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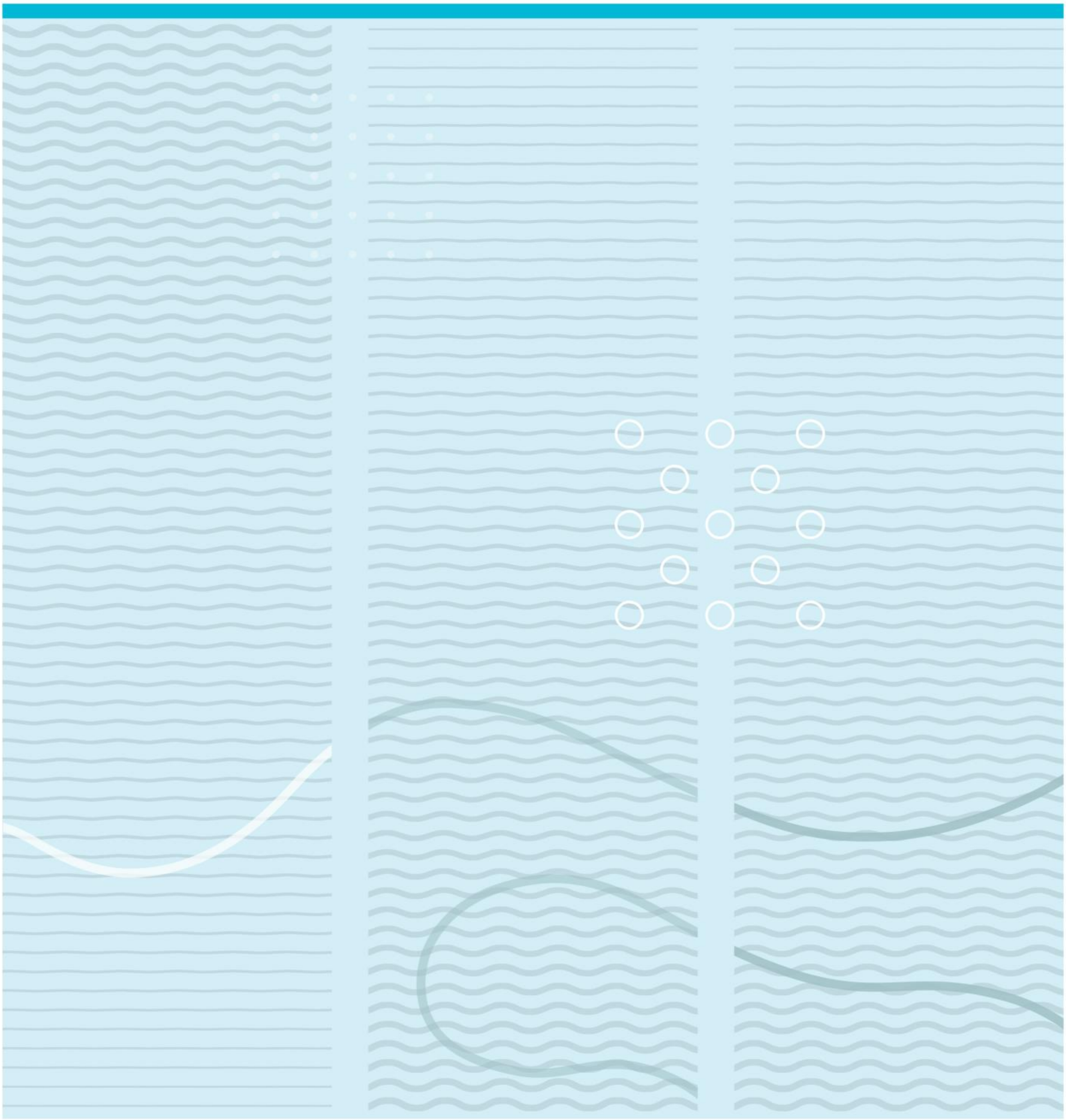
Redd Site Micro-Habitat Selection and Quantitative Analyis for Large Brown Trout in the Tokkeåi River Telemark, Norway

University College of Southeast Norway, Telemark, Norway



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This thesis is worth 60 study points

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Thank you
Irshad Khan

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Abstracts

The study of redd site microhabitat selection is very important for successful conservation and management of large brown trout. Number of redds is quantified by several reports before but this research has done microstudy on redd site selection. The aim of the study was to study and quantify spawning redd to explore association between physical variables. Direct underwater observation was done after the end of the spawning season in 2016, by using water binoculars and snorkeling to locate and quantify number of large redds in the river. Out of 44 redds found in the study area, medium sized redd (total redd length between 240-400 cm) was dominant (19 out of 44 redds). Number of spawning redd was reduced in 2016 as compared to previous study.

In this study, different microhabitat variables like total redd length, redd depth, water velocity, substrate particle size and morphological and mesohabitat were thoroughly studied. Mean and standard deviation of total redd length (mean ± SD) was 307.34± 135.62 cm and range was 665-74 cm. The correlations between depth and water velocity at 0 cm and 5 cm above the substrate were significant (0.042 < 0.05 at 0 cm and 0.020 < 0.05 at 5 cm above from the bottom at 5% level of significance), but, the correlations were weak, (r=0.157). The correlations between total redd length and average depth at redd was also significant, but again low (r= 0.322).

Redd substrates were dominated by pebble in the size range 31.1- 64 mm and small cobble sized 64-1- 128 mm with 42% and 29% respectively. About 83% of substrate found at the redd was pebble, small cobble and small pebble and within size ranges 16.1-128 mm. Non-turbulent stream flow characterized by run-shallow and run-deep morphology was most prevalent at the redd sites (observed 59 %) among six different types of flow type observed. Relative velocity was equal at Redd's front, depression length, left and right. Relative velocity and relative depth were at the mean range at maximum number of redds.

1 Introduction

For spawning, brown trout constructs a nest in shallower, deeper in the bottom of a stream, and this nest is commonly called a redd (Schneider, 2000). Redd is a spawning nest especially formed by female brown trout by using her tail to dig in a small area of gravel, often in the lowermost part of the river. In the redd, the female brown trout deposits her eggs which incubate for a relatively long period of time, generally from two to eight months (Nika, Virbickas, & Kontautas, 2011). The spawning site selection is depending upon environmental characteristics(Jonsson & Jonsson, 2011). The viability of oxygen within gravels at the spawning beds identified as one of crucial factor limiting embryonic survival(Greig, Sear, & Carling, 2007; Harvey, 1928; Ingendahl, 2001; Maret, Burton, Harvey, & Clark, 1993; Soulsby, Malcolm, & Youngson, 2001; Turnpenny & Williams, 1980).

The spreading of spawning sites and their microhabitat variable are sharply influenced by several natural geomorphological, hydrological characteristics, artificial river modification and climatic factors (Changxing, Petts, & Gurnell, 1999; Louhi, Mäki-Petäys, & Erkinaro, 2008; Moir, Gibbins, Soulsby, & Webb, 2004; Payne & Lapointe, 1997; Rabeni & Sowa, 1996). The most important microhabitat variable is depth, water velocity and substrate size are crucial for selection of spawning habitat site(Armstrong, Kemp, Kennedy, Ladle, & Milner, 2003; D. Crisp, 2000; Louhi et al., 2008). Temperature has also significant influence in the spawning of salmonids and a direct impact on the survival of eggs and the rate at which alevins grow(Armstrong et al., 2003; D. T. Crisp, 1993). Moreover, oxygen concentration and volume of fine sediment in the bottom substratum need to be considered when evaluating the intra-gravel condition for productive embryo development(Chapman, 1988).

However, Hydropower regulation has huge impact on spawning of brown trout. Hydropower regulation alters the flow pattern and flow levels of the river which in turn may influence the spawning activities of brown trout in the river(Newbery, 2008). In addition, river regulation tend to change the temperature regimes of affected rivers(Kraabøl, 2013). Therefore, knowledge about spawning behavior and redd site selection, i.e., microhabitat selection and morphological characteristics is very important for brown trout stock management and for river restoration projects(Madsen, 1995; Nika et al., 2011; Rubin, Glimsäter, & Jarvi, 2004).

In case of many freshwater system, large piscivorous are very important valued as human food resource(Jensen et al., 2015). They are crucial top-level predator has directly or indirectly effects on the behavior, life cycle, abundance and size composition of prey population in the river(Jensen, Amundsen, Elliott, Bøhn, & Aspholm, 2006). In Norway, population of piscivorous brown trout are in lesser quantity and they are in diminishing state(Pulliam, 1988; Wollebæk, Thue, & Heggenes, 2008). One of the main reasons for declining number of large brown trout is the exploitation of spawning rivers by hydropower companies. High-head storage hydropower plants are main renewable source of energy in Norway. Water stored in reservoir has high kinetic energy are diverted through turbine to generate electricity(Gaudard & Romerio, 2014). Demand of electricity is increasing in an alarming rate, the powerhouse processed water is released into downstream and crates artificial flow fluctuation is called hydropeaking(Person, 2013) . As a result of anthropogenic activities, for example water level in the river is increased or decreased dramatically is challenging to complete life cycle of brown trout(Wollebæk et al., 2008). Because of hydropeaking, major microhabitat variables like depth, water velocity, bottom substrate load, temperature and others abiotic factor are changed noticeably(Person, 2013).

Biotic factor like competition between the species may play an important role for spawning site selection(Mychek-Londer et al., 2013; Wootton, 1990; M. Zimmer & M. Power, 2006). It might prevent one species from selecting the most suitable spawning site and should use less suitable area. Moreover, study of morphological and mesohabitats by morphology and flow type is crucial for understanding of spawning behavior of brown trout. (Curry & Noakes, 1995; M. P. Zimmer & M. Power, 2006).

Tokkeåi River in Telemark, South-central Norway, is well known as a spawning river for large brown trout, ascending the river for spawning from the foraging areas in nearby Bandak Lake. Lake Bandak and the river Tokkeåi were colonized by sea trout that migrated inland after the last Ice Age about (10-12) thousand years ago(Heggenes, Sageie, & Kristiansen, 2009; Vandreregionen, 2018), got landlocked in the system, and has remained in a natural state in this ecosystem for 10,000 years. In Lake Badak, the large trout is found to be older with a steady and sustained growth(Heggenes, Fjellheim, & Brattestå, 2017; Heggenes et al., 2009). In the past several studies was done in Tokkeåi River in order to understand spawning behavir, spawning site selection and number of spawning brown trout(Heggenes et al., 2017; Kraabøl, 2010; Kraabøl et al., 2015). In a pilot study research work was done to find redd site microhabitat utilization by large trout in Tokkeåi River to develop a spawning model for wild large brown trout and to understand spawning behavior of large brown trout in Tinnelva, Boelva and Tokkeåi river of Telemark county.

In the past, localization and counts of large spawning redd in Tokkeåi River bed were performed using two basic method. First, surveys were performed using two basic methods. The survey was performed by using polarized sun glasses and river bank observation, combined with wading and use of a boat when necessary in 2011-2013 (Heggenes et al., 2017; Kraabøl et al., 2015).However, both before and after this, the main method has been direct underwater observation, but in combination with riverbank observation.

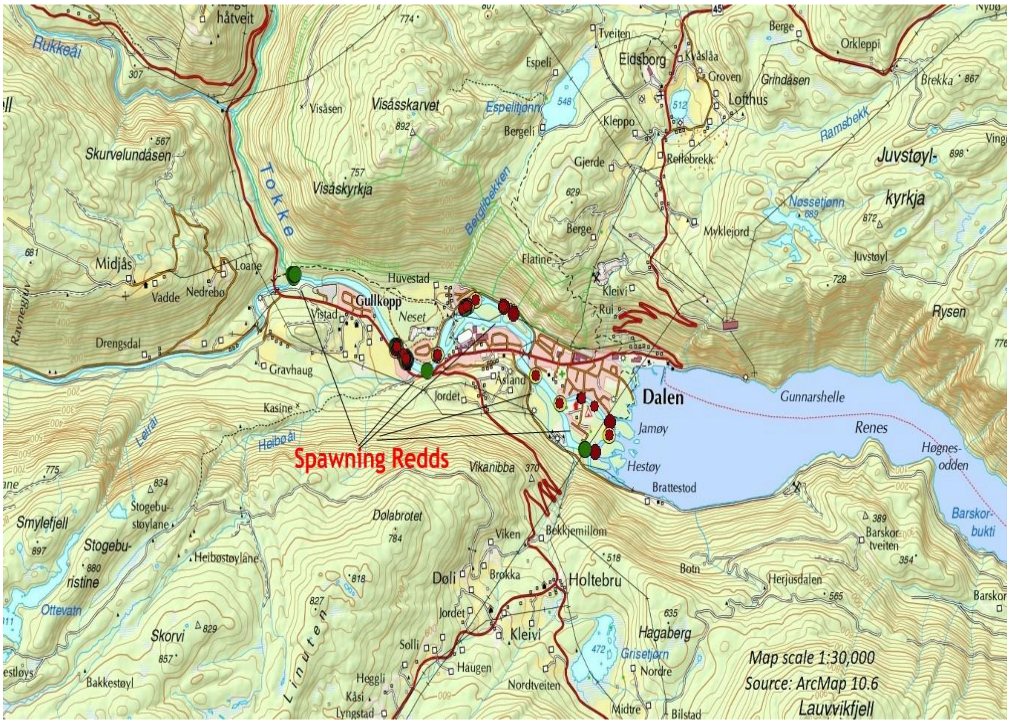
In 2014 and 2015, there was major flooding occurred in Tokkeåi which made direct observations difficult (Heggenes et al., 2017).The substrates for example stirring fine, gravel and stone in the river moved due to flooding so that redd observation was difficult or uncertain(Heggenes, Fjellheim, & Brattestå, 2016; Heggenes et al., 2017).

The objection of this research was to measure hydraulic characteristics at large redd sites to characterize and quantify spawning microhabitat sites used by large brown trout in Tokkeåi River. Finally, to explore association between physical variable and microhabitat selection at the redd in study area.

2 Methods and Material

2.1 Study Area

Tokkeåi River is situated in western Telemark, and flows into the downstream in to Bankdak Lake as show in Fig. 1 (Lundbo, 2017). Tokkeåi is popular and hub for spawning and reproduction of larger sized brown trout (Heggenes et al., 2016; Kraabøl et al., 2015; Tranmæl & Midttun, 2005; Wollebæk et al., 2008). Norwegian Water Resource and Energy Directorate (NVE) has listed Tokkeåi in the priority out of 22 rivers in Western Viken water area, based on assessing environmental improvement measures for fish stock and fishing (Schartum & Kraabøl, 2014).



Map scale 1:30,000

Source: ArcMap 10.6

Figure 1:The above map shows the whole study area alone with spawning reach of brown trout

Tokkeåi River channels a catchment of 2800 km^2 has 5,000 m spawning reach length, 0.55 mean gradient, 18 (0-300) m^3/s mean range annual flow, 72 masl elevation and 5 stream order belongs to Tokke-Vinje waterway (Kraabøl et al., 2015; Wollebæk et al., 2008). This river is the western main outlet of Skien River that drains the western parts of Hardangervidda (Kraabøl et al., 2015). Brown trout enter into the Tokkeåi River from the downstream lake and they are key species found during the spawning season.(Wollebæk et al., 2008).

The hydropower development and installations include construction of reservoirs, intakes, penstocks and their waterways, and have noticeable environmental effects on the fish in the river and the whole river ecosystem(Kraabøl, 2013; Kraabøl et al., 2015; Wollebæk et al., 2008). Sometimes, hydropower plant can be used to more or smaller extent for hydropeaking, which results in sudden alterations in flow and water levels downstream (Forseth et al., 2014). The hydropower regulation development in Tokkeåi River in 1961 has reduced flow with 12 m^3s^{-1} was only the natural residual water flow form catchment downstream(Kraabøl et al., 2015). Vinjar falling out by Nedrebøfossen Hell Hylén which was also called top point on lake trout transmitting stretch (Kraabøl, 2010).Tokkeåi total basin measured at the outlet of Bandak Lake is regulated to generate hydroelectric power (Kraabøl, 2010). The mean unregulated flow of water through the year at the outlet of Bandak Lake was estimated to 88.9 m^3s^{-1}. However, current flow of water due to regulation is reduced to 20.4 m^3s^{-1}, which is obviously high degree of regulation.(Kraabøl, 2010; Kraabøl et al., 2015; Tranmæl & Midttun, 2005; Trodden, 2002).

2.1.1 Lio Power Plants and Its impact on Tokkeåi River

The power was constructed in 1969 and station is close to Rukke bridge which is 5 km from the center of Dalen and water from the power plant is discharged into the Tokkeåi River (Kraabøl et al., 2015). The present capacity of plant is 43 MW is responsible for hydroelectric production(Statkraft, 2018). Now, the power plant is upgraded with increased capacity of 43MW and yearly production can be increased by up to 18 GWh to a total of 243 GWh. The main power plant is located 400 meters in to the mountain and it uses a 352 meter high fall from the Byrtevatn intake reservoir(Statkraft, 2018). After the operation of water from Lio power plant, the water flows via a tunnel into

Tokkeåi River just downstream of Hell Hylén(Statkraft, 2018) as also shown in Fig 2. Lio power plant at full operation regulates water flow of 12 m^3s^{-1} into Tokkeåi. Operating the water flow from Lio power therefore constitute the major part of the water flow at the Storørretfø- rendering part of Tokkeåi. However, bypass valve is not installed in Lio power plant, so it not possible to let compensating water flow pass the power station during any breakdown.

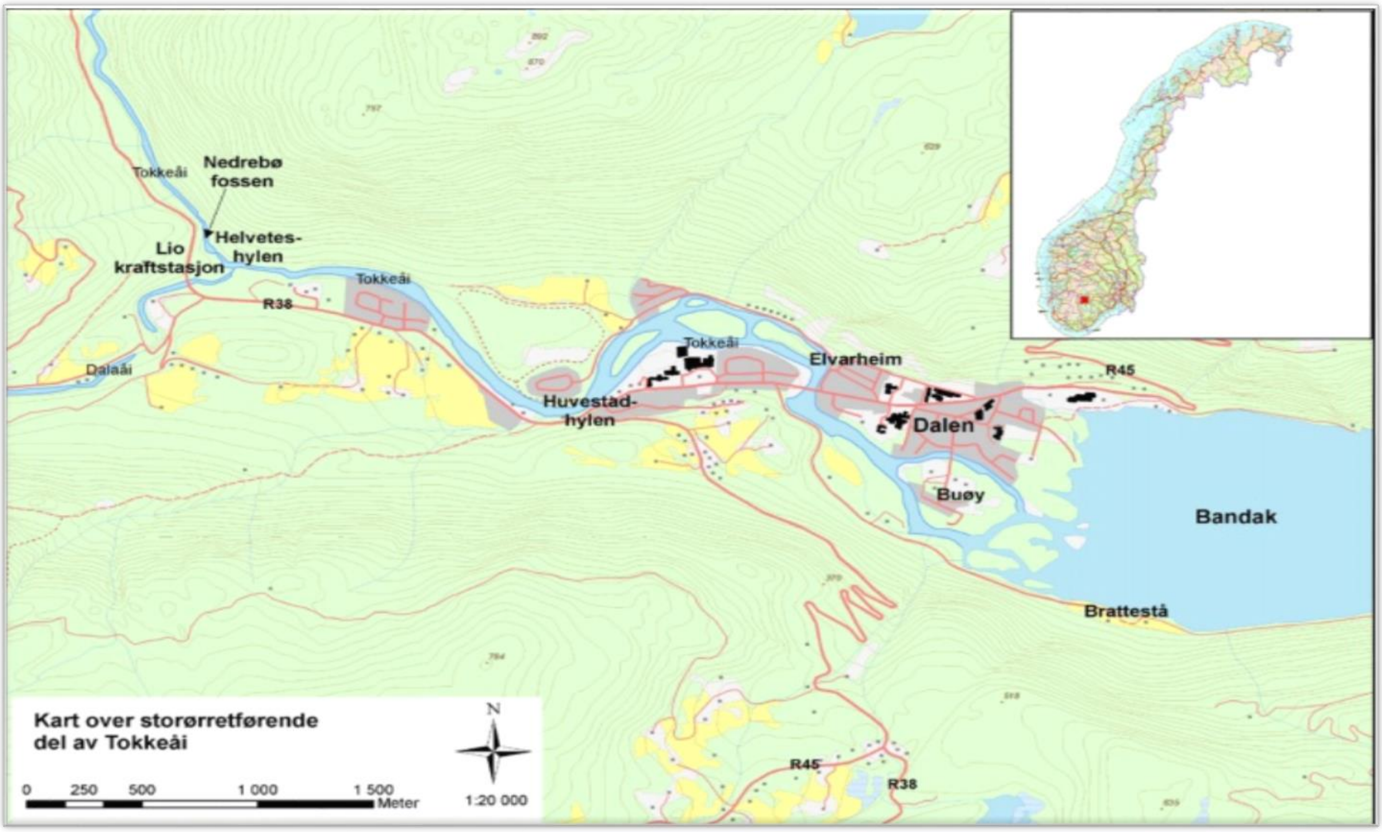


Figure 2: Map of the lake trout- bearing portion of Tokkeåi between the outlet of Lio hydroelectric plants in Biological Veteshylen and down to the ground in the northern part of Bandak(Kraabøl, 2010).

When Lio is not in operation, most of the time fail to fulfil present minimum water flow requirement. It takes 7 to 20 hours to enter Hell Hylén from Vinjar through slot opening cause delay and it prevent water flow at outlet of power plant (Kraabøl et al., 2015). During the period of 1971-1972, between Lio power plant and Bandak Lake were built in the Tokkeåi 17 stone weir, including 15 unconsolidated weirs and two stone block weirs. These weirs were made by stone and gravel from the bottom of Tokkeåi River and had direct impact on morphology and mesohabitat of the river. However, all of these weirs have been rebuild during the last three years to accommodate brown trout movement(Kraabøl et al., 2015).

2.2 Nature of Research and Data Collection Technique

In this study, large brown trout redds were located by direct underground observation. The research was based on quantitative as well as qualitative method. So, the nature of research for this research is descriptive.

2.2.1 Methods of Data Collection

The field data were obtained by direct surface and underwater observation. Based on the objective of this research, we have only collected data on large sized redds, however, we also saw many smaller sized redd in the study area. For this, we used measured length of about 100 cm and greater to confirm as large redd during diving and direct measurements(Wollebæk et al., 2008).

Major spawning activities in Tokkeåi was seen in middle of November 2016 is consistent with the observation made by researcher Kraabøl and Jan Heggenes in their respective research in Tokkeåi River(Heggenes et al., 2017; Kraabøl et al., 2015). To ensure observation of spawning activities in the Tokkeåi River, two of my colleagues, Per Tommy Fjellheim and Kai Brattestå, were searching for redds from late of September to until end of the spawning season around 2nd week of November 2016. In the field, direct on-site observations were made to count and measure redds during fieldwork 14-18 November 2016. Snorkeling is commonly used method to estimate the number of spawning redds in rivers(Joyce & Hubert, 2003). It is difficult to survey with wading in stream with deeper water or pool with high velocity, snorkeling helped to find spawning area and to count fish as well(Griffith, 1981; Joyce & Hubert, 2003). Active digging was done by leg to see bottom substrate particle and egg deposited by Large brown trout. After conforming large redd, field team measured redd total length by determining redd's maximum width (a), depression length (b) and tail length (c) (see, Fig.3) by meter stick and passed information to field crew to write in field sheet(Wollebæk et al., 2008; M. P. Zimmer & M. Power, 2006) .

To measure microhabitat and hydraulic characteristic we used the following instruments and clothing;

- Waders


Source:www.academy.com

In Norway, during November the weather is very cold, so, standing longer time in the water will reduce your body heat. Waders are important because they are very much helpful to protect us from cold water.

- Water binoculars and rubber boat

Water binoculars is a very powerful tool which helps us to see underwater substrate very clearly. We can see and detect types of substrates and eggs under the water.

We used rubber boat to search for spawning redds in deeper and more high velocity rivers areas.

- Meter stick and Field Sheet

The meter stick was 220 cm long, and used to measure the redd(s) maximum width, depression length, tail length and total length. Field sheets are used to record all field information. Field sheets used in this study are added in appendix.

- Camera

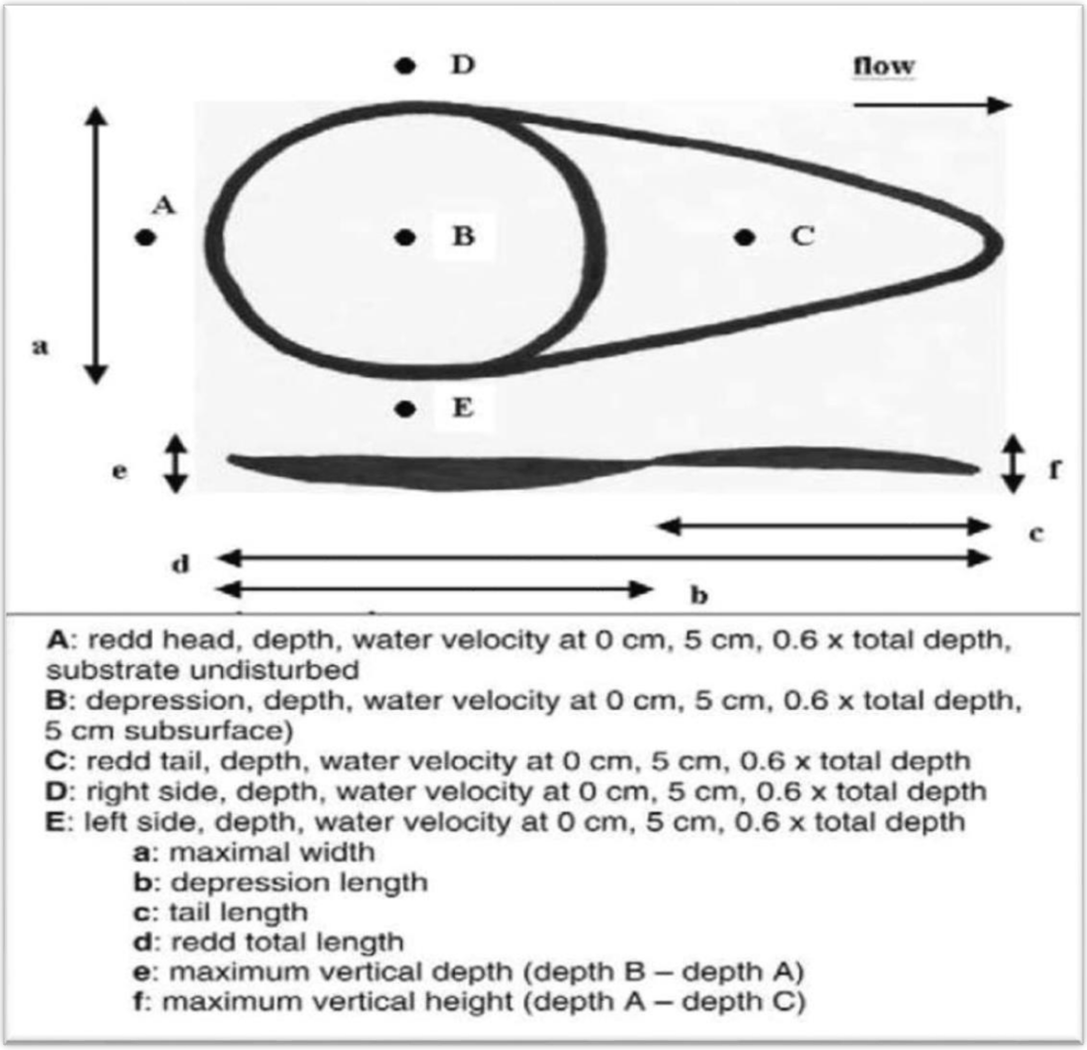
We used two types of cameras one for just normal photography, whereas another was used to take pictures of underwater to take photos of spawning bed as well as redds. The camera shown in the picture is Canon - EOS Rebel T7i DSLR Camera with EF-S 18-55mm IS STM Lens – Black.

- Water velocity meter & GPS

Water velocity (cm/s) was measured with a Høntzsch µP Flowtherm (http://www.hoentzsch.com/en/products/) and it was fitted with propeller with diameter 1.8 cm. Water velocity at the bottom (1-2 cm above the substrate) and at 5 cm was measured by water velocity meter (Wollebæk et al., 2008).

Spawning redd of brown trout counting was done in Tokkeåi River in 2011 to 2013 and 2015 in Tokkeåi(Heggenes et al., 2016, 2017). I have repeated same spawning redd counting in 2016 by using same methodology as well as same person who was actively participated for data collection last year. So, the results came from this research can be comparable with previous studied.

2.2.2 Theoretical Description of Redd

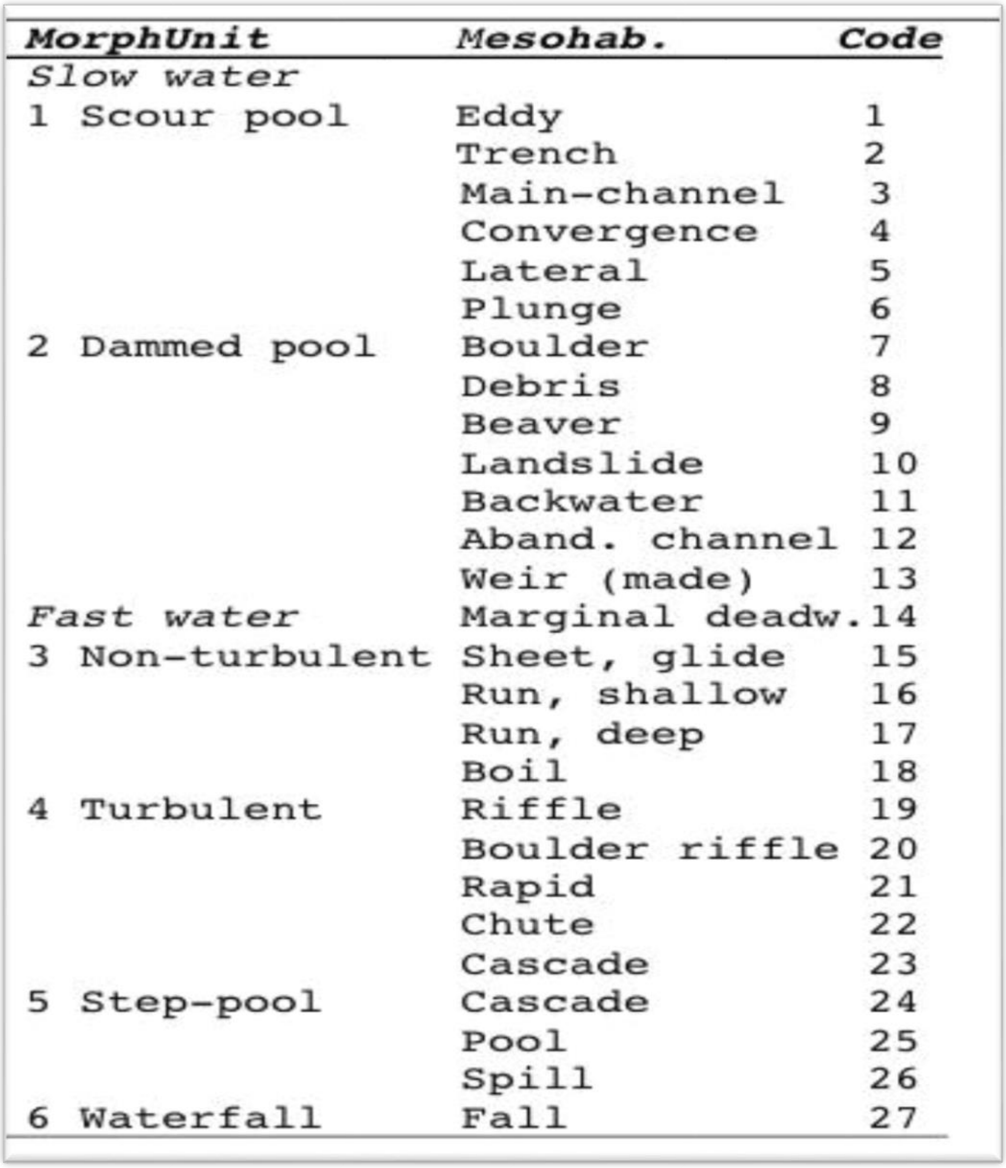


A: redd head, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth, substrate undisturbed
B: depression, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth, 5 cm subsurface)
C: redd tail, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth
D: right side, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth
E: left side, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth
- **a**: maximal width
- **b**: depression length
- **c**: tail length
- **d**: redd total length
- **e**: maximum vertical depth (depth B – depth A)
- **f**: maximum vertical height (depth A – depth C)

Figure 3: Schematic cross-section showing brown trout spawning redd, showing locations and their horizontal or vertical measurement of water velocity (cm/s), depth (cm), substrate particle size (cm), length (at the 0 & 5 cm) and width (at 0 & 5 cm (Wollebæk et al., 2008)).

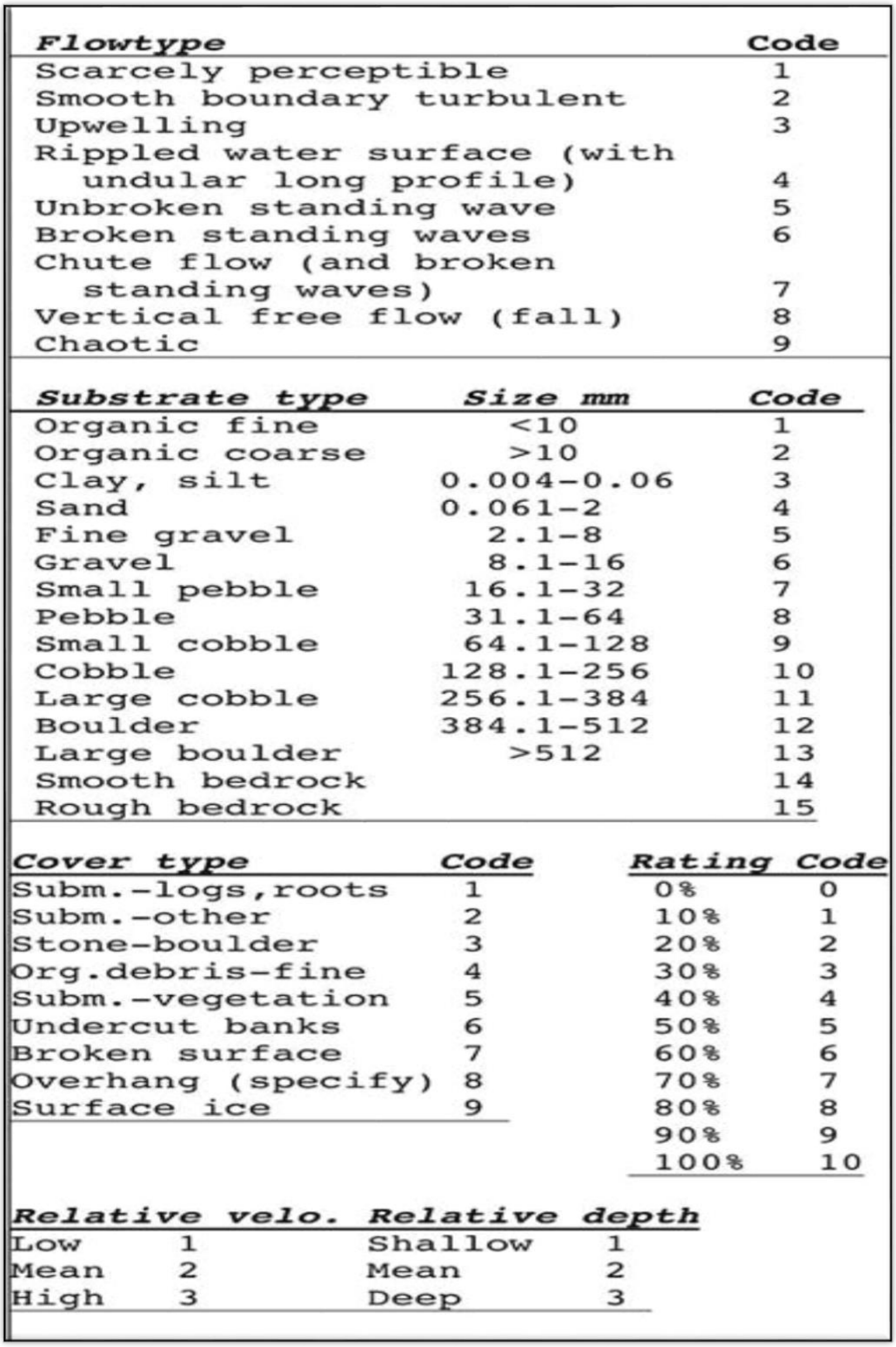
2.2.3 Observation Classification of Morphological Unit and Mesohabitats

To understand spawning of brown trout, study of morphology and mesohabitat gives us clue about their selection of spawning site(Newson & Newson, 2000; C. Padmore, 1998; C. L. Padmore, 1997).



MorphUnit	*Mesohab.*	*Code*
Slow water		
1 Scour pool	Eddy	1
	Trench	2
	Main-channel	3
	Convergence	4
	Lateral	5
	Plunge	6
2 Dammed pool	Boulder	7
	Debris	8
	Beaver	9
	Landslide	10
	Backwater	11
	Aband. channel	12
	Weir (made)	13
Fast water	Marginal deadw.	14
3 Non-turbulent	Sheet, glide	15
	Run, shallow	16
	Run, deep	17
	Boil	18
4 Turbulent	Riffle	19
	Boulder riffle	20
	Rapid	21
	Chute	22
	Cascade	23
5 Step-pool	Cascade	24
	Pool	25
	Spill	26
6 Waterfall	Fall	27

Figure 4: The table shows morphology of river at the redd site



Flowtype	Code
Scarcely perceptible	1
Smooth boundary turbulent	2
Upwelling	3
Rippled water surface (with undular long profile)	4
Unbroken standing wave	5
Broken standing waves	6
Chute flow (and broken standing waves)	7
Vertical free flow (fall)	8
Chaotic	9

Substrate type	*Size mm*	*Code*
Organic fine	<10	1
Organic coarse	>10	2
Clay, silt	0.004-0.06	3
Sand	0.061-2	4
Fine gravel	2.1-8	5
Gravel	8.1-16	6
Small pebble	16.1-32	7
Pebble	31.1-64	8
Small cobble	64.1-128	9
Cobble	128.1-256	10
Large cobble	256.1-384	11
Boulder	384.1-512	12
Large boulder	>512	13
Smooth bedrock		14
Rough bedrock		15

Cover type	*Code*
Subm.-logs,roots	1
Subm.-other	2
Stone-boulder	3
Org.debris-fine	4
Subm.-vegetation	5
Undercut banks	6
Broken surface	7
Overhang (specify)	8
Surface ice	9

Rating	*Code*
0%	0
10%	1
20%	2
30%	3
40%	4
50%	5
60%	6
70%	7
80%	8
90%	9
100%	10

Relative velo.		*Relative depth*	
Low	1	Shallow	1
Mean	2	Mean	2
High	3	Deep	3

Figure 5: Showing flow type, major substrate type, cover type, relative velocity and relative depth at the redd in Tokkeåi River (Newson & Newson, 2000; C. Padmore, 1998; C. L. Padmore, 1997)

2.3 Statistical Analysis

2.3.1 Non- Parametric Spearman Rank Correlation

To quantify the relation between redd size and depths of the water at the redd site, we used Non-Parametric Spearman Rank Correlation analysis(Cook & Wheater, 2012). First need to check whether the correlation between the two variables is significant or not. If so, then we can also calculate how strong the correlation between studied variable is (Cook & Wheater, 2012).

The following hypothesis was set to test the relation between two variables:

Null Hypothesis H_0: If the correlation between two variables is significant (when $P< 0.05$, i.e. at 5% level of significance) then the correlation between two variables is significant.

Alternative Hypothesis H_a: The correlation between two variables is not significant (when $P> 0.05$, i.e. at at 5% level of significance).

In this study IBM SPSS 24- 2017 is used to calculate non- parametric Spearman rank correlation.

2.3.2 Data Processing and Analysis

The information collected by field work and secondary literature from previous studies were processed, analyzed and interpreted by using statistical tools, tables, graph, pie chart in Microsoft Excel 2016, Minitab 18 and IBM SPSS 24-2017.

3 Results

To meet objectives of this study, field data includes information on number of redds and quantitative measurements of redds required to analyze and write results. In addition, it also contains observational data about morphological units and mesohabitat by morphology and flow type.

3.1 Redd's Lengths and Water Velocities at Different Redd Positions

Descriptive statistics for redd's total length, max. width, depression length and tail length is explained in table 1.

Table 1: Mean, SD and range of total redd length, max. redd width, redd depression length and redd tail lengths.

	Total redd length	Redd max.width (cm)	Redd depression len. (cm)	Redd tail length (cm)
Mean	307.34	90	134.25	83.09
SD	135.61	38.37	72.08	38.51
Range	665-74	195-25	350-27	190-22
Source: Field data, Nov. 2016				

Table depicts microhabitat length variables of investigated redd sites in Tokkeåi River. Mean of total redd length and standard deviation (SD) were 307.34 cm and 135.61 cm respectively followed by range (665-74) cm as shown in table 1. Similarly, the redd's maximum width (mean ± SD) was 90 ± 38.37 with range of (195-25) cm. In addition, redd's depression length (mean ± SD) was (134.25 ± 72.08) and within the range (350-27) cm.

3.2 Brown Trout Redd Size and Velocities

Brown trout redd sizes were classified based on total red length to scrutinize the redd distribution patterns in the river. Brown trout redd size also gives clue about fish size as well. Redd size based on total redd length is pioneer study and suitable to explain density of large brown trout in the Tokkeåi River.

Brown Trout Redd Size based on Total Redd Length

The measured brown trout redds differed substantially with respect to length. We categorized brown trout redd length in to three classes, most likely roughly reflecting increasing spawned sizes. The criteria used to classify the redd sizes under this method; they are precisely explained as follows;

- Small redd (S): Redd total length less than 250 cm.
- Medium redd (M): Redd total length from 250 cm to 400 cm.
- Large redd (L): Redd total length larger than 400 cm.

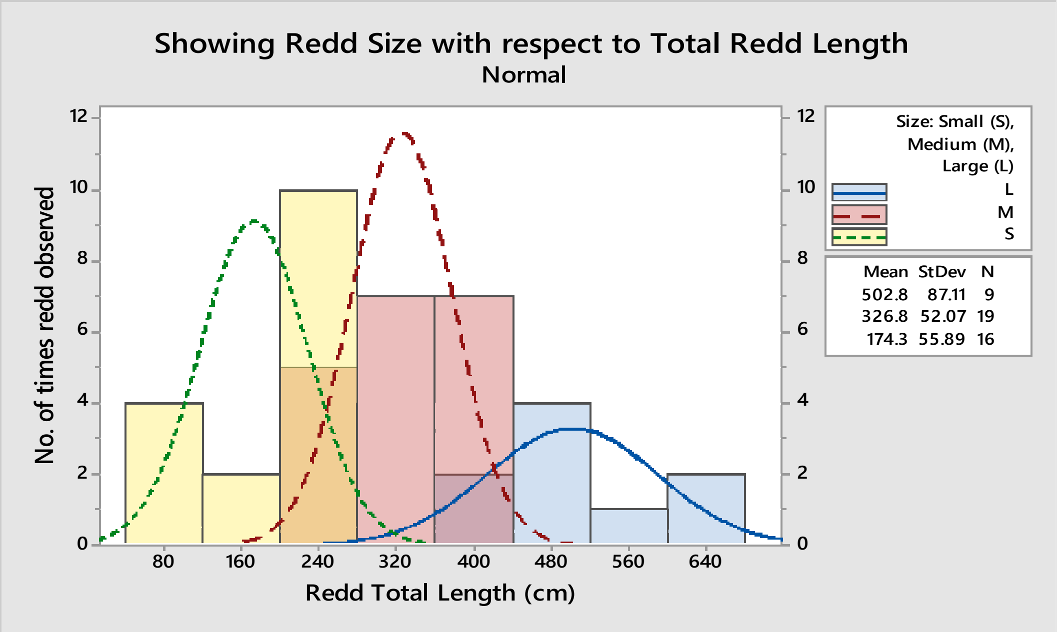


Figure 6: Histogram for redd size classes along with normality distribution curve with respect to total redd length.

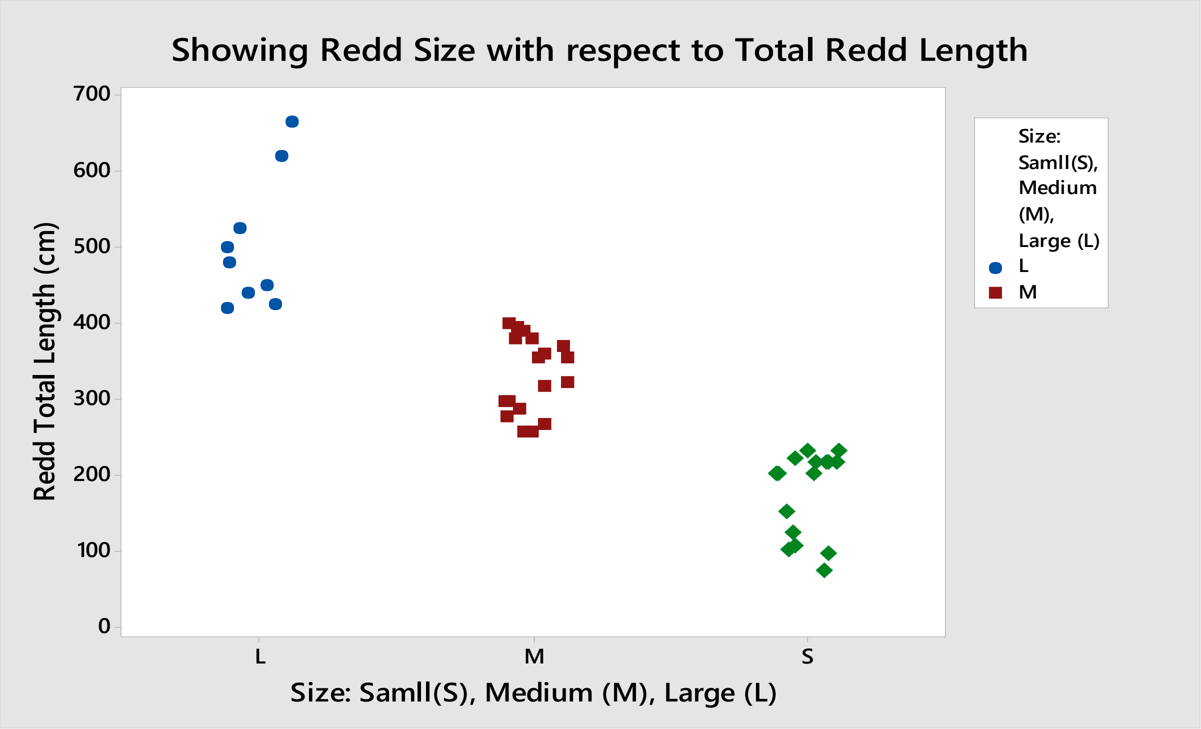


Figure 7: Dot graph of three different sizes of redd superimposed with density based on redd total length.

These three classes mostly likely reflect different redd size in the river. Redd size also depends on water velocity and substrate particle size(Jonsson & Jonsson, 2011).Medium sized redd was dominant (19 out of 44 redds) as compared to large and small sized redds (Fig 6). Also, medium sized redd was normally distributed as revealed by minitab data analysis (Fig. 6). Small sized redd was second most leading redd size and found to be 16 out of 44 redds in the Tokkeåi River. The figure 7 shows the density of brown trout redd with respect to total redd length. The density of medium sized redd was almost twice that of large sized redd (9 redds out of 44) as reveled by Fig 7.

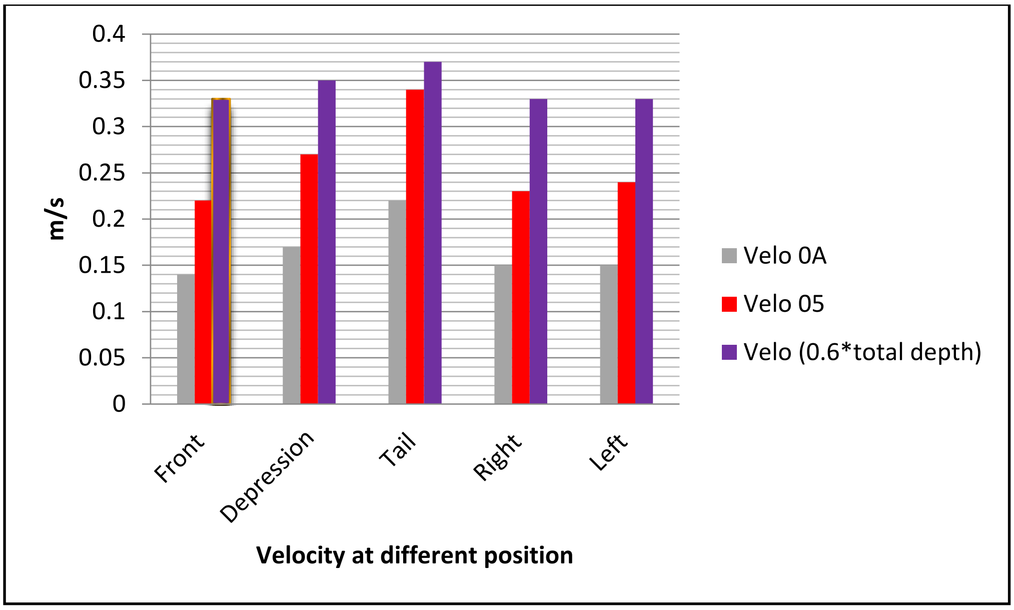


*Figure 8: The bar diagram illustrates the velocity at 0 cm (0A), 5 cm (05) and (0.6*total depth) above the bottom for five different positions in the redd, namely: Front center (a), Depression center(b), Tail center (c), Right side and Left side (see Fig. 2 for details).*

As expected, measured redd water velocities varied depending on position where measured. It is apparent from the graph (Fig. 10), velocity at 0 cm above the bottom of redd site was nearly less than half, i.e. 14 cm/s than the mean water colum velocity at 0.6*total depth which was 33 cm/s in front of redd. Also, velocity at (0.6* total length) above the bottom was the highest for all positions at the redd in Tokkeåi river. Water velocities measured in the redd tail (c), i.e, 22 cm/s at 0 cm, 27 cm/s at 5 cm above the bottom and 36.8 cm/s at 0.6*total depth were generally higher as compared to velocity at front, depression length, right and left.

3.3 Average Water Depths at Front, Depression, Tail, Right and Left

Average water depth is highest, i.e., 74.05 cm, in the center of the redd depression (Fig.10), as compared to other four positions for redd water depth. The differences were, however, rather small (Fig. 10; give data here in parentheses). Average water depths at the tail(c) was 65.75 cm, which is the lowest average depth measured.

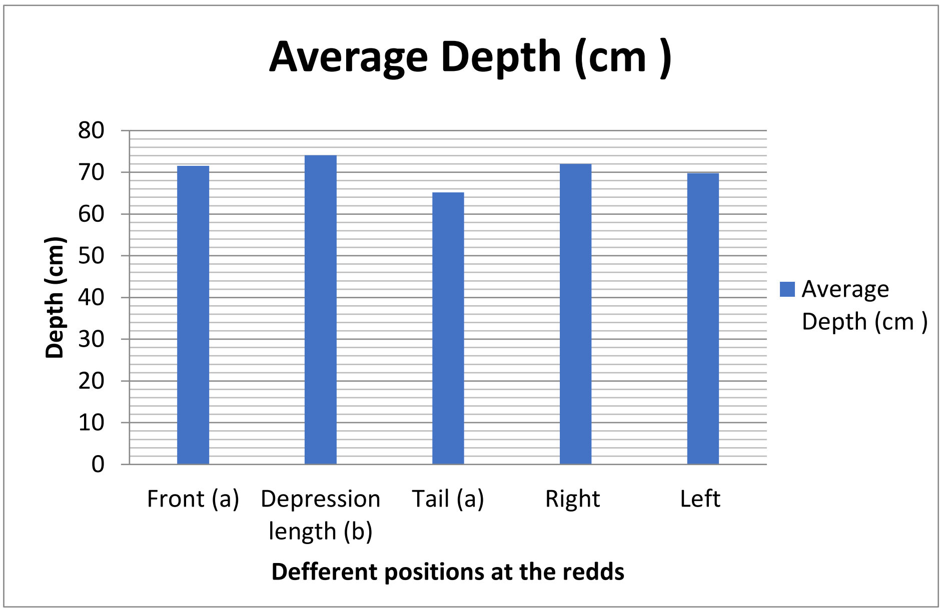


Figure 9: The bar diagram shows average depth at front (a), depression (b), tail (c), right and left (see Fig. 2 for details)

3.4 Correlation Analysis between Variables

3.4.1 Correlation Analysis between Water Depths (Average depth of A, B, C, D and E, Fig. 3) and Velocities at three different Positions

Table 2: The table shows Spearman's man rank correlations between water depths (Average of A, B, C, D and E) and water velocities at three different positions in the redd. Significant correlations are marked with asterisks.

Correlations						
			A: Depth	A: Velo 0A	A: Velo 05	A: Vel(0.6*total depth)
Spearman's rho	A: Depth	Correlation Coefficient	1.000	.137*	.157*	.048
		Sig. (2-tailed)	.	.042	.020	.476
		N	220	220	220	220

	A: Velo 0A	Correlation Coefficient	.137*	1.000	.735**	.363**
		Sig. (2-tailed)	.042	.	.000	.000
		N	220	220	220	220
	A: Velo 05	Correlation Coefficient	.157*	.735**	1.000	.582**
		Sig. (2-tailed)	.020	.000	.	.000
		N	220	220	220	220
	A: Velo 0/6	Correlation Coefficient	.048	.363**	.582**	1.000
		Sig. (2-tailed)	.476	.000	.000	.
		N	220	220	220	220
*. Correlation is significant at the 0.05 level (2-tailed).						
**. Correlation is significant at the 0.01 level (2-tailed).						

The correlation between redd's depth (average depth of A, B, C, D and E) (see Fig.3) and velocity at three positions (Velocity at 0 cm: 0A, 5 cm: 05 and 0.6*total length above the bottom) was significant. Both correlations were weak, i.e., r= 0.157 and 0.137 respectively (Table 2). However, the correlation between redd's depth (average depth of A, B, C, D and E) and velocity (0.6*total depth) was not significant at 0.05, i.e. P> 0.05.

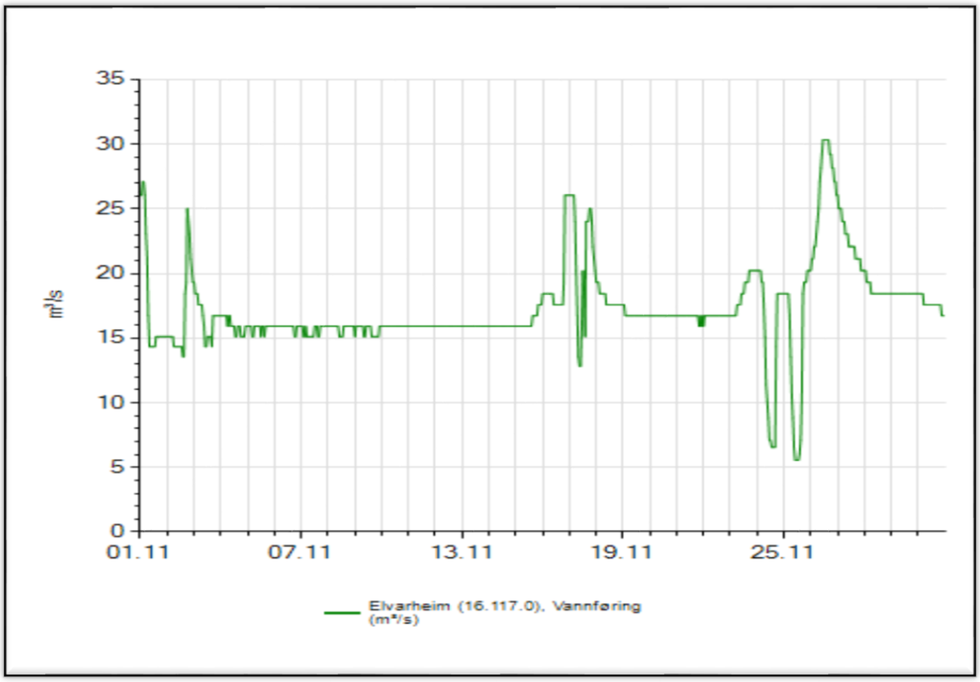


Figure 10: The above graph shows velocity of water(m^{3}s^{-1}) between 1st of November to 30th of November 2016 at Elvarheim in Tokkeåi River(NVE, 2018).

In figure12, water velocities of Tokkeåi River showed high fluctuation between 19th and 30th November 2016. The flow rate reduced to even less than 7 m^3s^{-1} on 25th of November but increased sharply to a peak of more than 30 m^3s^{-1} after one day. This flow regulation by Lio Power Plant has direct impact on spawning of brown trout in Tokkeåi river. Sudden increased in water level in the river can cause flooding, moving bottom substrates down to the river is vulnerable to trout spawning.

3.4.2 Correlation between Total Redd Length and Depth (average depth at A, B, C, D and E, See Fig 3) at the Redd

Table 3: Showing correlation between average depth (average depth at A, B, C, D and E) at redd and redd total length. Significant correlations are marked with asterisks.

Correlations

			Average depth at redd cm	Redd Total Length (cm)
Spearman's rho	Average depth at redd cm	Correlation Coefficient	1.000	.322*
		Sig. (2-tailed)	.	.033
		N	44	44
	Redd Total Length (cm)	Correlation Coefficient	.322*	1.000
		Sig. (2-tailed)	.033	.
		N	44	44

*. Correlation is significant at the 0.05 level (2-tailed).

The statistical result revealed, correlation between total redd length and water depth (average depth at A, B, C, D and E) at redd was found to be significant 5% level of significance (P= 0.033). Correlation (r= 0.322) between them were low to intermediate between these two variables.

3.5 Morphological Characteristics and Mesohabitats at the Redd Sites in Tokkeåi River

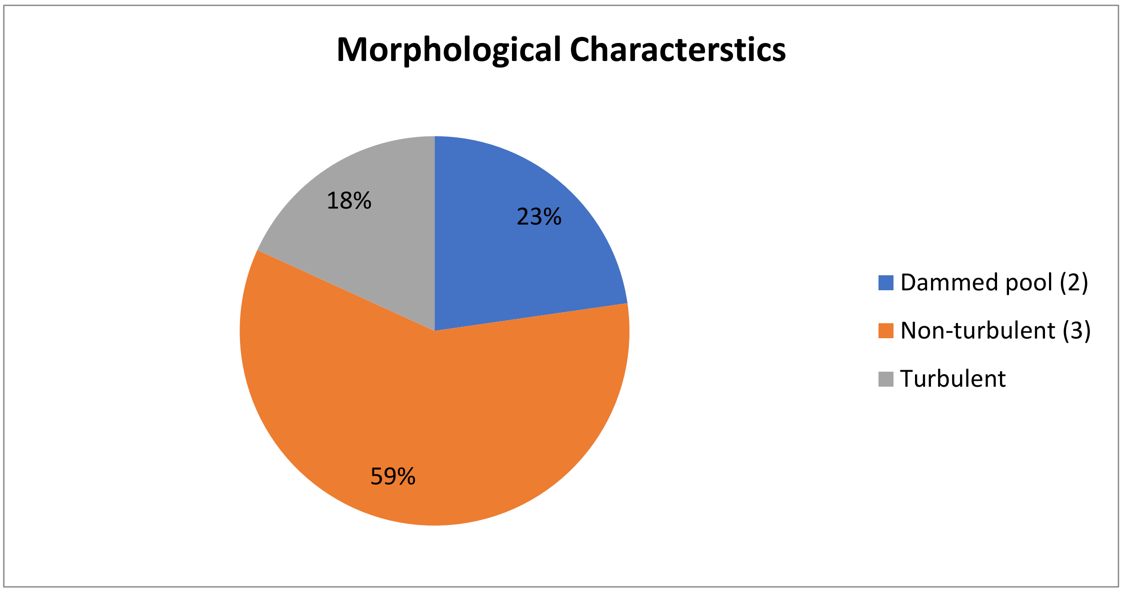


Figure 11: The pie chart depicts major type of morphology near redd in the study area.

Figure 13 shows the major morphological units at the observed and measured redd sites in Tokkeåi River. Out of the six types of morphological unit namely; scour pool, dammed pool, non-turbulent, turbulent, step-pool and water fall, non-turbulent was the most prevalent morpho dynamic unit at the redd sites, and was observed at 59 % (26 out of 44 redds) in the study area. Similarly, we also observed dammed pool (10 times out of 44, representing 23%) and turbulent (4 times out of 44, accounting for 18%) morphology near the red.

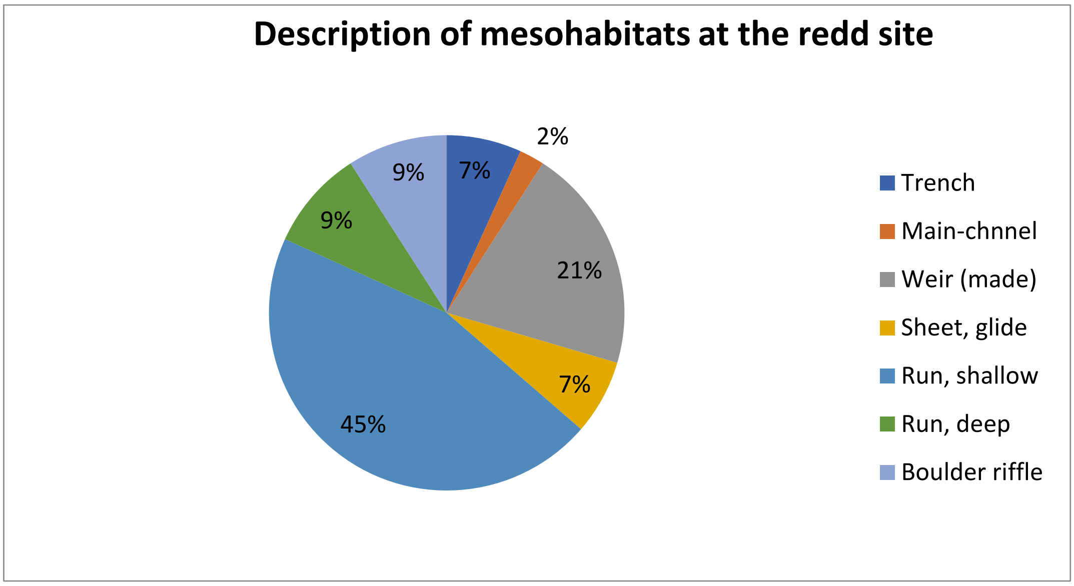


Figure 12: Description of mesohabitats at the redd in Tokkeåi River.

Run, shallow mesohabitat was predominant around redds, which accounts for 45% of the total mesohabitats types illustrated in (Fig 14). Weir (made) mesohabitat registered the second largest mesohabitat, 21%, Run, deep and boulder riffle were in equal proportion, each accounting for 9% of the total mesohabitat condition.

3.6 Flow Type at Spawning Redd in Tokkeåi River

Table 4: Major flow types at redd sites in Tokkeåi River.

Flow type	Code	No. of times
Scarcely perceptible	1	6
Smooth boundary turbulent	2	16
upwelling	3	0
Rippled water surface (with undular long profile)	4	21
Unbroken standing wave	5	1
Broken standing wave	6	0
chute flow (and broken standing waves)	7	0
Vertical free flow (fall)	8	0

Chaotic	9	0

According to the table 4, rippled water surface (with undular long profile) was the most dominant type of flow at the redd. Sooth boundary turbulent was the second prevalent flow type, seen 16 times out of 44 redds in the study area. Scarcely perceptible and unbroken standing wave flow type inhabited to the lesser extent.

3.7 Major Substrates in the Redds in Tokkeåi River

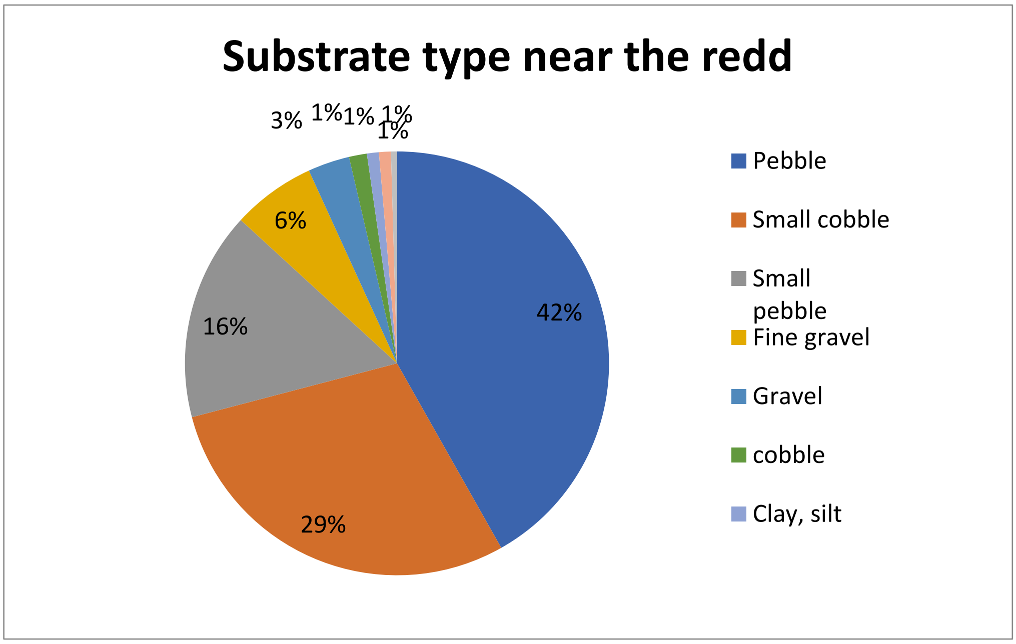


Figure 13: The pie-chart shows major substrate types in the redds in the study area.

Analysis of the substrate type data, indicated that, pebble is dominant substrate in the measured redd, and constitute 42% of the observations (Fig. 15). The size of the pebble was in the range of 31.1-64 mm (see annex 6). Also, small cobble was often found in the redds, i.e., at 29% of the measured site. Small cobble size was in the range 64.1-128 mm. We also found small pebble as the third largest substrate type proportion (16%), i.e., with substrate particle size in the range of (16.1-32) mm. The remaining 17% particles were fine gravel (6%), gravel (3%), cobble (1%), clay-silt (1%), sand (1%) and organic coarse (1%).

Majority of particle size was more than 83% were pebble, small cobble and small pebble was in the particle size range of 16.1-128 mm.

3.8 Relative Velocity and Relative Depth at Front, Depression Length, Tail, Right and Left at Redd in the Tokkeåi River.

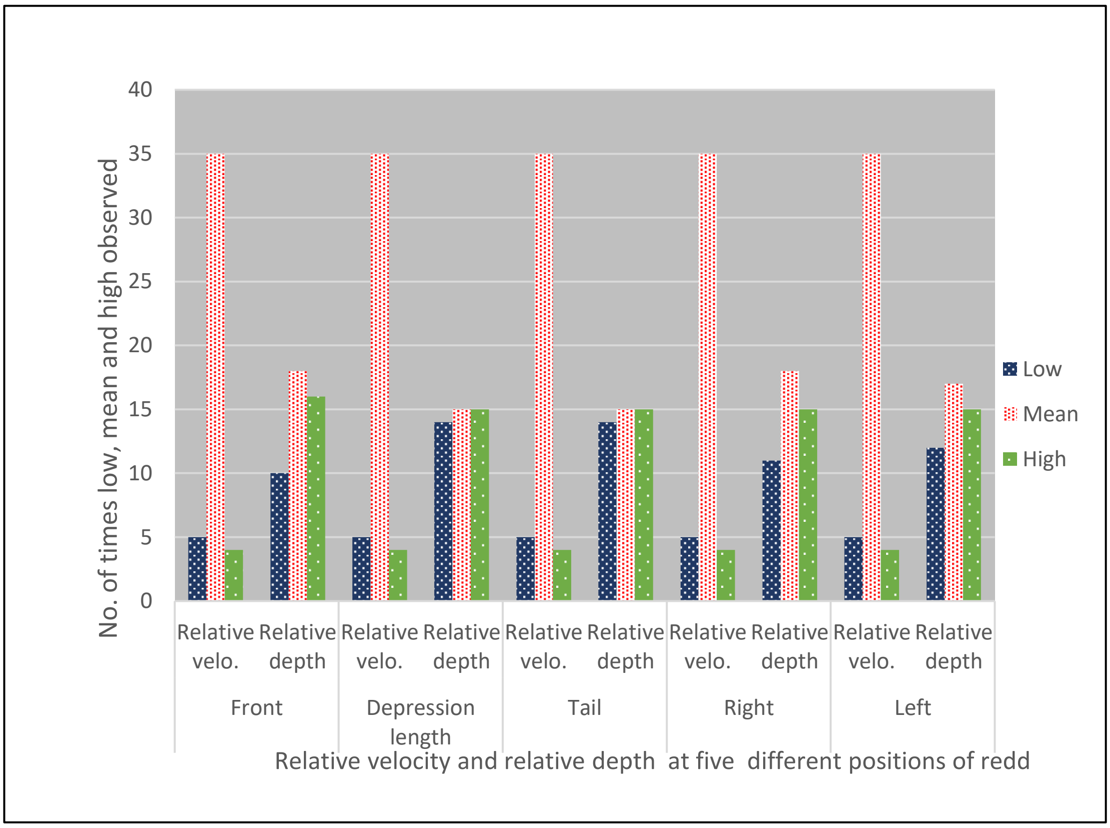


Figure 14: The bar diagram demonstrates relative velocity and relative depth at front, depression length, tail, right and left at redd in the Tokkeåi River.

Relative velocity was at mean for maximum number of observation and same at all five measured sites per redd namely (redd's front, depression, tail, left and right) as compared to surrounding river (Fig 16). On the other hand, relative depth was fluctuated at redd's (front, tail, right and left) whereas it was same at depression length and tail. Relative depth was high at redd's front, right and left in comparison to nearby river velocity.

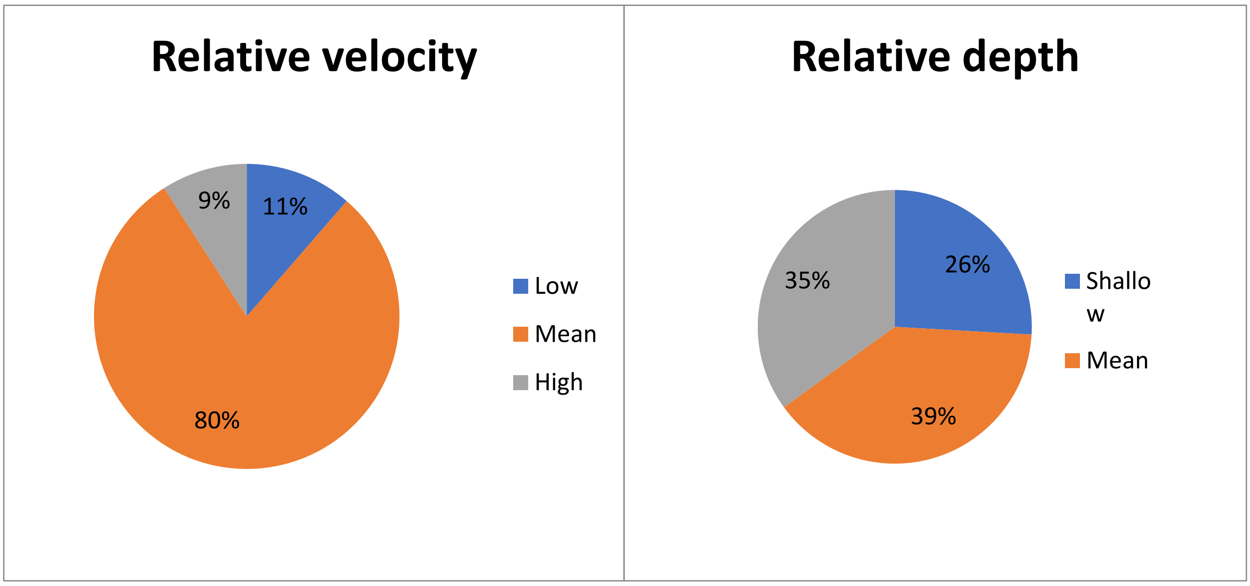


Figure 15: Pie charts shows relative velocity (average at A, B, C, D and E) and relative depth (average at A, B, C, D and E) at redd in the Tokkeåi River. (See Fig. 3)

Relative velocity and relative depth are observed based on direct observation at the redd. Relative velocity was most significant at mean and it was observed for around 80% of all sampling. It means that there was no apparent selection of redd sites that were substantially different from the immediately surrounding habitats with respect to water velocities. On the other hand, relative depth varied more, but with no apparent spatial pattern or direction, because it was nearly the same for all the three categories shallow, mean and deep.

4 Discussions

The present study describes suitable microhabitat mostly used by large brown trout for spawning with respect to total redd length, average depth, bottom substrate particle size and water velocity in the Tokkeåi River. Mean and standard deviation of total redd length (mean ± SD) in Tokkeåi River was (307.34 ±135.62) cm which was in the range of (665-74) cm. Mean and SD of total redd length is noticeably higher in 2016 compared to in 1998 and 2001. In 1998 and 2001, total redd length (mean ± SD) and the range was (192 ± 85) cm and (615-100) (Wollebæk et al., 2008). However, the range of total redd length in two study periods is apparently similar.

Similarly, mean, SD and range of the maximum width of redd (cm) in 2016 were 90 ± 38.37 (195-25) was found to be similar as compared to 1998 and 2001 which was 94 ±32 (235-45). In 2016, mean, SD and range of depression length at Redd was 134.25 ±72.08 (350-27) cm which was quite higher as compared to 1998 and 2001 which was 91 ±44 (380- 50).

Measured redd water velocities varied depending on the position where measured. Velocity at (0.6*total length) above the bottom was the highest for all position at the redd in Tokkeåi river. In front of redd, the velocity at 0 cm above the bottom was nearly less than half, i.e. 14 cm/s than the mean water column velocity at 0.6*total length which was 33 cm/s. However, in 1998 and 2001, the velocity at 0 cm above the bottom in front of redd was 20 m/s which was higher as compared to 2016. Water velocity in the redd's tail was always higher as compared to the front, depression, right and left. This result is same as compared to Crisp and Carling (1989), regardless of redd size, minimum 15 cm/s was required for spawning (D. Crisp & Carling, 1989). A study done by Heggberget et al. described that the mean velocities measured at 5 cm above the bottom and below the surface of water were in the range (27-55) cm/s is quite similar to current study (i.e., 27 cm/s) (Heggberget, Haukebø, Mork, & Ståhl, 1988).

Brown trout redd is the indication of number of fish showing spawning activity. Trout redd size can vary significantly with respect to fish size, but it also depends on substrate particle size and water velocity (Jonsson & Jonsson, 2011; Wollebæk et al., 2008). Medium sized redd was dominant 19 out of 44 redds in the river and normally distributed. The density of large-sized redds with respect to total redd length was just more than 50% of medium-sized redds. There was partial evidence for the effects of redd size on a distribution of redd.

In November 2016, 44 redds were measured in the study area. The number of redds in Tokkeåi River varies annually (Heggenes et al., 2017; Kraabøl et al., 2015). It depends on field conditions and survey methodology but also depends on flooding and river modification by hydropower company. The number of redds in 2012 and 2013 were 50 and 54 respectively which was quite higher as compared to 2016. However, in 2017, only 24 spawning redds was detected attributable to large flooding and huge mass movement of substrate particles in the river (Heggenes et al., 2017).

Average water depth is the highest, i.e. 74.05 cm, in the center of the redd depression as compared to other four positions. Also, in 1998 and 2001, average depth in front of redd was 85 cm, higher (71.51 cm) than in 2016 and average depth at the tail was 65.75 cm which is the lowest average depth measured at redd in Tokkeåi River.

Statistical analysis showed that the correlation between redd's depth (average depth of A, B, C, D, and E) (see Fig.3) and velocity at three positions (Velocity at 0 cm: 0A, 5 cm: 05 and 0.6*total length above the bottom) was significant. Both correlations were weak, i.e., r= 0.157 and 0.137 respectively (Table 2).

However, the correlation between redd's depth (average depth of A, B, C, D, and E) and velocity (0.6*total depth) was not significant at 0.05, i.e. P> 0.05 The correlation between total redd length and average depth at the redd was significant at 5 % level of significance (P < 0.05). Spearman rank correlation coefficient between these variables was (r=0.322). Spawning habitat used by brown trout is strongly influenced by depth of water in the stream (Jonsson & Jonsson, 2011; Kraabøl et al., 2015; Wollebæk et al., 2008). The larger size trout use deeper area so it requires more space and cover, so the correlation between water depth and trout size is strong (Heggenes, 1988).

The correlation between total redd length and average depth (average depth at A, B, C, D, and E) at the redd was positively correlated which is consistent with the result calculated by Wollebæk and Roy. Water velocity of Tokkeåi River displayed high fluctuation. This is due to river regulation by a Lio hydropower company, not only modifies river's surface particles but also increased water level in the river can cause unexpected flooding (Heggenes et al., 2016, 2017; Kraabøl et al., 2015). Flooding might be also another factor for the weak correlation between redd total length and average depth at five different positions in the redd. This can cause huge mass movement in the Tokkeåi River has adverse effects on spawning activities of large brown trout.

Brown trout might use non- turbulent morphology for most of the spawning activities in Tokkeåi River. Non-turbulent flow run-shallow and deep in the river stream was observed at 59% (26 out of 44 redds) was the most prevalent morpho dynamic unit at the redd sites. Run shallow and weir (made) mesohabitats were suitable for spawning. The proportion for both was 45% and 21% respectively. The same morphological condition is explained by Jonsson et al. in their book that brown trout spawn habitually in shallower and less swift waters (Jonsson & Jonsson, 2011).

Rippled water surface with undular long profile was seen nearly less than 50% (21 times out of 44 redds) at the redds site. Brown trout also prefer smooth boundary turbulent moderate flow for spawning. In small turbulent flows, cells were visible, water reflections are distorted and surface foam was moving in a downward direction. Brown trout can spawn in the large river, but most often they chose tributaries and small steams (Jonsson & Jonsson, 2011).

The large sized brown trout was selective in microhabitat use most often with respect to substrate type. The substrate particle size in the redd site varied noticeably. The most prevalent substrate was pebble (nearly 42%) and size in the range of 31.1-64 mm in the redd site. Similarly, small cobble size (64.1-128) mm constituted almost 29%. Fish always spawn in an area of the stream with a nonuniform particle size (Jonsson & Jonsson, 2011; Wollebæk et al., 2008). Majority of particle size, i.e. more than 83%, were the pebble, small cobble and small pebble and size in the range of 16.1-128 mm. Brown trout deposited their eggs between gravel and pebble with infrequent cobble and larger stone in between (Jonsson & Jonsson, 2011).

Relative velocity was at mean for the maximum number of observation (i.e.,80 %) and same at all five measured sites per redd viz. (redd’s front, depression, tail, left and right) as compared to the surrounding river. On the other hand, relative depth varied more, but with no apparent spatial pattern or direction, because it was nearly the same for all the three categories shallow, mean and deep

5 Conclusion and Recommendations

5.1 Conclusion

Large brown trout was selective in redd site microhabitat selection with respect to water velocity, depth and substrate particle size. Large brown trout redd size can be varied with reference to total redd length. Mean and standard deviation of total redd length (mean ±SD) in Tokkeåi was (307.34 ±135.62) cm which was in the range of (665-74) cm.

Water velocity in the redd's tail was always higher as compared to the front, depression, right and left in redd site. Average water depth is the highest, i.e. 74.05 cm, in the center of the redd depression. In general, total redd length size increased with increase in average depth at redd site, although, correlations between them was weak. Measurement of total redd length and average depth was significant and positively correlated. Redd size also influenced by water velocity at the different positions of redd site and positively correlated.

Brown trout use non- turbulent morphology and rippled water surface, smooth boundary turbulent flow for most of the spawning activities in Tokkeåi. Run shallow and weir (made) mesohabitats were also seen suitable for spawning. Majority of particle size, i.e. more than 83%, were pebble, small cobble and small pebble and size in the range of 16.1-128 mm in the redd. Relative velocity was at mean for the maximum number of observation (i.e.,80 %) and same at all five measured sites per redd. Relative depth varied more, but with no apparent spatial pattern or direction was observed.

In conclusion, the result obtained by this research is a basis for further study about the selection of spawning redd and can be used in the future for mitigation measure in Tokkeåi River. This finding could be used for improving spawning habitat to conserve the vulnerable large brown trout population. This will be helpful for the preservation, conservation, and production of brown trout not only in Tokkelåi River but also in other parts of Norway as well.

5.2 Recommendations

- The study should be continued further with same methodology and tools for comparative analysis of result in future.
- It is recommended that spawning redd counts should be continued as an environmental indicator.
- River modification by digging, evacuating of bottom substrate affects migration and spawning of large brown trout. So, hydropower regulation by Lio Power Plant in Tokkeåi should be minimized during spawning period of large brown trout.
- Core spawning area which is identified by this research should be monitored timely and can be developed as breeding centers for brown trout.

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7 List of Annexes

Annex 1: Showing Number of Redd with respect to Length and Size

	Max Width:a	**Deblengt : b**	**TailLengt h:c**	**Redd Total Length (cm)**
1	25	27	22	74
2	67	55	79	201
3	70	100	60	230
4	130	250	100	480
5	150	140	70	360
6	150	230	120	500
7	180	290	150	620
8	75	90	50	215
9	85	80	100	265
10	40	30	25	95
11	50	50	50	150
12	48	35	40	123
13	70	120	75	265
14	85	130	70	285
15	120	100	95	315
16	70	80	50	200
17	95	170	130	395
18	85	165	120	370
19	90	220	140	450
20	75	100	40	215
21	120	200	80	400
22	120	210	90	420
23	60	80	60	200
24	195	350	120	665
25	105	190	130	425
26	100	170	110	380
27	80	210	65	355
28	70	75	70	215
29	125	210	190	525
30	60	160	170	390
31	160	170	110	440
32	90	170	120	380
33	70	95	50	215
34	30	40	30	100
35	30	35	40	105
36	60	90	70	220
37	65	100	90	255

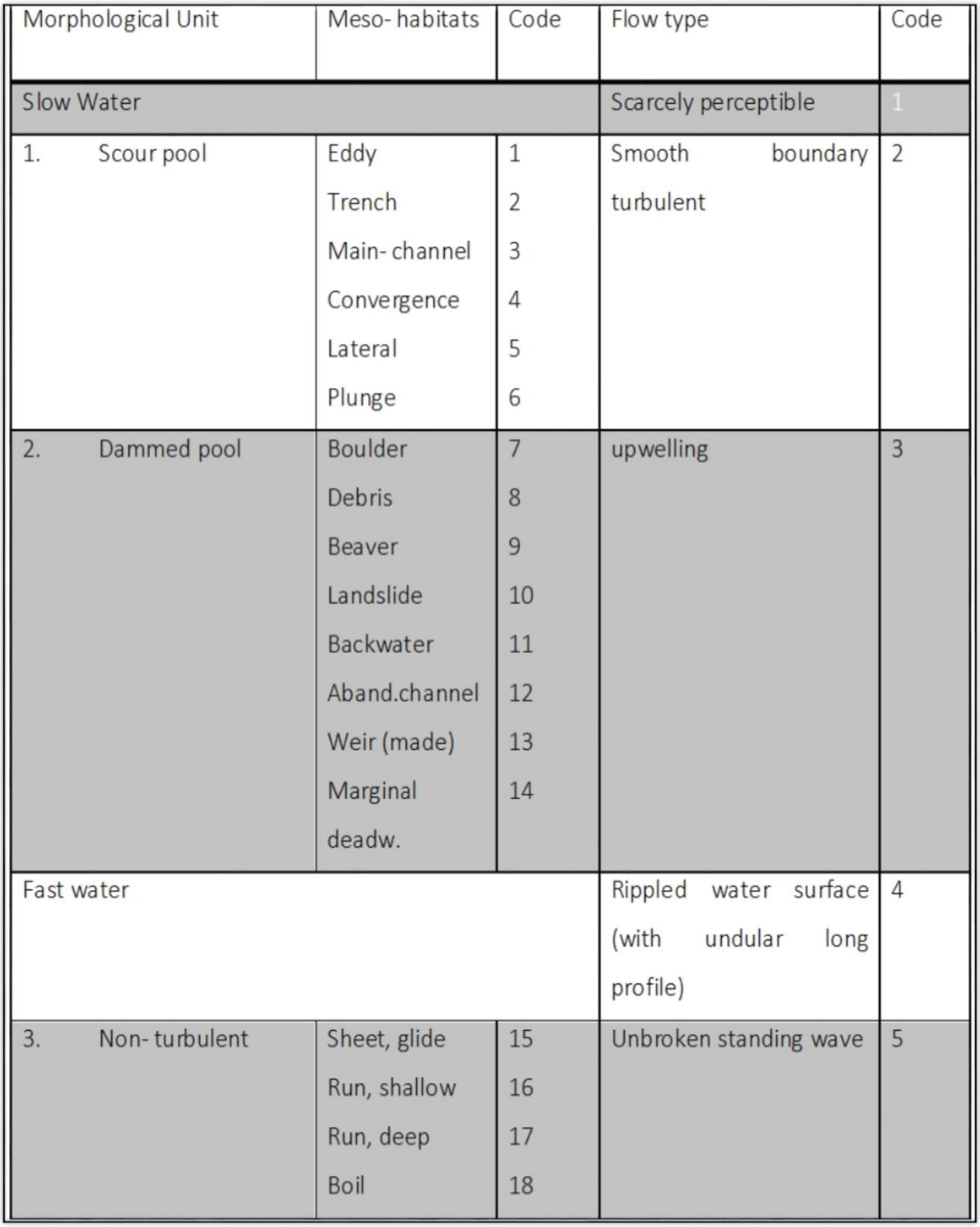
38	90	125	80	295
39	120	125	50	295
40	120	120	80	320
41	90	180	85	355
42	75	110	70	255
43	95	130	50	275
44	70	100	60	230

*Annex 2: The table demonstrates average depth and velocities at three different position (at 0 cm above the bottom, at 5 cm above the bottom and 0.6*total depth)*

A(Front)	Depth (cm)	Velocity 0A m/s	Velocity 05 m/s	Velocity at (0.6*total depth) m/s
Mean (x̄)	71.51	0.135	0.22	0.33
SD	20.26	0.11	0.12	0.15
Range	120-30	0.7-0.02	0.61-0.03	0.8-0.11
B (Depression)	Depth (cm)	Velocity 0A m/s	Velocity 05 m/s	Velocity at (0.6*total depth) m/s
Mean (x̄)	74.05	0.17	0.27	0.35
SD	20.48	0.11	0.16	0.17
Range	121-43	0.44-0.03	0.75-0.06	0.95-0.13
C (Tail)	Depth (cm)	Velocity 0A m/s	Velocity 05 m/s	Velocity at (0.6*total depth) m/s
Mean (x̄)	65.21	0.22	0.34	0.37
SD	20.15	0.16	0.20	0.18
Range	104-28	0.73-0.05	0.98-0.08	0.81-0.106
A(Right)	Depth (cm)	Velocity 0A m/s	Velocity 05 m/s	Velocity at (0.6*total depth) m/s
Mean (x̄)	72.02	0.15	0.23	0.33
SD	19.94	0.126	0.15	0.16
Range	117-40	0.68-0.03	0.71-0.04	0.95-0.09
A(Left)	Depth (cm)	Velocity 0A m/s	Velocity 05 m/s	Velocity at (0.6*total depth) m/s
Mean (x̄)	19.75	0.15	0.24	0.33
SD	18.92	0.12	0.17	0.18
Range	106-34	0.69-0.02	0.91-0.04	0.94-0.09

Annex 3: Observational classification of morphological and mesohabitats by morphology and flow type

(Newson & Newson, 2000; C. Padmore, 1998; C. L. Padmore, 1997)

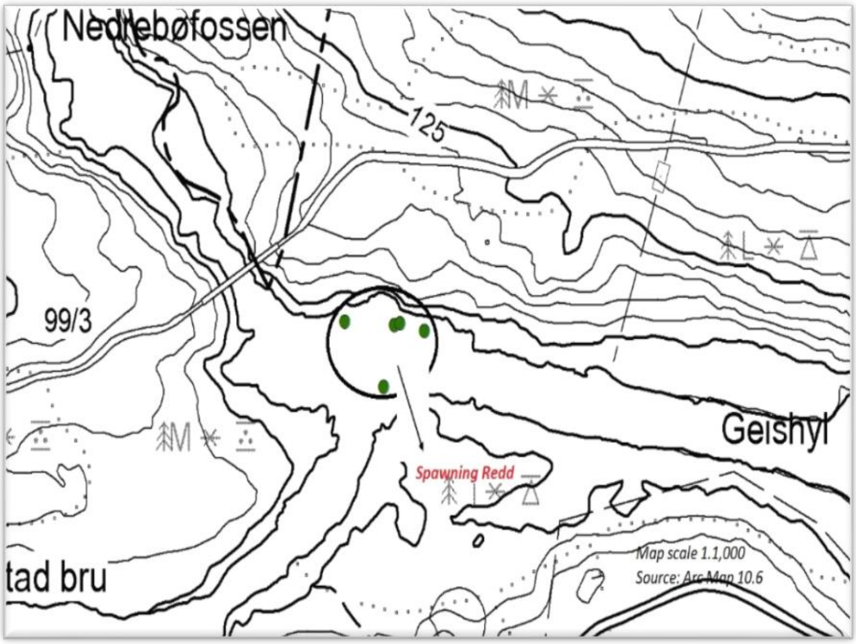


Morphological Unit	Meso- habitats	Code	Flow type	Code
Slow Water			Scarcely perceptible	1
1. Scour pool	Eddy Trench Main- channel Convergence Lateral Plunge	1 2 3 4 5 6	Smooth boundary turbulent	2
2. Dammed pool	Boulder Debris Beaver Landslide Backwater Aband.channel Weir (made) Marginal deadw.	7 8 9 10 11 12 13 14	upwelling	3
Fast water			Rippled water surface (with undular long profile)	4
3. Non- turbulent	Sheet, glide Run, shallow Run, deep Boil	15 16 17 18	Unbroken standing wave	5

Annex 4:Habitat Mapping in Tokkeåi River with ArcMap 10.6

The detail description of redd's geographical coordinate along with mapping and potential spawning bed is based on ArcMap 10.6 are shown below;

I. Number of redd found at the meeting point of Nedrebøfosse, Vistad bru and Geishyl

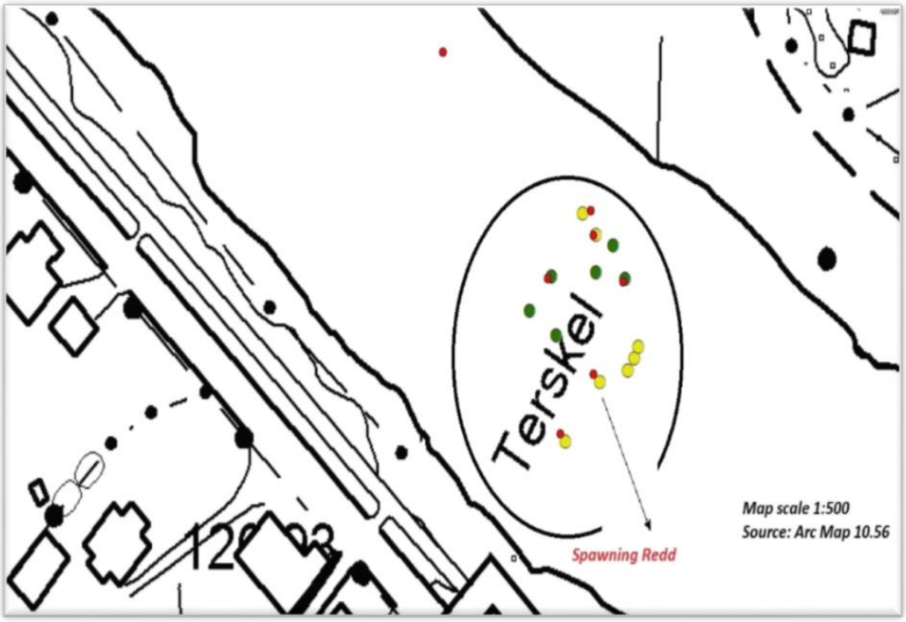


Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
1	440615.102, 6590749.074
2	440636.295, 6550748.2
3	440638.676, 6590748.28
4	440648.995, 6590746.375
5	440631.691, 6590728.912

II. Number redd found at Terskel infront of house +120/99

Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
6	441720.752, 65590148.779
7	441722.736, 6590150.102
8	441721.766, 6590153.053
9	441719.913, 6590156.492
10	441729.571, 6590162.975
11	441736.582, 6590168.531
12	441723.882, 6590174.616
13	441730.232, 6590178.453
14	441737.641, 6590180.437

III. Spawning redd at Terkel infrot of +120/4



Map scale 1:500
Source: Arc Map 10.56

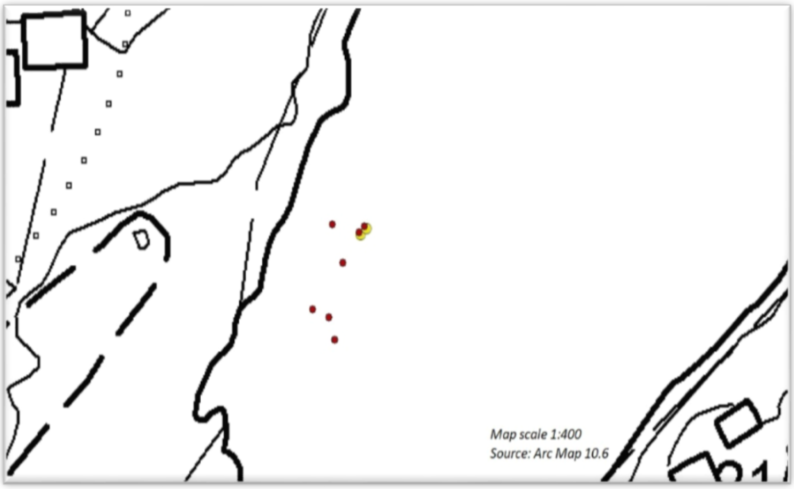
Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
15	441831.806, 6590050.527
16	441838.712, 6590060.21
17	441844.189, 6590062.115
18	441845.459, 6590064.02
19	441846.252, 6590065.925
20	441829.822, 6590067.751
21	441824.503, 6590071.72
22	441829.028, 6590077.197
23	441837.839, 6590077.832
24	441843.554, 6590076.8
25	441841.331, 6590082.277
26	441837.918, 650084.023
27	441835.219, 6590087.436

IV. Spawning redd at Huvestadhylen

Map scale 1:400
Source: Arc Map 10.6

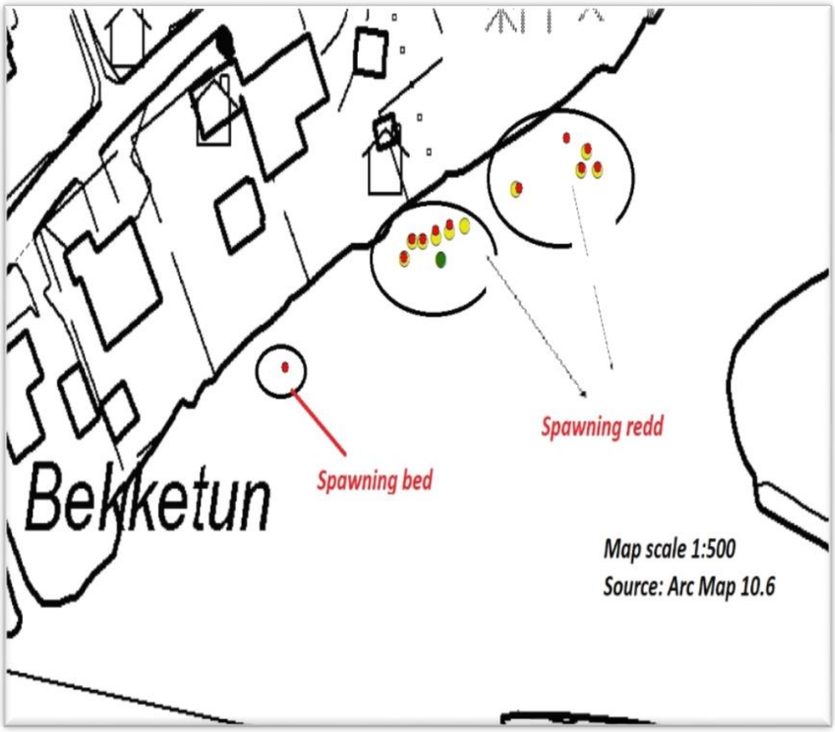
Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
27	442057.523, 6589983.111

V. Spawning redd and spawning bed marked with red color near Talleiv Huvestads veg infront of house no. +25/14



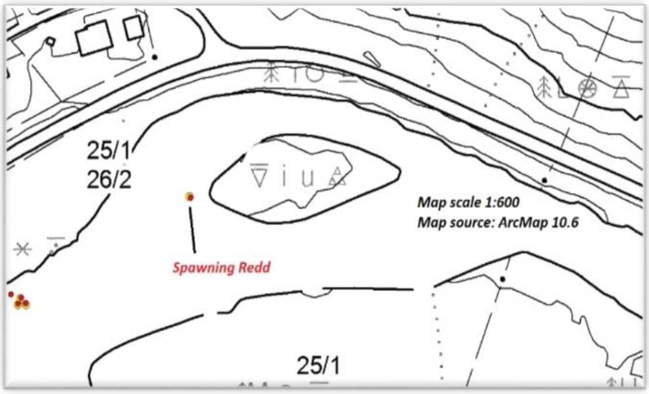
Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
28	442173.377, 6590104.019
29	442174.502, 6590105.011

VI. Spawning redd at Bekketun near house no. (+25/39)



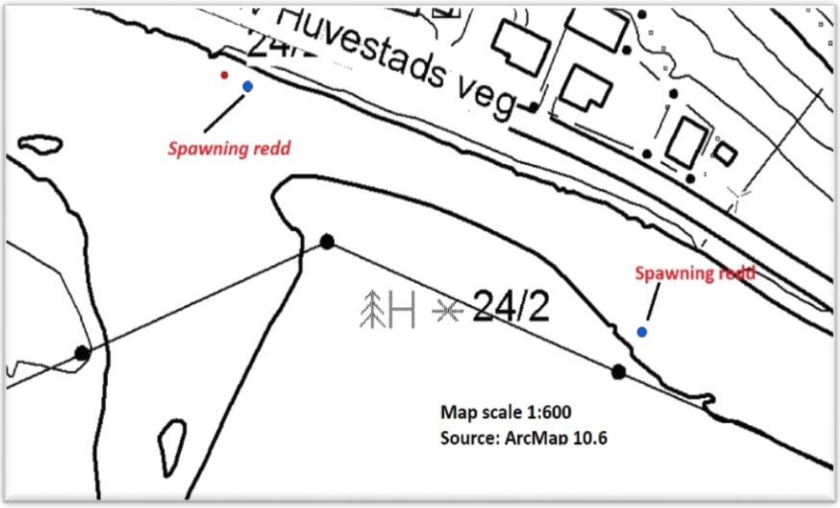
Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
30	442468.022, 6590483.024
31	442460.151, 6590483.156
32	442461.87,6590485.604
33	442464.119, 6594485.67
34	442467.096, 6590486.133
35	442469.94, 6590486.927
36	442473.247, 6590487.787
37	442484.426, 6590492.748
38	442498.581, 6590495.46
39	442499.64, 6590497.973
40	442502.153, 6590495.393

VII. Spawning redd at Lindøy



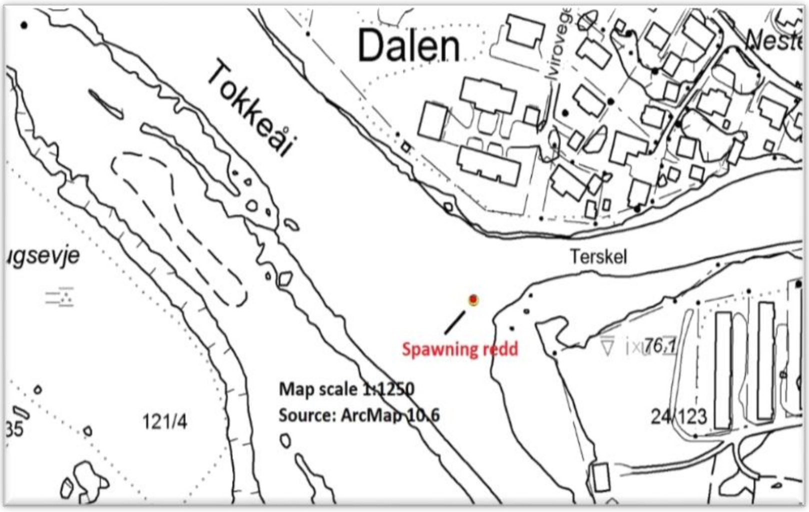
Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
41	442575.595, 6590540.26

VIII. Spawning redd at Talleiv Hauvestads veg in front of house (+24/2) and (24/2)



Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
42	442878.279, 6590489.301
43	442980.739, 6590430.762

IX. Spawning redd at Terskel



Redd No.	Geographic Co-ordinate Longitude and Latitude (meter)
44	443478.818, 6589721.942

Annex 5: The table shows relative velocity and relative depth at front, depression length, tail, right and left at redd in the Tokkeåi River.

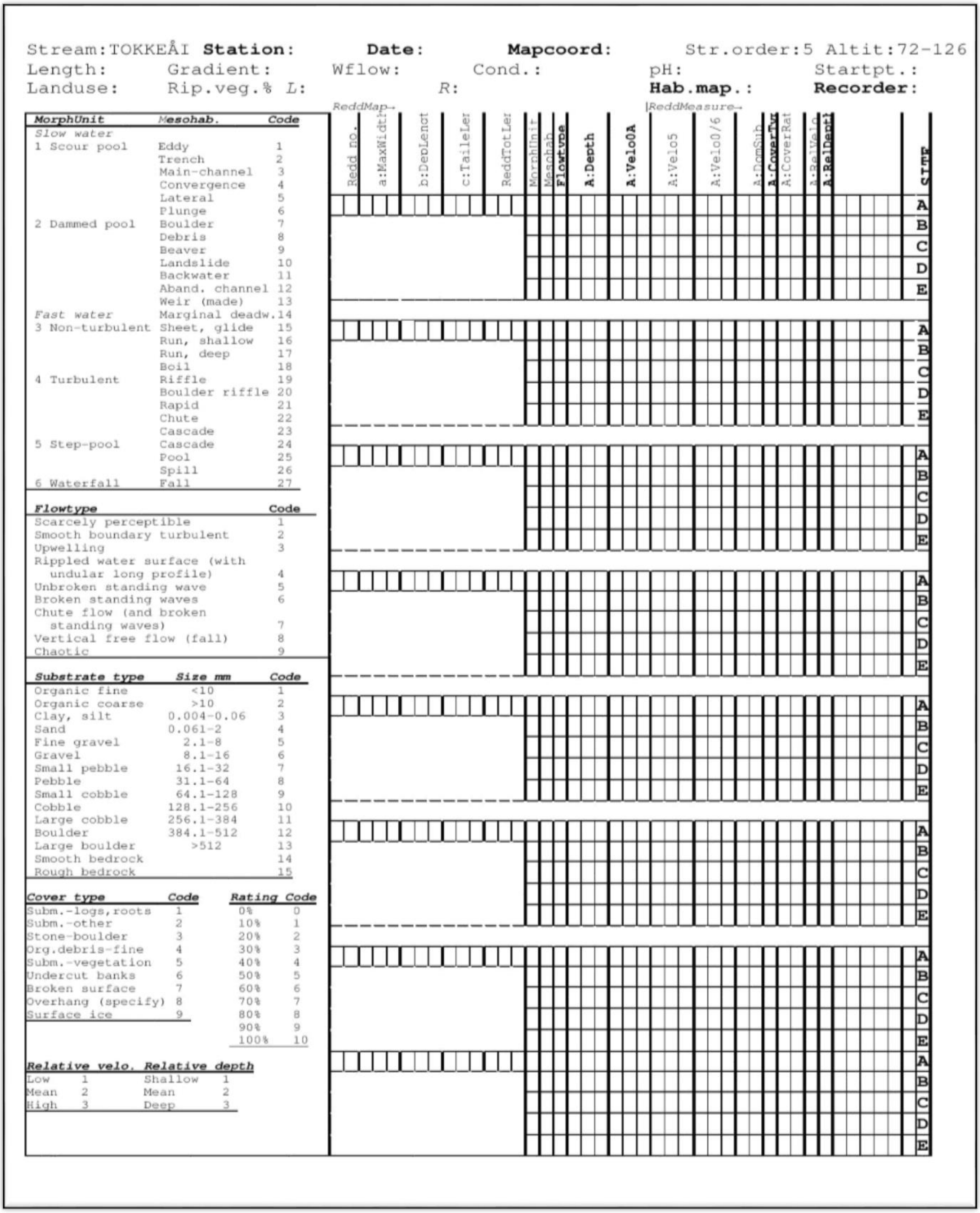
	Tail		Right		Left	
	Relative velo.	Relative depth	Relative velo.	Relative depth	Relative velo.	Relative depth
Low	5	14	5	11	5	12
Mean	35	15	35	18	35	17
High	4	15	4	15	4	15

	Front		Depth length	
	Relative velo.	Relative depth	Relative velo.	Relative depth
Low	5	10	5	14
Mean	35	18	35	15
High	4	16	4	15

Annex 6: Substrate types with respect to their sizes

Substrate type	Size mm	Code
Organic fine	< 10	1
Organic course	>10	2
Clay, silt	0.004-0.06	3
Sand	0.061-2	4
Fine gravel	2.1-8	5
Gravel	8.1-16	6
Small pebble	16.1-32	7
Pebble	32.1-64	8
Small cobble	64.1-128	9
Cobble	128.1-256	10
Large cobble	256.1-384	11
Boulder	384.1-512	12
Large boulder	>512	13
Smooth bedrock		14
Rough bedrock		15

Annex 7: The Field Sheet used during the field work



Stream:TOKKEÅI **Station:** **Date:** **Mapcoord:** Str.order:5 Altit:72-126
Length: Gradient: Wflow: Cond.: pH: Startpt.:
Landuse: Rip.veg.% *L*: *R*: **Hab.map.:** **Recorder:**

ReddMap→ *|ReddMeasure→*

Redd no.	a:MaxWidtr	b:DepLenct	c:TaileLer	ReddTotLer	MorphUnit	Mesohab	**Flowtype**	**A:Depth**	**A:Velo0A**	A:Velo5	A:Velo0/6	A:DomSub	**A:CoverTyr**	A:CoverRat	A:RelVelo	**A:RelDeptl**		**SITE**
																		A
																		B
																		C
																		D
																		E

MorphUnit	***Mesohab.***	***Code***
Slow water		
1 Scour pool	Eddy	1
	Trench	2
	Main-channel	3
	Convergence	4
	Lateral	5
	Plunge	6
2 Dammed pool	Boulder	7
	Debris	8
	Beaver	9
	Landslide	10
	Backwater	11
	Aband. channel	12
	Weir (made)	13
Fast water	Marginal deadw.	14
3 Non-turbulent	Sheet, glide	15
	Run, shallow	16
	Run, deep	17
	Boil	18
4 Turbulent	Riffle	19
	Boulder riffle	20
	Rapid	21
	Chute	22
	Cascade	23
5 Step-pool	Cascade	24
	Pool	25
	Spill	26
6 Waterfall	Fall	27

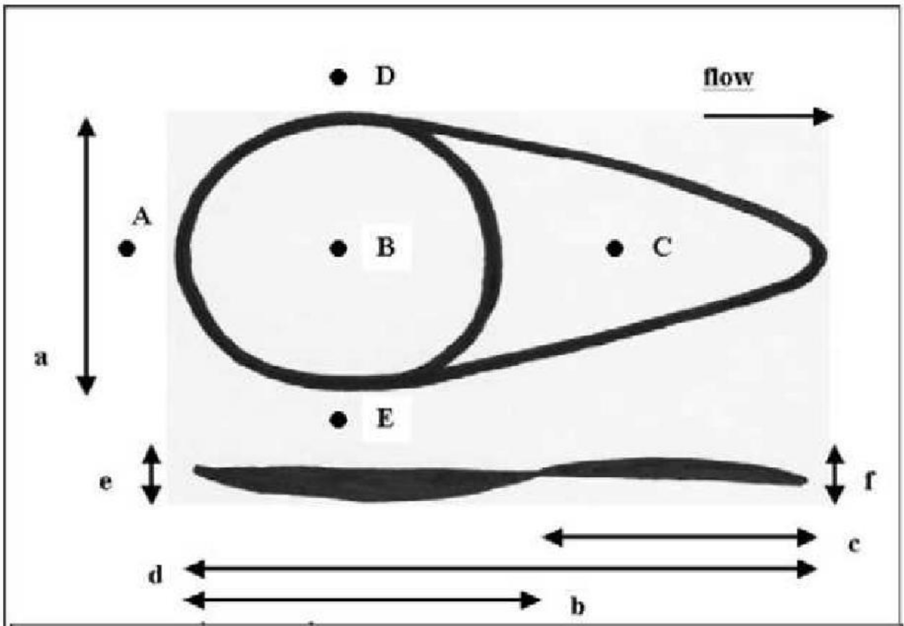
Flowtype	***Code***
Scarcely perceptible	1
Smooth boundary turbulent	2
Upwelling	3
Rippled water surface (with undular long profile)	4
Unbroken standing wave	5
Broken standing waves	6
Chute flow (and broken standing waves)	7
Vertical free flow (fall)	8
Chaotic	9

Substrate type	***Size mm***	***Code***
Organic fine	<10	1
Organic coarse	>10	2
Clay, silt	0.004-0.06	3
Sand	0.061-2	4
Fine gravel	2.1-8	5
Gravel	8.1-16	6
Small pebble	16.1-32	7
Pebble	31.1-64	8
Small cobble	64.1-128	9
Cobble	128.1-256	10
Large cobble	256.1-384	11
Boulder	384.1-512	12
Large boulder	>512	13
Smooth bedrock		14
Rough bedrock		15

Cover type	***Code***
Subm.-logs,roots	1
Subm.-other	2
Stone-boulder	3
Org.debris-fine	4
Subm.-vegetation	5
Undercut banks	6
Broken surface	7
Overhang (specify)	8
Surface ice	9

Rating	***Code***
0%	0
10%	1
20%	2
30%	3
40%	4
50%	5
60%	6
70%	7
80%	8
90%	9
100%	10

Relative velo.		***Relative depth***	
Low	1	Shallow	1
Mean	2	Mean	2
High	3	Deep	3



A: redd head, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth, substrate undisturbed

B: depression, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth, 5 cm subsurface)

C: redd tail, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth

D: right side, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth

E: left side, depth, water velocity at 0 cm, 5 cm, 0.6 x total depth

- **a**: maximal width
- **b**: depression length
- **c**: tail length
- **d**: redd total length
- **e**: maximum vertical depth (depth B – depth A)
- **f**: maximum vertical height (depth A – depth C)

FIGURE 2.—Diagram of a brown trout spawning redd, depicting locations and horizontal or vertical measurements of water velocity (cm/s), depth (cm), substrate particle size (cm), length (nearest 5 cm), and width (nearest 5 cm).