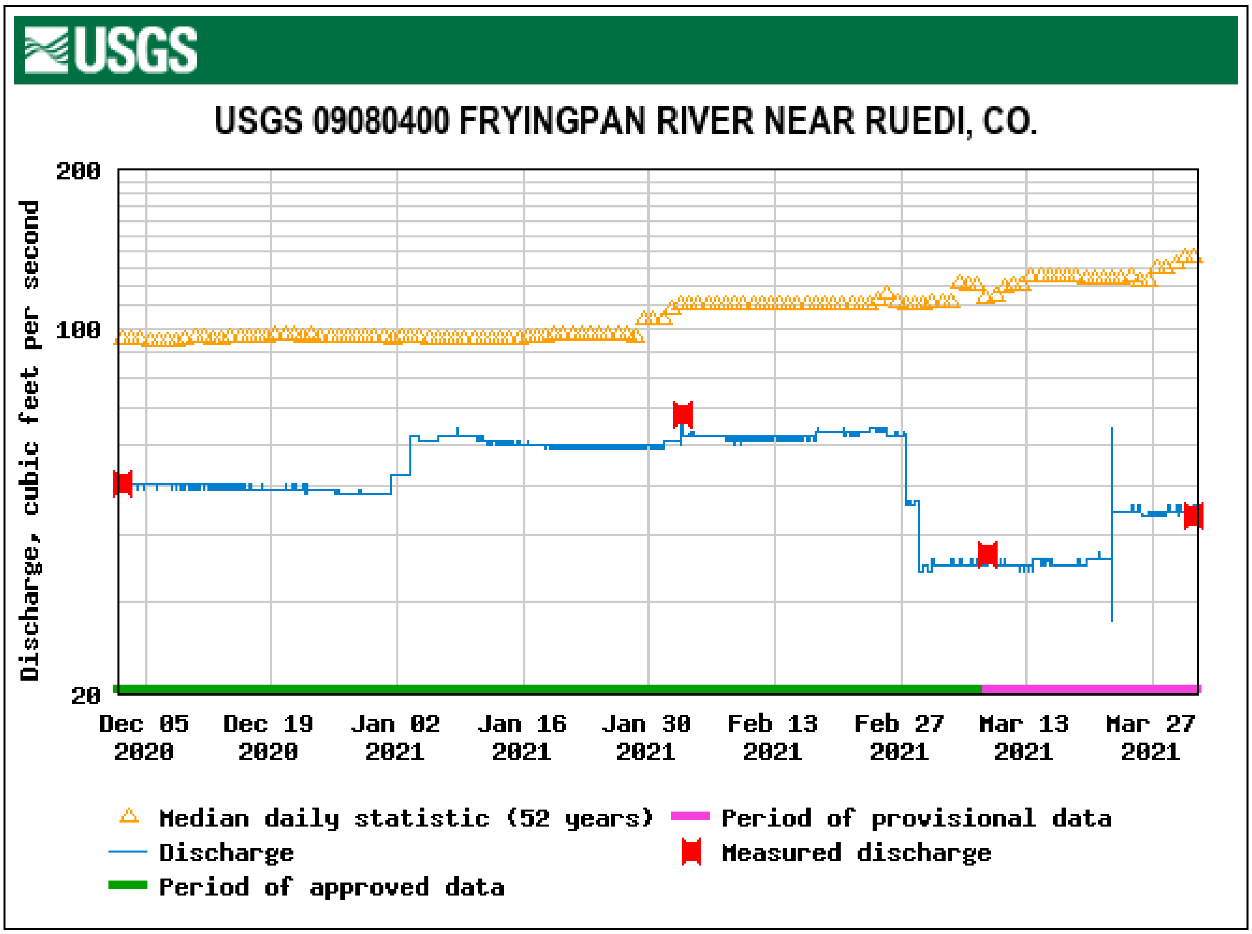



**Figure 3:** Discharge recorded by USGS gauge below Ruedi Dam within the period of ice surveying, December 3, 2020 through March 31, 2021. Noticeable changes occurred at the beginning of January (increase), the end of February (decrease), and mid-March (increase). Source: USGS

**Modeling**

While regression modeling was attempted for estimated coverage of anchor ice, results were unhelpful because the overwhelming majority of 0% coverage recordings caused unequal variance and non-normal residuals. Instead, logistic regression was conducted to determine the probability of anchor ice presence in relation to stream flow rate, air temperature, and water temperature. The logistic regression found that all three variables are negatively correlated with the odds of anchor ice being present. Specifically, for a one-unit increase in water temperature, the odds of anchor ice presence decrease by 99.19% ($p=0.002$). For a one-unit increase in stream flow, the odds of anchor ice presence decrease by 10.75% ($p=0.002$). Lastly, for a one-unit increase in air temperature, the odds of anchor ice presence decrease by 12.92% ($p=0.01$).

**Discussion of Results**

A clear pattern of anchor ice presence is evident throughout the survey period. Anchor ice was consistently present and abundant throughout December and early January, then was largely absent throughout the second half of January and throughout February and March, except for one day in March when it was present at all six sites. Logistic regression modeling for anchor ice presence found that the odds of anchor ice presence are negatively correlated with air temperature, water temperature, and stream flow rate. These findings make sense when looking at the trends of these variables throughout the duration of the survey period. Stream flow rate, water temperature, and stream flow rate all increased in January, while anchor ice presence decreased at that same time.

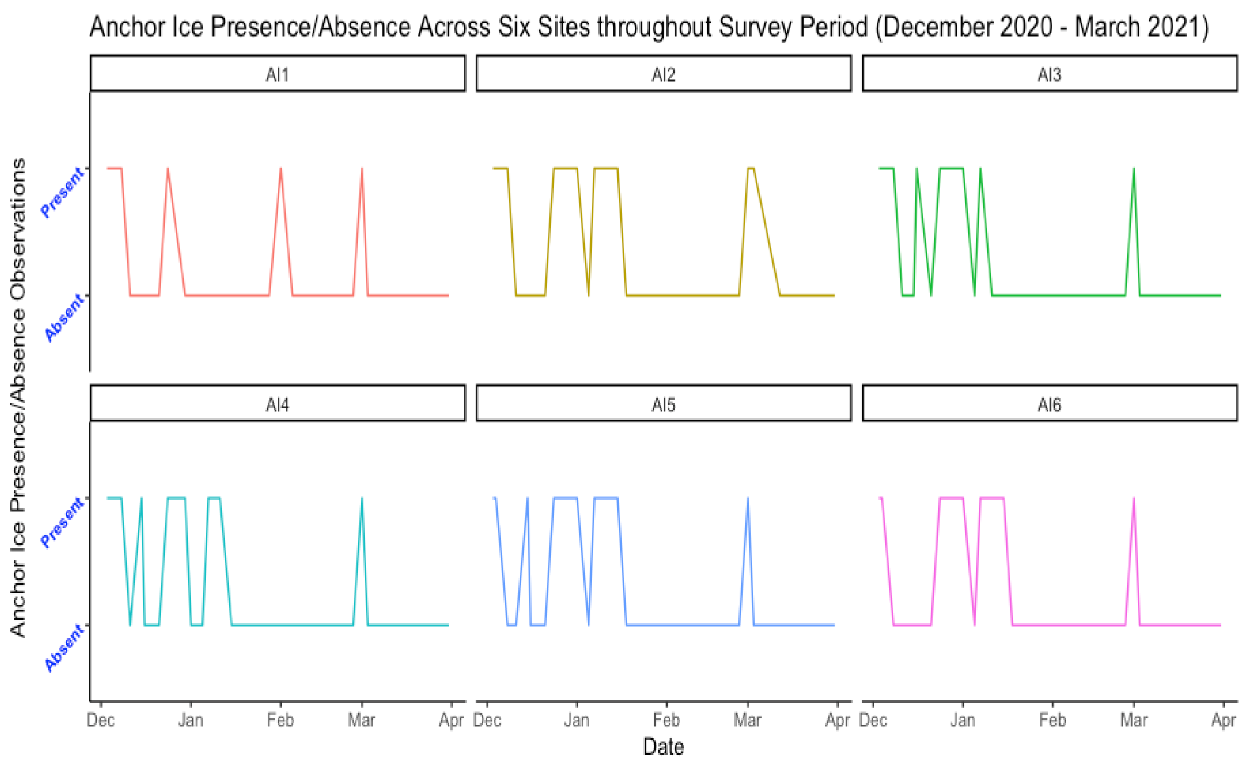



**Figure 4.** Anchor ice presence/absence at each site throughout the survey period (December 3, 2020 through March 31st, 2021) for all 32 survey days. Anchor ice was largely absent throughout late January, February, and March. Anchor ice was observed across all six sites on March 1st.

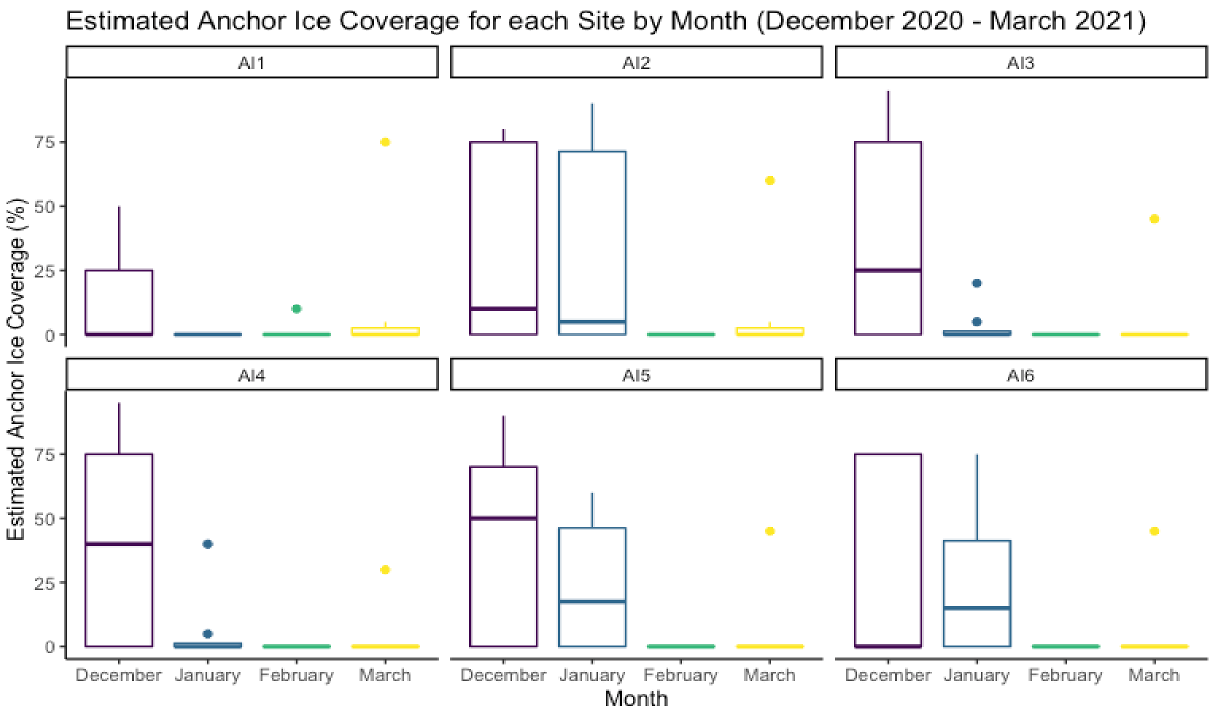


**Figure 5:** Estimated anchor ice coverage for each site by month throughout the survey period.

The one-day spike in anchor ice presence on March 1st then subsequent reduction two days later is the only time this occurred this season. Stream flow discharge rate decreased two days prior to March 1st, and to the lowest levels of the season the night before March 1st. It is possible that this sudden drop in discharge rate contributed to this ice formation. However, anchor ice presence did not persist in the river despite consistently low stream flow rates in the following weeks (**Figure 5**).

Although the logistic regression shows significant results that align with our hypotheses, it is not clear how well the choice of variables for this study directly align with anchor ice formation. Kempema (2008) identifies the rates of mixing in flowing water, heat transfer from water to air, and latent heat of fusion released as anchor ice grows as important parameters controlling anchor ice formation. While stream flow rate, water temperature, and air temperature can be used as proxies for these more specific parameters, they may not provide the degree of preciseness necessary to correlate these values directly with anchor ice formation.

*Site Differences*

Prior to surveying it was hypothesized that anchor ice presence and abundance would decrease with proximity to Ruedi Dam, due to relatively warm water discharged by Ruedi Dam. The data do not show evidence consistent with this hypothesis. The fewest number of anchor ice sighting across sites occurred at Site 1, the site furthest from Reudi Dam. However, it is important to note that for most of the season Site 1 was covered entirely by border ice, preventing observations of potential anchor ice.

Each of the sites were unique in grade, width, shade coverage, stream depth, and flow speed (rapid vs. runs). It is likely that while anchor ice formation within a stream requires certain environmental conditions, such as low air and water temperatures, the precise location that the anchor ice forms as well as the abundance of ice is highly subjective to local stream conditions. In order to better understand the effects of discharge from Reudi Dam on the formation of anchor ice in the Lower Fryingpan, it may be beneficial to incorporate more sites further upstream into this study. Similar anchor ice presence and coverage was observed at Sites 3 and 4 and Sites 5 and 6, respectively (**Table 3**). Therefore, researchers could consider eliminating Sites 3 and 5 from the study and adding at least two more sites further upstream.

Anchor ice dam at Site 2 (near Mile Marker 1).

*Recommendations*

Perhaps one of the most significant outcomes of this pilot study is determining areas where methodology can be improved moving forward. In order to maintain consistency of reporting throughout the season and integrity of data, inter-observer reliability must be prioritized. Anchor ice can be difficult to spot and estimations of its coverage are highly subjective. Fluctuating stream depth levels further complicate observations; it is more difficult to see anchor ice in deeper waters. All potential observers should spend one at least one full day of sampling together at the beginning of the season. This will allow them to establish focal areas for surveying at each of the sites, as well as provide the opportunity to calibrate their individual estimations to ultimately achieve observations of at least 80% sameness. Continuity from season to season, whether it be the same observer or comprehensive training conducted by the previous observer is ideal. Additionally, adding more sites further upstream will increase variability in water temperature and air temperature amongst the study sites, potentially illuminating more significant results on the scale that the level of data collection warrants. Increasing the survey period, particularly in the early season could also help to understand formation influences. Adding additional observational factors such as border ice depth and water depth could also prove useful.

## Conclusion

This anchor ice monitoring pilot season on the Lower Fryingpan River provides a strong basis for continuing this study long-term. There were noticeable correlations between anchor ice presence and the primary independent variables of interest: air temperature, water temperature, and stream flow rate. However, it is difficult to attribute changes in anchor ice to any single variable since all of them changed substantially in January alongside changes in anchor ice presence. Continuing this study for at least five more years is necessary to gain a stronger understanding of these trends. Additionally, taking measures to ensure inter-observer reliability and expanding the overall stretch of river to include more sites further upstream will result in a more robust data set moving forward.

## Works Cited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