The freshwater shrimp *Gammarus lacustris* (Malacostraca, Amphipoda) in lakes on the Hardangervidda mountain plateau, southern Norway: distribution and environmental requirements

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The distribution of the amphipod *Gammarus lacustris* on the Hardangervidda mountain plateau was mapped by screening published data from 245 lakes in 11 and 16 catchments in western and central/eastern areas, respectively. These data are primarily based on stomach analyses of brown trout *Salmo trutta*. In central/eastern areas, *G. lacustris* was recorded in 79% of all the lakes examined, while there are only two former records (4%) in the western area. The distribution pattern of *G. lacustris* on Hardangervidda appears to be related to environmental conditions. The apparent absence of *G. lacustris* in the western area may be explained by a combined effect of cold water due to higher deposits of snow and water with low ionic strength as a consequence of its bedrock of Precambrian gneisses and granites with little or no moraine cover. However, lakes in central/eastern areas sustain *G. lacustris* in spite of dilute water, as *G. lacustris* has been recorded in 89 lakes of which 28% had calcium concentration <1.0 mg L^{-1}, eight of them with pH <6.0. The lower lethal threshold for calcium concentration seems to be ~0.5 mg L^{-1}. *Gammarus lacustris* was found in lakes at altitudes of 832 to 1396 m a.s.l. Furthermore, their occurrence increased significantly with lake size, being 69% in lakes <1.0 km^2 and 97% in larger lakes. The number of refugia with better water quality is likely to increase with lake size. *Gammarus lacustris* is highly searched for as prey by all size groups of brown trout (15-45 cm). Access to proximity refugia that reduce predation pressure from fish may also increase with lake size. Climate changes are now in progress in this mountain area, and detailed mapping of *G. lacustris* is important in order to trace future range changes.

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INTRODUCTION

The amphipod *Gammarus lacustris* G.O. Sars, 1863 is a typical benthic littoral species, preferring shallow vegetated areas down to five m (Dahl 1915, 1917). *Gammarus lacustris* is an omnivore grazing on plant debris both from within the lakes and from allochthonous material, and to some extent, also preying on animals, including conspecifics (Dahl 1915; Wilhelm & Schindler 2000; Rognerud *et al.* 2003). Thus, *G. lacustris* plays an important ecosystem role in linking terrestrial detritus and periphytic algal production to higher trophic organisms such as fish. In the old days, *G. lacustris* was a problem for the fisheries due to its attraction to and destroying the fishing nets made of cotton, linen or hemp (Dahl 1915). Seen in retrospection, these materials might have been optimal substrates for periphytic algae.

The Hardangervidda mountain plateau is the largest peneplain (eroded plain) in Europe (Anonymous 1974). *Gammarus lacustris* was early stated as a staple food item for brown trout *Salmo trutta* Linnaeus, 1758 in lakes on this mountain plateau (Huitfeldt-Kaas 1911; Dahl 1917; Sømme 1941). Here, the brown trout is the only species in most lakes (Qvenild & Hesthagen 2019). They are rated among the best brown trout lakes in Norway, hosting large fish of high quality (Sømme 1941). A rich supply of crustacean food items is regarded as the main reason for prolonged growth of brown trout to sizes of one to three kg and even more (Huitfeldt-Kaas 1911; Dahl 1917; Sømme 1941). The largest brown trout properly reported on Hardangervidda was 81 cm in length and with a weight of 7.6 kg (Borgstrøm 2016). However, specimens greater than this are known; e.g. ~11 kg (Qvenild 2004). *Gammarus lacustris* is a conspicuous large (~1-2 cm) food item, often occurring with a grey-brown body that is easy to observe.

Thus, it is familiar to local fishermen and has a variety of local names such as “marflo, matflo, grunnåte, nettskjær, etc.” (Dahl 1915). The easy access to crustacean food items is also reflected in the carotenoid coloured flesh of brown trout, which makes them highly valued as human food.

Gammarus lacustris has a circumpolar distribution and is widely distributed in Norwegian lakes, indicating that it is well adapted to a wide range of environmental conditions (Økland & Økland 2007). The species is highly sensitive to acid water and it is frequently used as an indicator species, being not present at pH values <5.5 (Fjellheim & Raddum 1990). It is not usually found in lakes with pH <6.0 (Økland & Økland 2007). Furthermore, calcium is essential to all crustaceans and low levels may also affect their survival and pattern of distribution (Rukke 2002; Cairns & Yan 2009). In their review paper, Cairns & Yan set the lower lethal threshold of calcium for gammarids slightly above 1.0 mg L^{-1}, although lower levels at higher pH values have been recorded (Økland & Økland 2007). On Hardangervidda, there are many lakes with waters low in calcium (<1.0 mg L^{-1}) and with corresponding pH <6.0 (Skjelkvåle & Henriksen 1998). Even though gammarid studies suggest that crustacean populations may be somewhat adaptable to existence in calcium-poor environments (Cairns & Yan 2009), we hypothesize that *G. lacustris* in such lakes is living near to its lethal thresholds. To the extent that it is present in such dilute waters, additional stressors such as low thermal input and fish predation may be detrimental.

In mountain lakes in southern Norway, *G. lacustris* seem to have a preference for the temperature range of 10 to 14°C in summer (Økland & Økland 2007). Even though it appears to tolerate a wide range of temperatures, a minimum thermal input is needed to complete the life cycle. This is reflected in the phenotypic plasticity in its reproductive traits (Dahl 1915; Bjerknes 1974; Wilhelm & Schindler 2000; Økland & Økland 2007; Østbye *et al*. 2018). Both altitude and snow deposition provide a variety of temperature regimes in lakes on Hardangervidda (Qvenild & Hesthagen 2019), which is likely to affect the distribution and abundance of *G. lacustris* (Rukke 2002; Økland & Økland 2007).

With its perennial life cycle, *G. lacustris* is a permanently available food resource for fish in alpine lakes (Dahl 1930). However, heavy fish predation may affect both abundance and demographic structure, either temporarily or permanently (Dahl 1915, 1917; Sømme 1941; Aass 1969; Wilhelm & Schindler 2000; Museth & Borgstrøm 2010; Qvenild & Rognerud 2018). As fish may well exert high predation pressure on *G. lacustris*, access to proximity species refugia could be crucial in optimising its survival at a local level.

The distribution pattern of *G. lacustris* on Hardangervidda appears to be skewed, with most of the known localities being in the central and eastern areas (Anonymous 1974). However, their distribution has only been partially mapped. The main goal of this study was to compile for new records in the pertinent literature from this mountain plateau. To analyse the distribution pattern, we separated the area into a western and central/eastern region, due to differences in their geology, water quality and snow deposition. Our key question is whether the distribution pattern of *G. lacustris* on Hardangervidda can be explained by these environmental conditions.

MATERIAL AND METHODS

Study area

The Hardangervidda landscape is characterized by barren, treeless moorland interrupted by numerous pools, lakes, rivers and streams. The plateau covers an area of about 9800 km^2, of which the most remote parts account for about 8000 km^2 (Anonymous 1974). Our study area included 27 catchments (Table 1), comprising 6569 km^2 (Qvenild & Hesthagen 2019). The extent of these catchments was calculated using the NEVINA procedure (NVE Atlas, nve.no). In these catchments, 930 named lakes covering 656 km^2 have been identified (NVE Atlas, nve.no). They are located at altitudes between 414 to 1527 m a.s.l. and range in size from 0.004 to 78.77 km^2. In addition, there are approximately 11,600 small unnamed lakes and ponds ranging in size between 0.0006 and 0.7035 km^2 with a total area of 157 km^2 (Qvenild & Hesthagen 2019). Of the named lakes, 85% are situated at altitudes of 1100 to 1399 m a.s.l., while 11 and 4% are located at lower and higher altitudes, respectively. Most of the 36 natural lakes with bathymetric maps on Hardangervidda have a mean depth of <10 m (Qvenild & Hesthagen 2019). The 930 named lakes include 27 reservoirs for hydropower production, ranging in size from 0.48 to 78.77 km^2 (Appendix 1). The annual water level fluctuation ranged from 0.5 to 91.9 m, most of the lakes being regulated >10 m (77%) and 58% >20 m (NVE Atlas, nve.no).

The western area of Hardangervidda is dominated by rocky terrain and expanses of bare rock with thin or no moraine-covered bedrock of Precambrian gneisses and granites with sparse or no vegetation. The catchments in the eastern area also cover gneisses and granites, but due to deeper layers of the moraine, they are usually more vegetated. In the central part of Hardangervidda, the bedrock of Cambro-Silurian sedimentary origin provides a richer soil.

The water chemistry in the lakes closely reflects the local bedrock geology (Skjelkvåle & Henriksen 1998). The Hardangervidda National Park covers an area of 3422 km^2 in the most remote part of the plateau. Here, a detailed water quality monitoring programme was conducted in 102 lakes in 1997 (Skjelkvåle & Henriksen 1998). The water chemistry varied greatly, from lakes with very dilute water, to lakes with high ionic strength (conductivity range 0.53–3.63 mS m^{-1}). The calcium concentration and pH ranged between 0.33–5.73 mg L^{-1} and 5.35–7.28, respectively. The total organic carbon content (TOC) is low, as 85% of the lakes had <2.0 mg C L^{-1}. Lakes in the western area are particularly low in TOC with a mean of ~0.3 mg C L^{-1}.

There is a highly seasonal variation in both pH and calcium in lakes on Hardangervidda. The lowest pH and the highest values of calcium are usually recorded in the spring (Fjellheim *et al*. 2002, 2007, 2018). In fact, in small lakes and brooks, the calcium concentration in spring may be more than twice the minimum value later in the season. In bigger lakes, these variations follow the same pattern, but to a much smaller extent. We assume that the minimum ambient calcium value through the summer and autumn is the most critical for *G. lacustris* when the neonates develop into adults. Hence, we only used data from this period when assessing the occurrence of *G. lacustris*. We have summer-autumn values for calcium concentration with corresponding pH values from 219 natural lakes (Appendix 1).

The climatic conditions on Hardangervidda are also highly variable (Qvenild & Hesthagen 2019). The winter and summer precipitation are computed using the NEVINA procedure (NVE Atlas, nve.no) as mean values for the normal period 1961-1990 (Table 1). The snow deposition (October-April) differs substantially in a west to east gradient with an almost four-fold decrease from 1151 mm in Austdølo/ Ljoso catchment to 292 mm in Uvdalselvi catchment. The mean summer precipitation (May-September) in these two catchments varied less; being 614 and 332 mm, respectively. The mean winter and summer temperatures are computed similarly (Table 1).

Table 1. Number of lakes examined for *Gammarus lacustris* in the 27 catchments (no 1–20) studied on Hardangervidda (6569 km^2) of which 20 and 80% are in the western (W) or central/eastern (C/E) region, respectively. The mean winter and summer precipitation (mm) and winter and summer temperatures (°C), are given for the normal period 1961-1990 computed by the NEVINA procedure (NVE Atlas, nve.no). Of the 245 lakes properly examined for *Gammarus lacustris,* 65% produced positive records. Many of the lakes are repeatedly investigated given with a factor in the last column (RE = number of examinations/number of examined lakes).

No.	Catchment	Region	Catchment km^2	Lake area km^2	Winter precipitation (mm)	Summer precipitation (mm)	Winter temp. (°C)	Summer temp. (°C)	Total no. of lakes	No. of lakes exam.	% of lakes exam.	Lakes with positive records	% lakes with positive records	No. exam.	Repeat examinations (RE)
1	Austdøla	W	121	13	1 000	594	-4.2	4.3	22	10	45	0	0	16	1.60
2	Sima	W	121	4	832	504	-5.1	3.1	14	1	7	0	0	2	2.00
3A	Isdølo	C/E	55	2	725	434	-4.5	4.1	6	1	17	1	100	2	2.00
3B	Leiro	C/E	211	18	571	406	-6.1	3.7	22	8	36	1	13	12	1.50
3C	Svinto	C/E	35	0	497	356	-7.9	4.3	2	1	50	1	100	2	2.00
4	Bjoreio	C/E	150	9	527	356	-6.9	4.2	14	3	21	3	100	15	5.00
5	Veig	C/E	395	10	669	375	-5.9	4.4	37	20	54	12	60	37	1.85
6A	Erdalsvassdraget	C/E	63	1	809	387	-1.8	6.0	2	2	100	2	100	5	2.50
6B	Bjotveitelvi	W	16	1	944	447	-1.4	6.4	2	1	50	1	100	4	4.00
7A	Kinso	C/E	210	14	900	435	-4.0	4.5	31	15	48	7	47	35	2.33
7B	Vivippo	W	39	1	919	423	-1.6	5.7	4	3	75	0	0	5	1.67
8	Opo	W	63	4	984	460	-2.0	5.2	10	4	40	0	0	4	1.00
9A	Espeelvi	W	9	0	938	489	-2.7	5.1	1	1	100	0	0	1	1.00
9B	Vendo	W	29	4	1 013	518	-3.3	4.0	2	1	50	0	0	2	2.00
10	Tysso	W	381	44	1 062	590	-4.2	4.1	46	20	43	0	0	53	2.65
11	Austdølo/Ljoso	W	120	9	1 151	614	-3.2	4.5	13	3	23	0	0	3	1.00
12	Suldalsvassdraget	W	217	10	984	586	-5.3	3.9	7	1	14	0	0	2	2.00
13	Bora	W	171	18	742	442	-5.9	4.5	34	2	6	1	50	6	3.00
14	Songa	C/E	379	42	582	400	-5.8	4.8	44	11	25	6	55	25	2.27
15	Kvenna	C/E	828	61	571	390	-7.8	4.5	99	39	39	30	77	146	3.74
16	Møsvatn	C/E	525	104	434	380	-6.1	4.7	103	5	5	3	60	6	1.20
17	Mår/ Gøyst	C/E	732	102	304	339	-6.7	4.8	156	13	8	13	100	28	2.15
18A	Uvdalselvi	C/E	196	10	292	332	-6.6	5.1	39	5	13	5	100	10	2.00
18B	Ølmosåi	C/E	188	22	314	355	-6.8	4.8	37	5	14	4	80	11	2.20
19A	Lågen	C/E	1 179	134	511	344	-8.1	4.7	154	60	39	59	98	233	3.88
19B	Ufysja	C/E	61	3	322	323	-5.8	5.0	10	5	50	5	100	15	3.00
20	Ørteråni	C/E	76	16	404	339	-7.4	4.6	19	5	26	5	100	30	6.00
			6 569	656					930	245	26	159	65	710	2.90

Mapping the presence of *Gammarus lacustris*

Data regarding the presence or absence of *G. lacustris* were screened from relevant literature, such as technical reports and scientific papers (Appendix 1). The data covered 198 named lakes in 16 catchments in central/eastern areas, and 47 lakes in 11 catchments in western areas including 10 and 15 reservoirs, in the respective areas. The study lakes are located at altitudes between 464 to 1396 m a.s.l. and range in size from 0.02 to 78.77 km^2. In most of the literature, the occurrence of *G. lacustris* is based on brown trout stomach analyses. In more detailed investigations, the occurrence of different food items is given as volume% of individual fish. However, in many of the reports, only a note may be given for a positive finding of *G. lacustris*. Other methods used to detect *G. lacustris* on Hardangervidda have included Ekman bottom sampler (Dahl 1917; Amundsen 1976), Petersen sampler (Amundsen 1976), plankton sieves (Halvorsen 1973), benthic littoral kick samples (Walseng *et al*. 1994, 1996; Fjellheim *et al*. 2007) and artificial substrate (jute bags) (Fjellheim *et al*. 2007).

Brown trout is the most common fish species in lakes and rivers on Hardangervidda. In 3.1% of the named lakes (N=29), Arctic char *Salvelinus alpinus* (Linnaeus, 1758) also occur, mainly due to 20th-century stockings (Appendix 1). Furthermore, the Eurasian minnow *Phoxinus phoxinus* (Linnaeus, 1758) has been introduced into 42 named lakes (4.5%) since the 1970s.

Statistical analyses

Statistical analyses of the type one-way analysis of variance (ANOVA) and nominal logistic regression were performed with SPSS (IBM Corp. 2017. IBM SPSS Statistics for Windows, Version 25.0. Armonk,

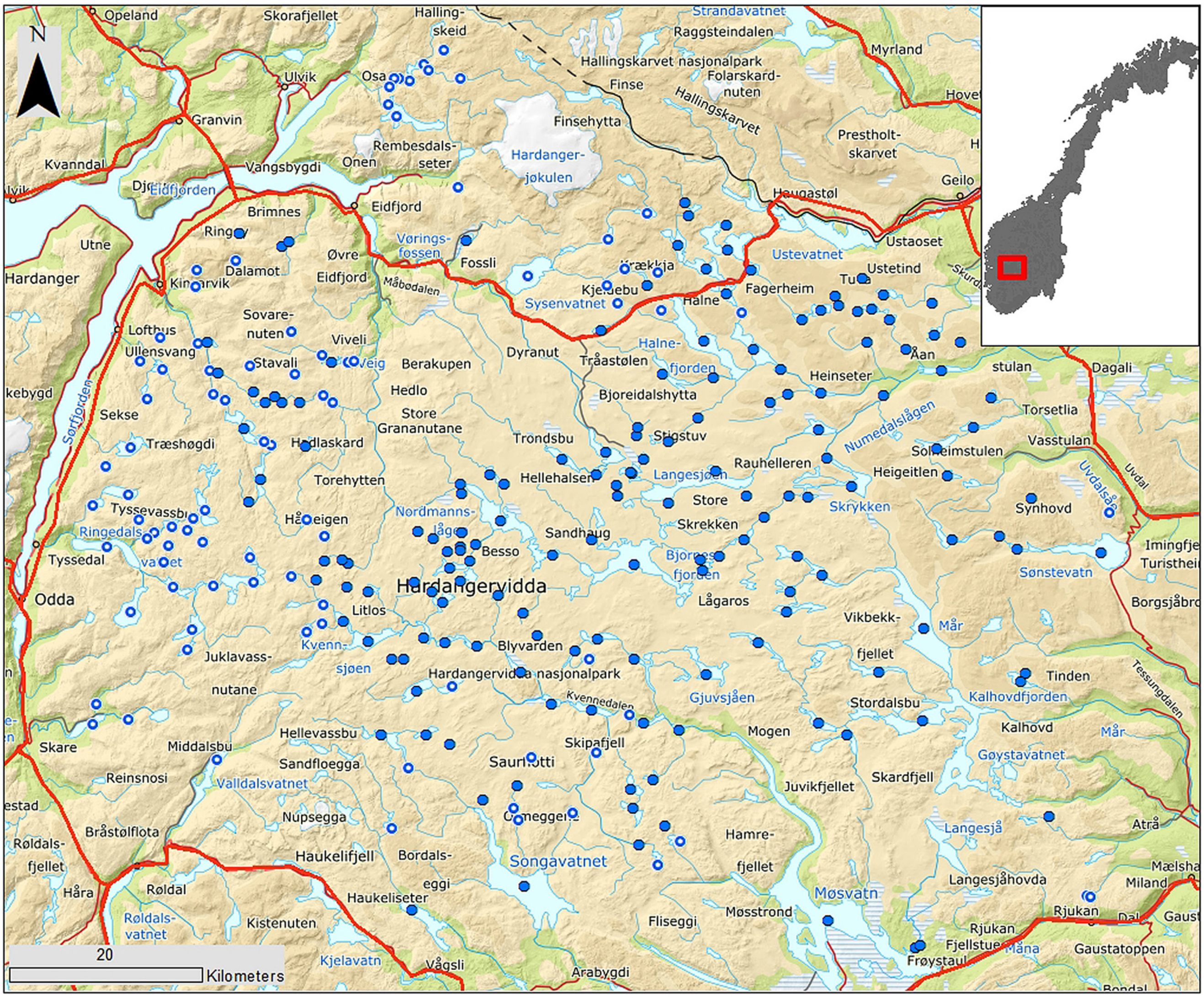

Figure 1. Lakes surveyed for the presence of *Gammarus lacustris* on Hardangervidda. Lakes with positive and negative findings are shown by filled and open dots, respectively. Details of the localities are given in Appendix 1. The Norwegian Mapping Authority CC BY 4.0.

Table 2. Number of natural lakes with *Gammarus lacustris* at different altitude intervals in 16 catchments located in central and eastern areas on Hardangervidda.

Altitude m a.s.l.	No. of lakes	Examined lakes	Lakes with *Gammarus lacustris*	Frequency%
<900	4	4	3	75
900-999	15	6	5	83
1000-1099	59	19	9	47
1100-1199	264	72	56	78
1200-1299	270	60	50	83
1300-1399	141	27	24	89
≥1400	12	0		
	765	188	147	78

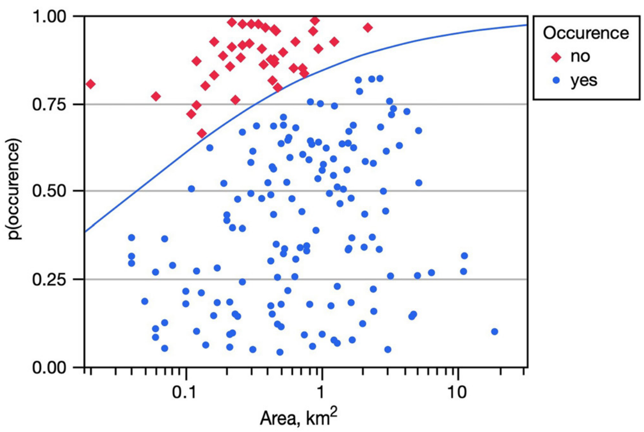

Figure 2. Logistic regression curve showing the probability of the occurrence of *Gammarus lacustris* on Hardangervidda as a function of lake area. Of the 188 lakes studied, *Gammarus lacustris* was found in 97% of the 62 lakes ≥1.0 km^2, while the species was found in only 67% of 126 lakes <1.0 km^2.

Table 3. Water quality in terms of pH and calcium concentration in 219 lakes on Hardangervidda with 191 and 28 lakes in the central/eastern (C/E) and western (W) areas, respectively. For the central/eastern area, the water quality is given for lakes with and without records of Gammarus lacustris, respectivelly.

Region		No. lakes	pH range	No. of lakes pH<6.0	Ca mean ±SD mg L^{-1}	Ca range mg L^{-1}	No. of lakes with Ca <1.0 mg L^{-1}
C/E	All lakes	191	5.19-7.28	20 (10%)	1.63±1.14	0.28-5.73	70 (37%)
C/E	Lakes with *G. lacustris*	89	5.49-7.26	8 (9%)	1.84±1.18	0.28-5.54	25 (28%)
C/E	Lakes without *G. lacustris*	102	5.19-7.28	12 (12%)	1.45±1.08	0.37-5.73	45 (44%)
W	All lakes	28	5.35-7.00	6 (21%)	0.76±0.39	0.32-1.68	22 (79%)
W and C/E	All lakes	219	5.19-7.28	26 (12%)	1.52±1.11	0.28-5.73	92 (42%)

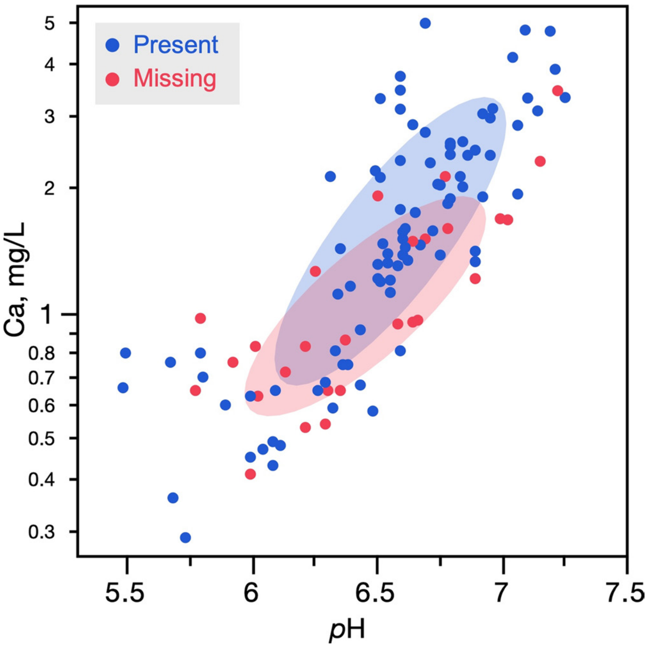

Figure 3. The bivariate distribution of pH and calcium (log-transformed) in water samples from the study lakes, grouped for lakes with or without *Gammarus lacustris* (N=89 and 27, respectively). The bivariate 50% confidence ellipses are drawn for each group.

NY) and JMP (SAS Institute Inc. 2019. Version 14.3. Cary, NC), respectively. The logistic regression was used to model the probability of the occurrence of *G. lacustris* as a function of lake size, and the result is visualised with a cumulative logistic probability plot. This presents the regression curve giving the probability for occurrence as a function of lake size, and the markers for the data are drawn at their *x*-coordinate, with the *y*-position jittered randomly within the range corresponding to their response category. We also visualised the bivariate distributions of calcium concentrations and pH in the study lakes by a scatter plot with confidence ellipses drawn for the lake groups with and without *G. lacustris*. The density ellipsoids are computed from the bivariate normal distribution fit to the variables.

RESULTS

Geographical distribution of *Gammarus lacustris*

A total of 710 observations covering 245 lakes, of which 159 lakes (65%) resulted in positive findings of *G. lacustris* (Figure 1, Table 1). Most of the records are from the 16 central and eastern catchments, being noted in 79% of the 188 natural lakes examined. From 47 lakes in the 11 western catchments, *G. lacustris* are reported from only two lakes (4%). In Lake Bordalsvatn, which is now a reservoir (regulated 39.0 m), *G. lacustris* was recorded before the impoundment, but never thereafter. In the other locality, Lake Vatnosetvatn, there is an old record of *G. lacustris*. This observation has proved to be difficult to verify and has not been replicated in later investigations.

Gammarus lacustris was recorded in 64% of the central and eastern lakes that were sampled once (N=80). This fraction increased to 76% and 96% with two sample repeats (N=37) and three or more sample repeats (N=71), respectively.

Gammarus lacustris in reservoirs

Our study area comprised 27 reservoirs for hydropower production, 25 of which were investigated for records of *G. lacustris*. The reservoirs were extensively studied after impoundment, but rarely before. In the central and eastern part of Hardangervidda, most of the reservoirs (N=10) were studied more than four times, and in six of them, *G. lacustris* still occur after many years of impoundment. Of these reservoirs, three are regulated less than six m (0.5-4.1 m) and three more than ten m (11.1-39.1 m). In the three reservoirs which are regulated less than six m, *G. lacustris* still play an important part as food for the brown trout. The four remaining reservoirs without *G. lacustris* are regulated from 18.5 to 66.0 m. In western areas, none of the 15 reservoirs produced positive findings of *G. lacustris* in recent years.

The significance of altitude and lake size

Data from the 188 natural lakes within the 16 catchments in the central and eastern areas of Hardangervidda were used to analyse the frequency of *G. lacustris* in relation to altitude and lake size. The lakes lie at altitudes from 832 to 1396 m a.s.l. The occurrence of *G. lacustris* is high with 75-89% in all 100-m intervals, except for the 1000-1099 m a.s.l. interval, where it was only 47% (Table 2). The highest located lake with *G. lacustris* was Lake Kolsnutgrysline situated at 1386 m a.s.l. The two lakes in the 11 western catchments with records of *G. lacustris* lie at altitudes of 869 and 891 m a.s.l., respectively.

The incidence of *G. lacustris* increased significantly with lake size as shown by the logistic regression: p (occurrence) = $(1+\exp(1.380 + 2.026 \cdot \log \text{Area}))^{-1}$ (likelihood-ratio chi-square test=12.65 $p<0.001$) (Figure 2). Of the 188 lakes examined, *G. lacustris* was found in 97% of the 62 lakes ≥1.0 km^2, while the species was found in only 69% of the 126 lakes <1.0 km^2.

Ambient water quality

In this context, we have used calcium and concurrent pH values from 219 natural lakes (Appendix 1). Lakes in western and central/eastern areas differed significantly in calcium (ANOVA-test, $F_{1,217}$=15.92 p<0.0001). The mean concentration of calcium in these two areas were 0.76±0.39 (N=28) and 1.63±1.14 (N=191) mg L^{-1}, respectively. However, in both areas a large proportion of the lakes were low in calcium, as 79% (N=22) and 37% (N=70), respectively, had concentrations <1.0 mg L^{-1} (Table 3). In both areas, the concurrent pH was also low, as respectively 21% (N=6) and 10% (N=20) of the lakes were <6.0.

Lakes in the central and eastern area with *G. lacustris* present, had significant higher concentrations of calcium than those with unknown status (19 examined lakes with negative records of *G. lacustris* and 27 lakes with only water quality analyses), with mean values of 1.84±1.18 (N=89) and 1.45±1.08 (N=102) mg L^{-1}, respectively (ANOVA-test, $F_{1,189}$=4.65 p<0.05).

The tendency for higher calcium concentrations in lakes inhabited by *G. lacustris* is illustrated in Figure 3. Here, the confidence ellipses for the distributions of calcium and pH for the lakes with and without *G. lacustris* clearly show that the crustacean inhabit the more calcium rich lakes in our data set, whereas pH seems to be less associated to its occurrence. Analyses of variance showed that the geometric mean of calcium concentrations were significant higher in lakes with *G. lacustris* (1.48 mg L^{-1}, 95% confidence interval: 1.29–1.70 mg L^{-1}) than in lakes without (1.03 mg L^{-1}, 95% confidence interval: 0.80–1.32 mg L^{-1}) (ANOVA-test, $F_{1,114}$=6.04 p=0.013). No such differences could be detected for pH ($F_{1,114}$=1.33 p=0.25).

DISCUSSION

Distribution pattern of *Gammarus lacustris* on Hardangervidda

The lakes on Hardangervidda are rated among the best brown trout lakes in Norway, and their relatively dense populations of *G. lacustris* are often mentioned as the main reason for prolonged growth and high quality of brown trout (Dahl 1915; Sømme 1941). Despite this, only a fragmentary mapping of this crustacean was available as recently as in the 1970s (Anonymous 1974). A large number of fishery investigations have been carried out since then, and in this study one of our main aims was to scan the pertinent literature in order to update the occurrence of the species. *Gammarus lacustris* is frequently found in fish stomachs, and thus an efficient method to map its occurrence in lakes on Hardangervidda. In fact, in most of the lakes examined, this is the only method used. However, other methods may be used simultaneously. In a study comprising 22 lakes, both bottom samplers (Ekman or Petersen) and fish stomachs were used, giving positive records of *G. lacustris* in 82 and 100% of the cases, respectively (Dahl 1917; Amundsen 1976). However, *G. lacustris* may be difficult to detect using conventional methods such as benthic littoral kick sampling, especially at low densities and/or patchy distribution (Walseng *et al*. 1994, 1996; Fjellheim *et al*. 2007). In a repeated monitoring program in 32 lakes known to contain *G. lacustris*, the species was detected by kick sampling in less than 50% of the lakes (Walseng *et al*. 1994, 1996). In a similar study, an artificial substrate (jute bags) and benthic littoral kick sampling were used in addition to stomach analyses of brown trout (Fjellheim *et al*. 2007). In these lakes where *G. lacustris* appeared in low numbers, only stomach analyses gave positive findings. Thus, we assume that fish stomach analysis is the most reliable method for detecting *G. lacustris*.

Our study revealed that the geographical distribution of *G. lacustris* on Hardangervidda is highly skewed. In the central and eastern area this crustacean is very common, being recorded in 79% of the lakes examined. In this area only 25% of the natural lakes (N=765) have so far been properly surveyed. This crustacean can be difficult to catch, and investigations that include more than two repeat samplings may be needed to be certain of detecting *G. lacustris*. Of the 188 lakes examined, only 38% have been investigated more than twice. Hence, the estimate of 147 localities hosting *G. lacustris* in this area should easily be increased by more targeted surveys. *Gammarus lacustris* has been reported from only two lakes (4%) in western areas. Our study thus confirms the distribution pattern observed at the beginning of the 1970s (Anonymous 1974).

Besides the examined lakes, there are a large number of unnamed small lakes in this area. According to Økland & Økland (2007), *G. lacustris* does not thrive in ponds, indicating that the environmental conditions in small bodies of water are not favourable to the completion of their perennial life cycle (Dahl 1915; Bjerknes 1974). This is probably because small water bodies are exposed to drying out and/or freezing solid (Dahl 1915). The smallest water body with *G. lacustris* yet reported on Hardangervidda is an unnamed headwater lake (0.0128 km^2, NVE ID no. 181955) in the Sævra tributary in Lågen catchment (Fjellheim 2004). There are approximately 1600 unnamed lakes that are larger than this. Thus, there is a considerable potential for new records of *G. lacustris* in this part of the mountain plateau.

Even though *G. lacustris* can thrive in small water bodies, there was a significant increase in the proportion of lakes containing *G. lacustris* with lake size. *Gammarus lacustris* is intensively sought for by brown trout and we assume that the proximity to refugia is better in bigger lakes because it will reduce predator-prey encounters.

In the central/eastern area, there are ten reservoirs. *Gammarus lacustris* is highly susceptible to water amplitude variations of more than six m, when they normally become extinct after some time (Dahl 1932; Aass 1969; Økland & Økland 2007). In reservoirs with such an impoundment regime, their abundance became too small to be of any significance as fish food. This fact is also evident in this study, as *G. lacustris* was of importance as fish food in only the three reservoirs which had a water level amplitude of less than six m (cf. Appendix 1). In the remaining seven reservoirs, with an amplitude >11 m, *G. lacustris* was only occasionally detected, in low numbers, in three of them (regulated from 11.1 to 39.1 m).

Environmental constraints may limit the distribution of *Gammarus lacustris*

Rapid postmoult calcification of the exoskeleton is vital for all crustaceans (Rukke 2002). In gammarids, a significant proportion of the total body calcium must be generated after a moult. Rates of calcium influx rise in line with external calcium concentration until a saturation point is reached. Experimental studies revealed that adult *G. lacustris* required ambient calcium concentrations of 2.5 to 5.0 mg L^{-1} to ensure complete calcification after moulting (Rukke 2002). When ambient calcium concentration is in the suboptimal range and down to the lower lethal threshold, remineralization of the exoskeleton is compromised, and reproduction and survival are threatened (Cairns & Yan 2009). Hence, low calcium concentrations may limit the distribution and success of calcium-demanding crustaceans in soft-water localities (Rukke 2002). In our study, it was clearly shown that the crustacean inhabits the more calcium rich lakes (Figure 3).

Gammarus lacustris is also very sensitive to low pH levels, and it is not normally found in waters with pH <6.0 (Borgstrøm & Hendrey 1976; Fjellheim & Raddum 1990; Økland & Økland 2007). In our study, pH seems to be less associated with the occurrence of *G. lacustris* (Figure 3). In natural lakes however, low calcium concentration often interferes with low pH levels and in such lakes, low pH may reinforce unfavorable conditions.

The western area, which is nearly free of *G. lacustris*, is extremely barren with a bedrock of granitic and dioritic gneisses, giving water low in calcium (0.76±0.39 mg L^{-1}). The catchments in the central and eastern areas, which are rich in *G. lacustris*, has a thicker moraine cover and the water quality is much better with respect to calcium (1.63±1.14 mg L^{-1}). In this area, *G. lacustris* has been recorded in 89 lakes, of which 28% had a calcium concentration <1.0 mg L^{-1}, eight of them with pH <6.0 (cf. Table 3). As a result, *G. lacustris* can survive in lakes with rather low calcium content. In some of the mountain lakes in southeastern part of Norway, *G. lacustris* was found at calcium levels down to approximately 0.7 mg L^{-1} (Økland & Økland 2007). These values from natural waters are significantly lower than the lower lethal threshold of approximately 1.0 mg L^{-1}, as suggested by Cairns & Yan (2009).

The lowest calcium values in our study were found in two acidified lakes; Svartevatnet and Svartevasstjørni in Lågen catchment. In 1993, calcium in these two lakes was measured at 0.28–0.35 mg L^{-1} (Fjellheim *et al*. 2002). A liming programme that aimed to improve the water quality in these two lakes started in 1994, which resulted in the re-appearance of *G. lacustris* in brown trout stomachs (Fjellheim *et al*. 2001, 2007). This may be due to the reintroduced specimens and/or proximity to species refugia with better water quality in the lakes. After the liming programme ended in 2013, calcium concentration was re-established near to the pre-liming level with 0.33–0.42 mg L^{-1}. Despite pH >6.0, *G. lacustris* was virtually absent. We therefore assume that calcium concentrations below 0.5 mg L^{-1} are lethal to *G. lacustris*. The lower lethal threshold of approximately 0.7 mg L^{-1} suggested for alpine lakes in Norway by Økland & Økland (2007), supposed that pH should exceed 6.0 to support *G. lacustris* in lakes with low calcium content. However, in our study, eight lakes with *G. lacustris* in the central/eastern area had pH <6.0 and a calcium concentration between 0.28 and 0.79 mg L^{-1}. *Gammarus lacustris* living in such waters must be regarded as "living at the edge" of their physiological abilities. Consequently, its lower lethal threshold for calcium seems to be at ~0.5 mg L^{-1}, which is close to the value proposed by Økland & Økland (2007) for mountain lakes.

Even though the lakes in the two areas have quite different levels of calcium, 28% of the lakes (N=89) with positive findings of *G. lacustris* in the central/eastern area have calcium concentration <1.0 mg L^{-1} (cf. Table 3). Consequently, the calcium concentration in many lakes in the western area ought not to be critical for survival. Thus, additional stressors decisive for its absence in this part of Hardangervidda need to exist.

Water temperature is crucial to all aquatic crustaceans, having a significant impact on their growth, development and generation time (Wilhelm & Schindler 2000; Rukke 2002; Økland & Økland 2007). *Gammarus lacustris* has a wide latitudinal and altitudinal distribution in the Northern Hemisphere, indicating that it is well adapted to a wide range of thermal regimes. In mountain lakes in southern Norway, it appears to prefer summer temperatures between 10 to 14°C (Økland & Økland 2007). Even though it tolerates a wide range of temperatures, a minimum thermal input is needed to reach maturity and completion of its life cycle. In Norway, the life cycle roughly spans one year in low-land lakes (Økland & Økland 2007). However, in colder lakes at elevated altitudes it becomes perennial. On Hardangervidda, a two-year life cycle has been documented (Dahl 1915; Bjerknes 1974). In high-altitude Canadian lakes (>2300 m a.s.l.), a low thermal input is compensated for by prolonged development with a three-year life cycle (Wilhelm & Schindler 2000). A perennial life cycle has also been recorded for *G. lacustris* living in a low-land cave with a significantly lower temperature than in a neighbouring surface lake (Østbye *et al*. 2018). This phenotypic plasticity in reproductive traits appears to be a key factor in the maintenance of successful populations in a wide range of aquatic habitats (Wilhelm & Schindler 2000).

On Hardangervidda, there is a steep fall in snow deposition from west to east, with 1151 mm in the Austdøla/Ljoso catchment in the west to only 292 mm in the Uvdalselvi catchment in the east (Table 1). All the western catchments have snow deposits >700 mm. This provides a significant delay in the ice break-up in the former area, resulting in colder lakes and shorter ice-free seasons (Borgstrøm 2016; Qvenild & Hesthagen 2019).

In the central/eastern area, there was no significant variation in the occurrence of *G. lacustris* in lakes at altitudes of up to 1396 m a.s.l. They may also exist in some of the 34 lakes that are situated above this height. However, only two of them have so far been examined for this species, both with negative results. Nationwide, *G. lacustris* is commonly found in lakes at all altitudes, from sea level up to 1560 m a.s.l. (Økland & Økland 2007). The thermal conditions vary significantly with elevation as a lapse rate in air temperature of about 0.6°C 100 m^{-1} elevation is highly reflected in the water temperature (Kvambekk & Melvold 2010; Qvenild *et al*. 2018). As a result, both altitude and snow deposition provide a variety of temperature regimes in lakes on Hardangervidda.

Taken separately, temperature and water quality should not be decisive factors in determining the presence or absence of *G. lacustris* in the western lakes. In addition, life history and phenotypic traits may simply be functions of the living environment through, for example, temperature-diet-predation conditions (Wilhelm & Schindler 2000; Cairns & Yan 2009; Østbye *et al*. 2018). For this reason, additional stressors may contribute to the distribution pattern of *G. lacustris* seen on Hardangervidda. Temperature is the only environmental factor that significantly affects crustacean moulting frequency (Rukke 2002). Due to its lower temperature and shorter ice-free season and waters with low ionic strength (cf. Skjelkvåle & Henriksen 1998) in the western lakes, these may also be more nutrient-poor with lower productivity (cf. Wilhelm & Schindler 2000). Low ambient calcium concentrations have revealed significant negative effects on survival, growth and calcium content of *G. lacustris*. This may result in later onset of reproduction, reduced carapace rigidity and increased vulnerability to cannibalism and predation. Higher calcium requirement of neonates compared to adults may reinforce any negative effects on *G. lacustris* (Rukke 2002).

Gammarus lacustris – a highly preferred food item for fish

As a relatively large crustacean of up to two cm in length, *G. lacustris* has proved to be among the most important food items for brown trout in lakes on Hardangervidda, together with *Lepidurus arcticus* (Pallas, 1793) and *Eurycercus lamellatus* A.F.M. (Dahl 1917; Sømme 1941). The effects of brown trout predation on *G. lacustris* in Norwegian mountain lakes is well documented (Dahl 1915, 1917, 1930; Sømme 1941; Aass 1969; Museth & Borgstrøm 2010; Qvenild & Rognerud 2018). On Hardangervidda this is also the case for Arctic char (Dahl 1920; Aass 1969) and Eurasian minnow (Rognerud *et al*. 2003). In lakes that contain these two species in addition to brown trout, *G. lacustris* may occur in small numbers and be difficult to detect. In such cases, proximity to species refugia may be crucial.

Possible effects of climate change

Alpine ecosystems are expected to face pronounced impacts of climate change. For the Norwegian mainland as a whole, a general increase in precipitation has been observed since the 1980s (Hanssen-Bauer *et al*. 2017). This pattern is also seen on Hardangervidda, where the annual winter deposition has risen during the same period, including a greater number of snow-rich winters with a reduced variation in a direction from west to east (Qvenild *et al*. 2018). Increased precipitation impacts on the run-off, resulting in more dilute waters (Presthus Heggen *et al*. 2010). This may create even more hostile conditions for *G. lacustris* living in localities at critical levels of calcium.

A significant increase in spring-summer (May-September) air temperatures since the 1980s have also been documented for Hardangervidda (Qvenild *et al*. 2018). This trend may be reflected in warmer aquatic habitats (Kvambekk & Melvold 2010; Lindholm *et al*. 2012; Qvenild *et al*. 2018). Warmer lakes in the eastern part of the plateau may be handled by *G. lacustris* through its phenotypic plasticity in the reproduction traits (cf. Wilhelm & Schindler 2000). Even though *G. lacustris* is able to survive temperatures up to 26°C, it should not exceed 18°C for longer periods (Wilhelm & Schindler 2000). Thus, we consider that *G. lacustris* will be able to survive in larger lakes on Hardangervidda, especially in stratified lakes with colder refugia. In 2003–2016, maximum temperatures above 20°C were not measured in the lakes monitored by temperature loggers (Qvenild *et al*. 2018). However, in small and shallow lakes and ponds, a warming as projected towards 2100 may reduce the range of *G. lacustris*. This has already been experienced for another crustacean species such as the Arctic fairy shrimp (*Branchinecta palludosa* O.F.Müller 1788) (Lindholm *et al*. 2012, 2015). From a conservation point of view, a detailed mapping of *G. lacustris* is fundamental in order to document future range changes.

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Appendix 1. Specific information about 348 lakes in 27 catchments with 11 catchments in the western region (W) and 16 catchments in the central and eastern region (C/E) on Hardangervidda, of which 245 were surveyed for the occurrence of *Gammarus lacustris*. **Reg** indicates that a lake is regulated. The number of examinations is specified together with any associated positive records. The numbered references are given below the table.

Region	Catchm. no.		Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583		No. exam.	No. pos rec.	Date	pH	Ca mg L^{-1}	References
									X	Y						
W	1		Austdøla	16747	Olbogavatnet		1194	0.35	70461	6741101	0		07.08.71	6.80	0.52	43
W	1		Austdøla	16781	Reipstjørnane		1192	0.13	72883	6740013	0		08.08.71	6.90	0.32	43
W	1		Austdøla	16637	Vestre Memorge-vatnet		1263	0.16	80149	6743690	0		09.08.71	7.00	1.68	43
W	1		Austdøla	1923	Søre Grøndals-vatnet		1153	1.05	73417	6747708	0		07.09.68	5.60	0.64	112
W	1		Austdøla	16623	Floskefonnvatnet		1081	0.19	70313	6745100	0		11.09.68	6.10	0.80	112
W	1		Austdøla	16664	Austdalsvatnet		1161	0.32	75886	6742930	1	0	08.08.71	6.90	1.20	43
W	1		Austdøla	1921	Langvatnet	x	1158	6.40	69287	6739016	2	0	06.08.71	6.90	0.32	43,112
W	1		Austdøla	16656	Austdalsvatnet		1059	0.08	72588	6743812	1	0				46
W	1		Austdøla	16787	Grasbotntjørni		1107	0.12	68354	6740315	1	0				46
W	1		Austdøla	16677	Rossevatni		954	0.09	69545	6743018	1	0				46
W	1		Austdøla	1917	Austdølnutvatnet	x	1040	0.63	70590	6742742	2	0				46, 112
W	1		Austdøla	16712	Austdølvatnet		907	0.13	68552	6742080	2	0				46, 112
W	1		Austdøla	16682	Rossevatni		936	0.06	68971	6743002	2	0				46, 112
W	1		Austdøla	1918	Rundavatnet	x	1040	1.28	72020	6744428	2	0				46, 112
W	1		Austdøla	1922	Kvilinganut-vatnet		1140	0.53	74117	6745937	1	0	09.09.68	6.00	0.40	112
W	2		Sima	1915	Holmavatn		1216	0.45	76822	6740581	0		16.08.67	6.70	1.00	112
W	2		Sima	1914	Rembesdals-vatnet		905	1.29	76463	6735115	0		27.07.67	6.90	1.16	112
W	2		Sima	17050	Skykkjedals-vatnet		837	0.43	75584	6731638	2	0	13.09.08	6.65	1.48	46, 60
C/E	3	A	Isdølo	1906	Isdalsvatnet		832	1.07	76533	6726176	2	1	14.06.88	6.52	2.12	46, 56
C/E	3	B	Leiro	17369	Svartetjørni		1141	0.14	90234	6721458	0		04.08.97	6.46	0.92	19
C/E	3	B	Leiro	17370	Skardstjørnane		1126	0.12	90854	6721189	0		17.08.04	7.00	4.07	19
C/E	3	B	Leiro	17291	Dalboretjern		1153	0.12	92974	6723206	1	0	04.08.97	6.38	0.85	67
C/E	3	B	Leiro	17322	Skardstjørnane		1124	0.29	91140	6721561	1	0	04.08.97	6.51	1.91	67
C/E	3	B	Leiro	17289	Halnetjørni		1259	0.16	96421	6722876	1	0				67
C/E	3	B	Leiro	17402	Dyratjørnane		1173	0.25	92219	6719647	2	0	04.08.97	5.93	0.75	67
C/E	3	B	Leiro	17305	Inste Olavsbu-vatn		1175	0.64	95206	6721531	2	2				67
C/E	3	B	Leiro	17070	Finsbergvatnet		1190	1.23	95280	6728945	1	0	01.06.98	6.02	0.82	109
C/E	3	B	Leiro	17149	Langavatnet		1124	0.74	91211	6726281	1	0	05.08.99	6.03	0.62	110
C/E	3	B	Leiro	1907	Sysenvatn	x	880	10.42	82835	6722461	3	0	29.07.67	6.60	0.88	46, 56, 112
C/E	3	C	Svinto	17720	Stigstutjørni		1218	0.05	94317	6706801	3	3				3, 34, 74
C/E	4		Bjoreio	17673	Nøkkatjørni		1353	0.115	80895	6710029	0		09.10.97	7.26	5.73	88
C/E	4		Bjoreio	27430	Tinnhølen		1213	4.54	90972	6704204	8	8	12.10.97	7.05	4.16	16, 17, 20, 56, 67, 71, 74, 108
C/E	4		Bjoreio	1910	Langavatnet		1222	2.65	86436	6703503	4	3	09.10.97	7.10	4.85	67, 71, 74
C/E	4		Bjoreio	17865	Kleivshovd-tjørnane		1215	0.82	89929	6701871	4	4				67, 71, 74
C/E	5		Veig	18157	Meinsvatnet		1371	0.284	62964	6697312	0		28.09.89	6.53	1.08	88
C/E	5		Veig	18103	Langgrøvatnet		1347	0.325	65266	6698738	0		09.10.97	6.73	2.27	88
C/E	5		Veig	18002	Øvre Solvatnet		1320	0.264	59097	6701176	0		09.10.97	7.28	2.96	88
C/E	5		Veig	17531	Vassdalsvatni		1222	0.42	58355	6716740	1	0	09.10.97	7.00	1.68	67
C/E	5		Veig	17715	Vatnalivatnet		1045	0.64	62617	6709369	1	0	09.10.97	7.23	3.45	67
C/E	5		Veig	18287	Grytevatnet		1396	0.34	61722	6695491	1	0				67
C/E	5		Veig	17710	Nautavad		1060	0.11	61616	6710060	1	0				67

Appendix 1. Continued.

Region	Catchm. no.	Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583 X	Y	No. exam.	No. pos rec.	Date	pH	Ca mg L^{-1}	References
C/E	5	Veig	18228	Herrevatnet		1317	0.14	71445	6695987	1	1				71
C/E	5	Veig	18421	Grøndalsvatni		1268	0.30	64263	6692710	1	1				74
C/E	5	Veig	17620	Vivetjørnane		1009	0.16	64265	6713570	1	0			1.00	112
C/E	5	Veig	67665	Nedre Vivevatn		1009	0.02	64814	6713675	2	0				112
C/E	5	Veig	17614	Reinavatnet		1082	0.26	61500	6714260	1	0				117
C/E	5	Veig	17975	Vierslatjørn		1244	0.12	75911	6700837	2	1				13, 67
C/E	5	Veig	17997	Heisantjørnane		1244	0.20	76015	6699894	3	1	17.07.96	6.50	2.20	13, 67, 74
C/E	5	Veig	17849	Bersavikvatnet		1231	1.65	59771	6704861	3	2	09.10.97	7.26	3.32	3, 67, 116
C/E	5	Veig	18434	Grøndalsvatni		1281	0.22	61784	6692865	3	1	09.10.97	7.15	3.08	40, 67, 74
C/E	5	Veig	18409	Grøndalsvatni		1268	0.56	63593	6693034	3	2				40, 74
C/E	5	Veig	17616	Vasslivatn		1041	0.85	62549	6713510	3	1			0.96	67, 112, 117
C/E	5	Veig	17730	Hanasteinsvatnet		1196	0.07	56589	6709950	2	2				67, 116
C/E	5	Veig	17735	Skinhovda		1152	0.50	59177	6709412	2	1				67, 116
C/E	5	Veig	17737	Tresnutvatnet		1193	0.22	57334	6709418	2	1				67, 116
C/E	5	Veig	17668	Langavatnet		1195	0.44	58651	6712245	2	1	09.10.97	7.03	1.67	67, 117
C/E	5	Veig	18224	Herrevatnet		1367	0.46	73027	6695197	3	3	09.10.97	7.11	5.54	67, 74
C/E	6 A	Erdals-vassdr.	27433	Vetlevatnet		884	0.06	57341	6725553	1	1				117
C/E	6 A	Erdals-vassdr.	17300	Busetevatnet		884	0.43	58125	6726003	4	3	30.07.67	6.90	1.40	67, 74, 112, 117
W	6 B	Bjotveitelvi	27428	Vatnosetvatnet		869	0.44	52863	6726935	4	2				3, 67, 74, 117
C/E	7 A	Kinso	27475	Trollavatnet		1280	0.230	54314	6715304	0		31.10.95	6.60	1.40	88
C/E	7 A	Kinso	18214	Sandvatnet		1363	0.87	59963	6697198	1	0	09.10.97	7.16	2.32	67
C/E	7 A	Kinso	27527	Gravdalsvatnet		1012	0.12	50169	6710198	1	0				67
C/E	7 A	Kinso	27534	Nasavatnet		1057	0.19	51466	6709620	1	0				67
C/E	7 A	Kinso	27495	Lonavatnet		1125	0.52	54075	6713136	2	0	09.10.97	6.79	1.59	67
C/E	7 A	Kinso	27510	Fodnastølsvatnet		955	0.33	50687	6712409	2	1	09.10.97	7.22	3.89	67
C/E	7 A	Kinso	17878	Kinsevatnet		1184	0.26	56181	6704912	2	0			3.32	67
C/E	7 A	Kinso	27500	Kinsevatnet		940	0.21	49818	6712693	2	0				67
C/E	7 A	Kinso	27573	Sperrådalsvatn		1179	0.14	55531	6705279	1	0			2.44	112
C/E	7 A	Kinso	27478	Stavalivatnet		900	0.69	49566	6715667	5	2			2.12	3, 67, 74, 112
C/E	7 A	Kinso	27476	Rjuvavatnet		889	0.30	48598	6715537	2	0			2.24	67, 112
C/E	7 A	Kinso	27523	Austmannavatnet		1170	0.19	54407	6710520	3	2				67, 116
C/E	7 A	Kinso	27533	Holmavatnet		1186	0.56	55661	6709363	3	3				67, 116
C/E	7 A	Kinso	27637	Omkjelsvatnet Øvre		1202	0.55	53915	6699113	2	2	09.10.97	7.07	1.93	67, 70
C/E	7 A	Kinso	1913	Omkjelsvatnet Nedre		1199	2.39	55086	6701409	3	3			2.32	67, 74, 112
C/E	7 A	Kinso	1912	Veivatnet		1172	4.68	53384	6706672	5	5			3.16	67, 74, 112, 116
W	7 B	Vivippo	27436	Birgesdalsvatnet		1183	0.66	52528	6724099	1	0				67
W	7 B	Vivippo	27444	Vassdalsvatnet		1122	0.43	48533	6723050	1	0				67
W	7 B	Vivippo	27450	Grytingsvatn		700	0.24	48434	6721377	2	0				67
W	8	Opo	27473	Kjølevatni		1109	0.050	44306	6716792	0		02.10.97	6.14	0.71	88
W	8	Opo	27472	Kjølevatni		1108	0.28	44724	6716168	1	0		6.14	0.71	67
W	8	Opo	27528	Yskjebotnvatnet		1105	0.75	43328	6709676	1	0	02.10.97	6.59	0.93	67
W	8	Opo	27504	Skriksetvatn		1016	0.19	42663	6713653	1	0				67
W	8	Opo	1904	Opesjovatnet		1014	1.25	44930	6712854	1	0	02.10.97	6.65	0.94	112
W	9 A	Espeelvi	27611	Mostjørn		1238	0.25	39059	6702750	1	0				73

Appendix 1. Continued.

Region	Catchm. no.	Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583 X	Y	No. exam.	No. pos rec.	Date	pH	Ca mg L^{-1}	References
W	9 B	Vendo	1903	Store Vendevatnet	x	1268	3.64	41667	6704733	2	0	01.08.10	6.80	1.28	56, 58, 112
W	10	Tysso	27762	Løkene		1309	0.157	49829	6683280	0		09.10.97	6.08	0.69	88
W	10	Tysso	18713	Jukletjørn		1431	0.522	56089	6688253	0		15.09.97	6.23	0.59	88
W	10	Tysso	27600	Illakleivløkene		1362	1.283	50388	6701774	0		09.10.97	6.29	0.43	88
W	10	Tysso	18887	Juklevatni		1430	0.381	56982	6684844	0		09.10.97	6.31	0.41	88
W	10	Tysso	27668	Selsløken		1323	0.557	52128	6695930	0		09.10.97	6.51	0.53	88
W	10	Tysso	27680	Tyssehølen		1162	0.11	43332	6695188	1	0				56
W	10	Tysso	1898	Nedre Håvardsvatn	x	1264	5.46	54458	6690703	5	0	01.08.10	6.67	1.03	56, 57
W	10	Tysso	27661	Hadletgrøna		1264	0.35	42541	6697205	1	0				73
W	10	Tysso	27758	Hattasteins-vatnet		1287	0.92	47553	6683669	1	0				73
W	10	Tysso	27693	Langtjørn		1305	0.27	45054	6692759	1	0				73
W	10	Tysso	27669	Nedre Veidedalsvatn		1312	0.15	47503	6696107	1	0				73
W	10	Tysso	27682	Reinakolltjørn		1359	0.18	45595	6694481	1	0				73
W	10	Tysso	27677	Øvre Veidedalsvatn		1333	0.22	49095	6694926	1	0				73
W	10	Tysso	1892	Nonskardvatnet		1284	1.39	54087	6693281	2	0	09.10.97	6.67	0.95	73, 113
W	10	Tysso	1889	Ringedalsvatnet	x	464	7.25	39127	6694395	5	0				12, 56, 79, 113
W	10	Tysso	1901	Langevatnet	x	1190	6.36	41622	6687621	5	0	01.08.10	6.28	0.53	56, 57, 58, 73, 113
W	10	Tysso	27663	Holmevatn		1271	0.84	45895	6696516	4	0	01.08.10	6.36	0.64	56, 58, 73, 113
W	10	Tysso	1890	Øvre Tyssevatn	x	1333	2.92	49307	6698163	4	0	01.08.10	6.38	0.64	56, 58, 73, 113
W	10	Tysso	1894	Nibbehølen	x	1191	2.06	46031	6690183	4	0	01.08.10	6.40	0.64	56, 58, 73, 113
W	10	Tysso	27672	Stednesvatnet		1213	0.15	44070	6695812	2	0				56, 73
W	10	Tysso	1902	Breidavatn	x	1232	3.35	47989	6685761	3	0				56, 73, 113
W	10	Tysso	1900	Nedre Bersåvatnet	x	1029	0.88	37725	6698727	3	0				56, 73, 113
W	10	Tysso	27650	Nedre Tyssevatn		1317	0.43	48130	6697391	3	0				56, 73, 113
W	10	Tysso	1893	Øvre Bersåvatnet	x	1106	3.37	41421	6699804	3	0				56, 73, 113
W	10	Tysso	1897	Øvre Nybuvatnet		1191	0.68	50202	6690302	3	0				56, 73, 113
W	11	Austdølo/ Ljoso	1703	Isvatnet		1223	1.785	44738	6676790	0		21.09.95	5.35	0.38	88
W	11	Austdølo/ Ljoso	27797	Søre Blåvatnet		1219	0.617	44889	6681121	0		09.10.97	5.66	0.33	88
W	11	Austdølo/ Ljoso	23168	Raudnosvatnet		978	0.233	42015	6675600	0		02.10.97	5.95	0.37	88
W	11	Austdølo/ Ljoso	23143	Ljosevatn		630	0.57	38106	6678046	1	0				67
W	11	Austdølo/ Ljoso	1702	Reinsnosvatnet		594	3.35	37648	6675989	1	0				67
W	11	Austdølo/ Ljoso	23161	Svartavatn		813	0.26	41372	6676488	1	0				67
W	12	Suldalsvassdr.	23154	Grønhellervatn		1006	0.111	50924	6676616	0		02.10.97	5.93	0.60	88
W	12	Suldalsvassdr.	11783	Vivassvatnet		930	0.476	52601	6675590	0		02.10.97	6.17	0.79	88
W	12	Suldalsvassdr.	1866	Valldalsvatnet	x	745	7.33	50628	6672273	2	0	01.08.11	6.33	0.63	56, 59
W	13	Bora	12157	Nedre Poddevatnet		1203	0.39	66134	6665519	0		15.09.83	6.50	1.68	42
W	13	Bora	85	Holmasjøen		1261	1.888	63572	6667242	0		21.09.95	5.84	0.36	88

Appendix 1. Continued.

Region	Catchm. no.	Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583 X	Y	No. exam.	No. pos rec.	Date	pH	Ca mg L-1	References
W	13	Bora	12118	Åremotvatni	x	1180	1.13	68743	6665138	1	0	15.09.83	5.90	1.08	94
W	13	Bora	55	Bordalsvatnet	x	891	7.69	70888	6656673	5	3	15.09.83	6.50	2.62	65, 68, 93, 99
C/E	14	Songa	25	Storhellervatnet		1108	0.56	72762	6664387	0		12.09.04	6.20	0.76	42
C/E	14	Songa	19129	Tangasjøen		1401	0.405	64777	6678455	0		02.10.97	6.82	2.10	88
C/E	14	Songa	12029	Gjevdøltjørni		1285	0.19	85697	6667223	0		13.09.83	6.03	0.62	89
C/E	14	Songa	12092	Nedre Berutjørni		1242	0.13	81943	6665987	1	0	15.09.83	5.80	0.96	42
C/E	14	Songa	12024	Midtre Berutjørni		1289	0.23	81376	6667306	1	0	02.10.97	6.22	0.52	42
C/E	14	Songa	11743	Hedlevatnet		1161	2.07	67627	6674859	1	1	02.10.97	6.75	2.04	42
C/E	14	Songa	11904	Filleherberg-vatnet		1149	0.36	70429	6671441	1	0				42
C/E	14	Songa	11808	Merakktjørni		1291	0.46	83274	6672489	1	0				42
C/E	14	Songa	11933	Øvre Berutjørni		1307	0.42	81745	6669624	2	1	12.09.84	6.00	0.62	42, 64
C/E	14	Songa	11786	Bamsetjønn		1348	0.12	74737	6673951	2	1				42, 75
C/E	14	Songa	11734	Store Urevatnet		1255	1.00	72331	6674883	2	2	15.09.83	6.60	3.11	67, 74
C/E	14	Songa	12021	Fjarefittjørni		1176	0.04	78159	6668176	1	1				75
C/E	14	Songa	10	Songa	x	974	30.01	82524	6659180	12	5	12.09.84	6.40	1.63	14, 64, 74, 84, 92, 100
C/E	14	Songa	12030	Ugletjørni		1195	0.88	87497	6666718	1	0	02.10.97	6.30	0.53	Own data
C/E	15	Kvenna	18910	Tjønndalstjønnane		1205	0.35	90674	6681005	0		15.09.83	6.30	2.04	42
C/E	15	Kvenna	11937	Ormetjørni		1273	0.726	84810	6669553	0		24.09.86	5.92	0.61	88
C/E	15	Kvenna	18735	Kollstjørn		1332	0.595	58549	6688256	0		15.09.97	6.31	0.65	88
C/E	15	Kvenna	19228	Vollenuttjørnan		1303	0.204	95786	6674151	0		02.10.97	6.39	0.73	88
C/E	15	Kvenna	18894	Mjågevatn		1148	0.703	95370	6680696	0		02.10.97	6.64	1.01	88
C/E	15	Kvenna	11729	Brutjørnane		1250	0.289	82473	6674617	0		02.10.97	6.67	1.37	88
C/E	15	Kvenna	18660	Storhellertjørni		1270	0.153	101243	6685788	0		21.09.94	6.16	0.38	106
C/E	15	Kvenna	18523	Elsjåen		1233	0.082	95298	6688551	0		21.09.94	6.76	1.94	106
C/E	15	Kvenna	12173	Kostveitvatnet		1390	0.93	96393	6661411	2	0	13.09.83	5.78	0.64	42, 54
C/E	15	Kvenna	12135	Hokkebrotvatnet		1383	0.52	94405	6663497	2	2	13.09.83	5.81	0.69	42, 54
C/E	15	Kvenna	11763	Møruvatnet		1163	0.47	89964	6673078	1	0	02.10.97	6.22	0.82	48
C/E	15	Kvenna	38	Skardvatnet		1149	0.97	93901	6682778	2	2				51, 74
C/E	15	Kvenna	18545	Sledalsvatnet		1288	0.43	58269	6691313	1	0				53
C/E	15	Kvenna	18831	Vassdalsvatni		1299	0.74	59870	6685608	1	0				53
C/E	15	Kvenna	18919	Tuevatni		1282	0.36	69955	6682678	1	0				70
C/E	15	Kvenna	78	Gjuvsjåen		1210	5.11	101369	6681191	1	1	21.09.95	6.44	0.66	74
C/E	15	Kvenna	18495	Grottjørnanene		1322	0.44	71055	6690732	1	1	10.07.78	6.60	3.46	114
C/E	15	Kvenna	15	Nedre Bjørnavatnet		1136	2.13	75023	6679965	2	0	02.10.97	6.78	2.13	114,115
C/E	15	Kvenna	18700	Kollsvatnet		1182	0.61	61644	6688435	9	0	11.09.97	6.70	1.50	11, 40, 41, 53, 70, 76, 90
C/E	15	Kvenna	43	Litlosvatnet		1170	1.52	63673	6686656	8	7	15.08.95	6.56	1.19	11, 40, 52, 70, 87, 114, 115
C/E	15	Kvenna	19	Kvennsjøen		1166	5.00	66324	6684631	5	5	15.08.95	6.62	1.43	16, 52, 70, 74, 114
C/E	15	Kvenna	18511	Reinavatnet		1327	0.63	79782	6689329	2	1	31.07.03	6.96	2.40	19, 67
C/E	15	Kvenna	18556	Valgardsvatni		1322	0.80	72971	6689771	2	1				3, 67
C/E	15	Kvenna	276148	Sandhyl		1027	0.52	98546	6675337	2	2				3, 74

Appendix 1. Continued.

Region	Catchm. no.	Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583 X	Y	No. exam.	No. pos rec.	Date	pH	Ca mg L^{-1}	References
C/E	15	Kvenna	18597	Skavatn		1249	0.47	64063	6690187	5	3	08.07.78	6.70	5.04	40, 41, 53, 74, 114
C/E	15	Kvenna	18782	Vassdalsvatni		1282	0.45	61466	6686400	2	0	15.09.97	6.26	1.25	40, 53
C/E	15	Kvenna	41	Store Meinsvatn		1384	1.40	93738	6667249	4	4	12.09.84	5.90	0.59	42, 54, 74, 114
C/E	15	Kvenna	12053	Kolsnutgrysline		1386	0.50	97056	6665449	3	2	15.09.83	5.50	0.79	42, 74, 114
C/E	15	Kvenna	18558	Krokavatnet		1236	0.42	60847	6691012	7	2	06.07.78	6.80	2.57	45, 53, 70, 74, 90, 114
C/E	15	Kvenna	13	Briskevatnet		1068	2.62	89550	6677403	5	5	15.09.83	6.60	3.74	48, 50, 74, 77
C/E	15	Kvenna	12	Vollevatnet		1030	1.66	94853	6676114	6	6	13.09.83	6.63	1.33	49, 50, 74, 77, 114
C/E	15	Kvenna	19079	Honserudvatnet		1045	0.38	93458	6676917	3	0				49, 77
C/E	15	Kvenna	14	Gunleiksbuvatnet		1071	1.29	85362	6678032	6	5	15.08.95	6.62	1.59	50, 74, 77, 114, 115
C/E	15	Kvenna	17	Sandvatn		1112	1.57	82122	6681359	16	16	12.09.84	6.40	1.15	50, 74, 81, 82, own data
C/E	15	Kvenna	18854	Kringlesjåen		1255	0.72	89249	6682690	5	0	17.08.95	6.31	0.64	51, 114, 115, own data
C/E	15	Kvenna	39	Fjellsjåen		1195	2.31	90148	6684863	7	6	16.08.95	6.37	0.74	51, 114, 115, own data
C/E	15	Kvenna	18827	Dargesjåen		1205	0.64	87775	6683553	7	5	17.08.95	6.30	0.67	51, 86, 114, 115, own data
C/E	15	Kvenna	16	Øvre Bjørnavatnet		1147	2.92	71335	6679440	5	2	15.08.95	6.53	1.46	52, 70, 74, 114
C/E	15	Kvenna	18773	Krokavatni		1150	1.21	72085	6684881	2	2				52, 74
C/E	15	Kvenna	66946	Midtre Krokavatn		1141	0.93	74249	6684438	2	2				52, 74
C/E	15	Kvenna	18	Nedre Krokavatn		1141	1.16	77610	6684108	3	2	03.07.78	6.70	2.73	52, 74, 114
C/E	15	Kvenna	42	Valgardsvatni		1319	1.84	74012	6688631	4	4	16.08.95	6.36	1.42	67, 70, 74, 114
C/E	15	Kvenna	40	Urdevatnet		1329	1.55	93521	6669198	5	4	16.08.95	6.00	0.44	74, 114, 115
C/E	15	Kvenna	11836	Vesle Meinsvatnet		1353	0.57	95821	6670235	5	4	16.08.95	6.05	0.46	74,114,115
C/E	15	Kvenna	18581	Ambjørsvatnet		1269	0.81	66343	6689682	3	1	11.09.97	6.60	2.33	8, 40, 74
C/E	15	Kvenna	18770	Blånuttjørnane		1310	0.31	83830	6685129	1	1	09.10.97	6.72	2.30	80
C/E	15	Kvenna	18923	Tuevatni		1288	0.26	68807	6682727	1	1				70
C/E	16	Møsvatn	11881	Mortåtjørni		1241	0.86	106073	6668293	0		12.09.84	5.40	0.48	42
C/E	16	Møsvatn	12073	Grunnostjørni		1208	0.42	121236	6662626	0		15.09.83	6.20	1.19	42
C/E	16	Møsvatn	37	Langesjå		1145	6.99	126347	6662765	0		12.09.84	6.80	1.31	42
C/E	16	Møsvatn	12040	Reinarvatnet		1394	0.31	107009	6665028	0		13.09.83	5.19	0.78	89
C/E	16	Møsvatn	12146	Tuddøltjørn		1237	0.63	116638	6661056	0		13.09.83	5.67	0.70	89
C/E	16	Møsvatn	12032	Bukketjørn		1240	0.25	117722	6664058	0		13.09.83	6.05	0.71	89
C/E	16	Møsvatn	3	Møsvatn	x	919	78.77	114017	6655587	2	2	15.09.83	5.90	0.84	3
C/E	16	Møsvatn	12178	Landsetvatnet		1077	0.22	140859	6658142	1	0				7
C/E	16	Møsvatn	12188	Middøltjønne		1072	0.06	141341	6658117	1	0				7
C/E	16	Møsvatn	12409	Finnerottjørni		923	0.17	123664	6653003	1	1				42
C/E	16	Møsvatn	12395	Hondletjørni		924	0.24	123124	6652780	1	1				42
C/E	17	Mår/ Gøyst	18698	Sletteidvatni		1306	0.42	112017	6683971	0		15.09.83	5.60	0.65	42
C/E	17	Mår/ Gøyst	18661	Sletteidvatni		1303	0.13	114440	6684637	0		15.09.83	5.80	0.51	42
C/E	17	Mår/ Gøyst	19131	Vesle Saure		1147	0.99	113143	6673633	0		12.09.84	6.00	0.66	42

Appendix 1. Continued.

Region	Catchm. no.		Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583 X	Y	No. exam.	No. pos rec.	Date	pH	Ca mg L^{-1}	References
C/E	17		Mår/ Gøyst	36649	Haraldsjå		1080	1.02	131505	6671824	0		15.09.83	6.70	2.69	42
C/E	17		Mår/ Gøyst	18642	Viktjørn		1354	0.397	118551	6684136	0		24.09.95	6.02	0.44	88
C/E	17		Mår/ Gøyst	19044	Torstjørni		1220	0.378	109305	6676249	0		21.09.95	6.25	0.53	88
C/E	17		Mår/ Gøyst	18679	Sletteidvatni		1302	0.99	114495	6684111	0		13.09.83	5.76	0.55	89
C/E	17		Mår/ Gøyst	18845	Bakketjørn		1155	0.35	122801	6679611	0		13.09.83	6.05	0.84	89
C/E	17		Mår/ Gøyst	18562	Tangetjørnan		1261	0.232	101792	6687524	0		21.09.94	6.19	0.43	106
C/E	17		Mår/ Gøyst	18132	Austre Søltjørni		1197	0.599	128236	6692302	0		21.09.94	6.24	0.50	106
C/E	17		Mår/ Gøyst	18187	Vestre Søltjørni		1182	0.380	125474	6691715	0		21.09.94	6.29	0.56	106
C/E	17		Mår/ Gøyst	17925	Skjortetjørnan		1161	0.159	117274	6698507	0		21.09.94	6.50	1.66	106
C/E	17		Mår/ Gøyst	18456	Melrakktjørnane		1278	0.136	118023	6687392	0		21.09.94	6.55	1.33	106
C/E	17		Mår/ Gøyst	18133	Kosadalsvatnet		1136	0.551	116563	6693404	0		21.09.94	6.65	1.47	106
C/E	17		Mår/ Gøyst	11868	Torkjelstjørn		1168	0.07	136954	6666425	1	1				3
C/E	17		Mår/ Gøyst	92	Rosjå		1174	2.03	134023	6680450	2	2	12.09.84	6.80	2.41	3,7
C/E	17		Mår/ Gøyst	18721	Ljostjørn		1178	0.42	134529	6681268	1	1				7
C/E	17		Mår/ Gøyst	108	Kalven		1294	1.35	110072	6689697	1	1	21.09.94	6.09	0.42	66
C/E	17		Mår/ Gøyst	104	Hettefjorden		1228	2.33	113371	6691453	1	1	21.09.94	6.39	0.74	66
C/E	17		Mår/ Gøyst	96	Eidsjoren		1229	2.05	110808	6693400	1	1	21.09.94	6.44	0.90	66
C/E	17		Mår/ Gøyst	103	Reksjå		1207	2.81	119289	6681420	1	1	13.09.83	5.68	0.75	74
C/E	17		Mår/ Gøyst	93	Vråsjåen		1115	2.68	113053	6676124	1	1	12.09.84	6.10	0.64	74
C/E	17		Mår/ Gøyst	109	Viuvatnet		1324	3.03	109773	6687654	1	1	15.08.00	6.12	0.47	74
C/E	17		Mår/ Gøyst	94	Kallungsjåen		1246	3.17	106784	6684434	1	1	02.10.97	6.49	0.57	74
C/E	17		Mår/ Gøyst	75	Gøystvatnet	x	1087	31.26	123821	6676361	5	3	15.09.83	6.00	0.67	3, 47, 74
C/E	17		Mår/ Gøyst	36	Mår	x	1121	20.55	123922	6685973	10	4	12.09.84	6.10	0.94	3, 9, 47, 74, 79
C/E	17		Mår/ Gøyst	107	Store Saure		1120	1.63	115955	6674870	2	1	15.09.83	5.80	0.79	55, 62
C/E	18	A	Uvdalselvi	17543	Tjørngrøtjørnane		1195	0.046	133342	6710378	0		29.10.95	6.19	0.81	88
C/E	18	A	Uvdalselvi	17887	Gråvårtjørn		1213	0.203	129358	6698072	0		21.09.94	5.98	0.42	106
C/E	18	A	Uvdalselvi	17823	Langetjørni		1149	0.484	130951	6699604	0		21.09.94	6.08	0.54	106
C/E	18	A	Uvdalselvi	17796	Fiskeløktjørni		1184	0.862	129576	6700826	0		21.09.94	6.27	0.66	106
C/E	18	A	Uvdalselvi	17790	Kruketjørna		1137	0.167	131680	6700934	0		21.09.94	6.55	1.28	106
C/E	18	A	Uvdalselvi	17868	Gryttjørni		1206	0.289	133127	6698172	0		21.09.94	6.76	1.88	106
C/E	18	A	Uvdalselvi	17773	Bollatjørni		1181	0.72	126457	6701741	1	1	21.09.94	6.61	1.37	3
C/E	18	A	Uvdalselvi	17828	Hæratjønn		1249	0.07	135130	6699473	1	1				3
C/E	18	A	Uvdalselvi	385	Skarvsvatnet		1117	3.68	125273	6704599	2	2	21.09.94	6.76	1.37	3, 74
C/E	18	A	Uvdalselvi	411	Tøddølvatnet		1101	1.29	129152	6706737	1	1	12.10.97	7.20	4.82	74
C/E	18	A	Uvdalselvi	427	Store Ormetjørni		1187	0.71	130989	6709879	5	5	21.09.94	6.85	2.01	38, 39, 63
C/E	18	B	Uvdalselvi	17848	Øvre Halstjørnane		1190	0.105	122882	6699607	0		29.10.95	6.56	1.64	88
C/E	18	B	Uvdalselvi	17837	Falkenuttjørnane		1271	0.127	127220	6699829	0		21.09.94	5.97	0.46	106
C/E	18	B	Uvdalselvi	18055	Nordre Holstadtjørni		1198	0.281	124708	6694234	0		21.09.94	6.15	0.39	106
C/E	18	B	Uvdalselvi	18052	Nedre Afdalstjørni		1102	0.265	131663	6693752	0		21.09.94	6.29	0.65	106
C/E	18	B	Uvdalselvi	18089	Søre Holstadtjørni		1199	0.251	125832	6693465	0		21.09.94	6.32	0.62	106
C/E	18	B	Uvdalselvi	17935	Dragøytjørni		1172	0.234	124531	6697263	0		21.09.94	6.35	0.90	106
C/E	18	B	Uvdalselvi	17867	Halstjørn		1190	0.425	123493	6698934	0		21.09.94	6.54	1.20	106
C/E	18	B	Uvdalselvi	18264	Store Gryttjørni		1234	0.391	137346	6688573	0		21.09.94	6.63	1.42	106
C/E	18	B	Uvdalselvi	18191	Nedre Nutetjørnane		1217	0.194	134645	6690674	0		21.09.94	6.64	1.59	106

Appendix 1. Continued.

Region	Catchm. no.	Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583 X	Y	No. exam.	No. pos rec.	Date	pH	Ca mg L^{-1}	References
C/E	18	B	Uvdalselvi	17810	Mjågesjoren		1205	0.250	136935	6699369	0		21.09.94	6.95	2.78	106
C/E	18	B	Ølmosåi	410	Smågefjorden		1172	2.37	126931	6695185	1	1	21.09.94	6.33	0.58	74
C/E	18	B	Ølmosåi	17979	Kvonneviertjørni		1103	0.11	131830	6695521	1	1				74
C/E	18	B	Ølmosåi	426	Damtjørn		1223	0.44	143306	6697950	1	0				104
C/E	18	B	Ølmosåi	17949	Sønstevatnet	x	1060	12.53	142350	6693775	4	3	21.09.94	6.55	1.27	63, 74, 104
C/E	18	B	Ølmosåi	409	Vikvatn		1064	1.22	133668	6694102	4	3	21.09.94	6.68	1.45	63, 74, 97, 104
C/E	19	A	Lågen	18274	Øvre Bessvatnet		1313	0.06	76469	6694619	0		17.07.96	6.56	2.04	19
C/E	19	A	Lågen	18612	Lakadalstjørnane		1285	0.14	81147	6688201	0		31.07.03	6.83	2.65	19
C/E	19	A	Lågen	18086	Reinsmyrtjørni		1294	0.06	85109	6697360	0		30.07.98	6.84	2.90	19
C/E	19	A	Lågen	18445	Vegarhovdtjørnan		1255	0.194	102718	6689092	0		21.09.95	6.20	0.52	88
C/E	19	A	Lågen	18211	Feitfisktjørnan		1230	0.268	107376	6692928	0		12.09.97	6.37	0.55	88
C/E	19	A	Lågen	18536	Langebutjørnan		1235	0.144	88840	6688873	0		02.10.97	6.44	2.03	88
C/E	19	A	Lågen	18076	Torjustjørnan		1220	0.691	96849	6695359	0		02.10.97	6.74	2.03	88
C/E	19	A	Lågen	18478	Lakadalstjørnane		1268	0.154	82119	6690318	0		02.10.97	6.82	3.95	88
C/E	19	A	Lågen	67633	Andersosen		1308	0.124	76272	6705286	0		09.10.97	7.00	4.37	88
C/E	19	A	Lågen	17492	Grønenuttjørnan		1180	0.096	111175	6714372	0		12.10.97	7.14	4.47	88
C/E	19	A	Lågen	17456	Herbutjørnan		1183	0.180	114588	6715696	0		12.10.97	7.21	5.01	88
C/E	19	A	Lågen	18338	Steintjørni		1307	0.874	105369	6690638	0		21.09.94	6.01	0.37	106
C/E	19	A	Lågen	18469	Sørtjørn		1225	0.579	98746	6688587	0		21.09.94	6.21	0.51	106
C/E	19	A	Lågen	18239	Bakketjørnan		1240	0.103	106117	6692561	0		21.09.94	6.30	0.83	106
C/E	19	A	Lågen	18199	Nottartjørni		1223	0.543	98972	6693651	0		21.09.94	6.35	1.04	106
C/E	19	A	Lågen	17653	Nordskarvet		1123	1.702	120711	6706344	0		21.09.94	6.39	1.00	106
C/E	19	A	Lågen	18466	Langebu-tjørnan		1246	0.466	87396	6688826	0		21.09.94	6.44	1.11	106
C/E	19	A	Lågen	18096	Veisetjørnan		1237	0.213	94612	6695944	0		21.09.94	6.55	1.32	106
C/E	19	A	Lågen	17565	Lometjørni		1225	0.278	99207	6712469	0		21.09.94	6.57	1.06	106
C/E	19	A	Lågen	17999	Lomavikan		1210	0.209	95448	6698337	0		21.09.94	6.57	1.44	106
C/E	19	A	Lågen	18050	Torjustjørnan		1220	0.627	98330	6696625	0		21.09.94	6.59	1.61	106
C/E	19	A	Lågen	276916	Danemannstjønni		1166	0.255	110914	6701192	0		21.09.94	6.63	1.46	106
C/E	19	A	Lågen	17332	Båtstjørni		1157	0.711	102267	6721178	0		21.09.94	6.66	1.47	106
C/E	19	A	Lågen	17981	Brutjørnan		1220	0.587	93030	6698601	0		21.09.94	6.68	1.52	106
C/E	19	A	Lågen	17624	Skaupsjøtjørnan		1157	0.340	100267	6710074	0		21.09.94	6.68	1.97	106
C/E	19	A	Lågen	17800	Dagfisketjørni		1167	0.878	112359	6701694	0		21.09.94	6.72	1.71	106
C/E	19	A	Lågen	18023	Storfisktjørni		1235	1.127	90270	6697238	0		21.09.94	6.77	2.17	106
C/E	19	A	Lågen	17685	Kalvetjørnan		1170	0.058	99694	6708108	0		21.09.94	6.84	2.40	106
C/E	19	A	Lågen	17460	Orsjøtjørni		1079	0.43	122190	6714827	1	1	21.09.94	6.80	1.88	2
C/E	19	A	Lågen	17591	Halstjørni		1022	0.08	119782	6710045	1	1				2
C/E	19	A	Lågen	17612	Vesle Selstjørni		1128	0.10	109866	6710191	1	1				2
C/E	19	A	Lågen	17807	Austre Bakkatjørn		1213	0.60	94866	6703502	1	1	21.09.94	6.60	1.77	3
C/E	19	A	Lågen	66954	Hølen		1157	0.47	113891	6703571	2	2	21.09.94	6.55	1.31	16
C/E	19	A	Lågen	417	Krossvatnet		1165	1.69	111939	6699586	2	2	21.09.94	6.59	1.29	16, 74
C/E	19	A	Lågen	18290	Høgevardetjørn		1357	0.23	74515	6693954	1	1	17.07.96	6.32	2.13	19
C/E	19	A	Lågen	18650	Holbergtjørnane		1314	0.21	82385	6687575	1	1	31.07.03	6.93	1.90	19
C/E	19	A	Lågen	18257	Bessvatnet		1303	0.30	77497	6694635	1	1	02.10.97	7.07	2.84	67
C/E	19	A	Lågen	18336	Dimmedalstjørni		1325	0.16	76839	6692957	1	1		5.90		67
C/E	19	A	Lågen	17411	Hetjørni		1162	0.22	96712	6718971	1	0				67

Appendix 1. Continued.

Region	Catchm. no.	Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583 X	Y	No. exam.	No. pos rec.	Date	pH	Ca mg L^{-1}	References
C/E	19 A	Lågen	17959	Holmavatn		1260	0.10	80443	6700892	1	1				67
C/E	19 A	Lågen	18289	X-tjørn		1326	0.04	75897	6694381	1	1				71
C/E	19 A	Lågen	18305	Y-tjørn		1330	0.04	75917	6693986	1	1				71
C/E	19 A	Lågen	17843	Vestre Bakketjørn		1211	1.63	93717	6702002	1	1	21.09.94	6.35	1.10	74
C/E	19 A	Lågen	17750	Holmetjørnane		1207	0.77	97434	6705361	1	1				74
C/E	19 A	Lågen	17357	Hytetjørne		1193	0.06	115119	6719447	1	1				74
C/E	19 A	Lågen	18193	Melrakktjørni		1211	0.50	102715	6693467	1	1				74
C/E	19 A	Lågen	18225	Nordre Skjærhøltjørn		1218	0.44	100813	6693069	1	1				74
C/E	19 A	Lågen	17895	Reinavatnet		1173	0.53	109940	6699644	1	1				74
C/E	19 A	Lågen	17965	Skrovstjørni		1222	0.13	92249	6699618	1	1				74
C/E	19 A	Lågen	17988	Tjuvhyttjørni		1182	0.24	107380	6697413	1	1				74
C/E	19 A	Lågen	279619	Vestre Bakketjørn		1212	1.29	93573	6702169	1	1				74
C/E	19 A	Lågen	392	Storekrekkja		1151	4.18	101435	6723196	1	1	21.09.94	6.09	0.48	105
C/E	19 A	Lågen	17584	Skaupungen		1150	0.17	102161	6711896	1	1			1.76	112
C/E	19 A	Lågen	415	Halnefjorden	x	1130	13.70	101185	6715697	16	16	21.09.94	6.72	1.81	1, 2, 3, 44, 61, 83, 96, 105, 112
C/E	19 A	Lågen	17040	Svartevatnet		1233	1.13	99538	6728768	14	7	25.07.93	5.69	0.35	10, 33, 35, 67, 107
C/E	19 A	Lågen	17343	Breidvatnet		1162	1.00	118578	6719115	4	4				16, 17, 18, 74
C/E	19 A	Lågen	17364	Korta		1163	0.26	117084	6718774	4	4				16, 17, 74
C/E	19 A	Lågen	396	Geitvatnet		1197	1.55	105307	6695177	4	4	21.09.94	6.52	1.18	16, 21, 27, 74
C/E	19 A	Lågen	18374	Bismarvatnet		1331	1.88	74729	6692150	6	3		6.00		19, 67, 70, 74
C/E	19 A	Lågen	17397	Heinungen		1138	0.37	105066	6718724	3	1	21.09.94	6.34	0.80	2, 105
C/E	19 A	Lågen	390	Orsjoren		951	2.37	125791	6712627	5	5	21.09.94	6.73	1.57	2, 15, 17, 103
C/E	19 A	Lågen	17454	Bjordalsvatn		1121	0.52	118134	6715599	2	2	21.09.94	6.97	3.12	2, 3
C/E	19 A	Lågen	414	Øvre Hein		1113	6.33	106335	6714906	6	6	21.09.94	6.56	1.11	2, 3, 105, 112
C/E	19 A	Lågen	66935	Heintjønne		1112	0.58	109162	6712787	3	3	17.07.67	6.60	0.80	2, 3, 112
C/E	19 A	Lågen	394	Geitsjøen		1112	3.22	113050	6706544	6	6	22.07.67	6.90	1.32	2, 3, 16, 17, 112
C/E	19 A	Lågen	416	Skrykken		1158	5.09	116530	6700686	6	6	21.09.94	6.51	1.30	2, 3, 16, 74
C/E	19 A	Lågen	17583	Nedre Hein		1075	1.23	113349	6710330	8	8	26.07.92	6.61	1.50	2, 3, 44, 74, 105, 112
C/E	19 A	Lågen	391	Veslekrækkja		1148	1.98	103447	6720601	4	2	21.09.94	6.27	0.64	2, 44, 105, 112
C/E	19 A	Lågen	17366	Nedre Bjørkevatn		1161	0.84	120435	6717924	5	5	21.09.94	6.84	2.13	2, 74
C/E	19 A	Lågen	17617	Store Selstjørni		1135	0.49	107988	6709350	3	3	21.09.94	6.96	2.96	2, 74, 112
C/E	19 A	Lågen	17318	Langetjørni		1201	0.31	114730	6720445	4	4				3, 16, 17
C/E	19 A	Lågen	420	Nordmannslågen		1244	10.88	79991	6697139	9	9	30.07.98	6.87	2.40	3, 16, 67, 71, 74
C/E	19 A	Lågen	18253	Skjærhøl		1216	0.94	101092	6691921	3	3				3, 16, 74
C/E	19 A	Lågen	428	Skaupsjøen		1155	2.95	96915	6712322	4	4	21.09.94	6.85	2.59	3, 16, 74, 101
C/E	19 A	Lågen	17477	Skiftesjøen		1236	0.82	90493	6716874	9	9				3, 35, 74
C/E	19 A	Lågen	395	Langesjøen		1210	11.04	97530	6698934	7	7	29.10.95	6.61	1.56	3, 4, 16, 17, 72, 95, 102
C/E	19 A	Lågen	418	Bjornesfjorden		1223	18.38	93966	6692522	8	8	21.09.94	6.55	1.38	3, 4, 5, 6, 16, 74, 102

Appendix 1. Continued.

Region	Catchm. no.		Catchment	NVE ID no.	Lake	Reg.	Altitude m a.s.l.	Area km^2	ESPG: 2583 X	Y	No. exam.	No. pos rec.	Date	pH	Ca mg L^{-1}	References
C/E	19	A	Lågen	419	Lakjen		1243	3.12	85395	6693471	3	3	02.10.97	6.93	3.03	3, 67, 71
C/E	19	A	Lågen	17826	Flotatjørni		1209	0.77	102363	6702249	3	3	21.09.94	6.76	2.03	3, 72
C/E	19	A	Lågen	17908	Langesjøtjørni		1209	0.26	105566	6699604	6	6	21.09.94	6.66	1.74	3, 72
C/E	19	A	Lågen	17018	Svartevasstjørni		1237	0.40	99168	6730136	15	4	25.07.93	5.74	0.28	33, 35, 36, 37, 107
C/E	19	A	Lågen	17746	Stigstuvtjørni		1212	0.06	94207	6705959	2	2				34, 74
C/E	19	A	Lågen	393	Dragøyfjorden		1180	3.33	98419	6725710	21	18	31.05.93	5.49	0.65	67, 111, own data
C/E	19	A	Lågen	421	Dimmedalsvatnet		1334	1.70	75845	6690862	5	5	11.07.78	6.80	2.53	67, 70, 74, 114
C/E	19	A	Lågen	18208	Gravagjelstjønn		1346	0.21	75958	6695803	2	1	24.07.01	6.65	2.85	67, 71
C/E	19	A	Lågen	17898	Nordvatnet		1256	1.02	78918	6701916	3	3	29.10.95	6.52	3.30	67, 71, 74
C/E	19	A	Lågen	18164	Øvre Krakavadtjørni		1225	0.74	89462	6695153	2	2				74
C/E	19	A	Lågen	17899	Kleivshovd-tjørnane		1214	0.44	92044	6700797	1	1	21.09.94	6.51	1.20	74
C/E	19	B	Ufysja	17222	Tindevatnet		1265	0.192	121472	6722322	0		21.09.94	6.62	3.52	106
C/E	19	B	Ufysja	17297	Svantjern		1129	0.21	124886	6719724	1	1				2
C/E	19	B	Ufysja	17244	Tuvetjørni		1236	0.20	117562	6722207	4	4	21.09.94	6.90	2.47	16
C/E	19	B	Ufysja	17432	Usgrimsvatni		1213	0.15	127748	6715609	1	1				74
C/E	19	B	Ufysja	17401	Ljosevatnet		1182	0.90	125104	6716355	5	5	21.09.94	6.79	1.83	2, 16, 74
C/E	19	B	Ufysja	17281	Holværvatnet		1183	1.43	119750	6720539	4	4	21.09.94	7.11	3.31	2, 17, 74
C/E	20		Ørteråni	17104	Øvre Trestiklan	x	1149	0.48	103479	6727779	3	1	28.08.05	6.43	0.70	22, 23, 24
C/E	20		Ørteråni	17371	Skjerjavatnet		1192	1.57	113282	6718885	10	9				28, 29, 30, 31, 32, 69, 74, 83, 91
C/E	20		Ørteråni	553	Ørteren	x	1147	9.44	103584	6725146	10	5	26.08.05	6.53	1.80	3, 22, 23, 25, 26, 74, 78
C/E	20		Ørteråni	67975	Lægreidvatnet	x	1147	1.74	106124	6723166	5	4	23.08.05	6.77	2.30	3, 22, 23, 74, 78
C/E	20		Ørteråni	17395	Grønevatnet		1190	1.21	111304	6718009	2	2				3, 74

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