Introduced European minnow *Phoxinus phoxinus* in alpine lakes may increase total mercury concentration in brown trout *Salmo trutta*

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In Norway, the cyprinid European minnow *Phoxinus phoxinus* has been spread far outside its previous natural distribution area, with lots of establishments in mountain lakes where brown trout *Salmo trutta* originally was the only fish species. We have analysed δ¹⁵N and total mercury (THg) concentration in brown trout from eight lakes, situated between 1031 and 1244 m a. s. l. on the Hardangervidda mountain plateau, southern Norway. One of the lakes is inhabited by brown trout and European minnow, while in the other seven lakes, brown trout is the only fish species. δ¹⁵N of brown trout were significantly higher in the population with co-existing European minnow, indicating a higher trophic position of brown trout in this population than in the allopatic populations, probably caused by piscivory, as indicated by frequent occurrence of European minnow in brown trout diet. The mercury concentrations in brown trout from this lake had values up to around 0.4 mg THg per kg wet weight. The concentrations were significantly higher than in the lakes without European minnow, and together with the δ¹⁵N values, indicating that translocation and establishment of European minnow may increase the trophic position of brown trout in previously allopatic populations, and thereby also increase the mercury level.

**INTRODUCTION**

A high number of small-sized fish species are spread over country borders or within a country, partly because they are used as live bait or introduced as food enhancement for local fish species. Typical examples are the spreading of redside shiner *Richardsonius balteatus* Richardson, 1836 in North America (Larkin & Smith 1954; Johannes & Larkin 1961), and the European minnow *Phoxinus phoxinus* Linnaeus, 1758 in Europe (Hesthagen & Sandlund 1997, Museth et al. 2007). The European minnow is an indigenous species in south-eastern Norway and parts of northern Norway (Huitfeldt-Kaas 1918), but the species has been translocated to all counties during the previous century (Hesthagen & Sandlund 1997), as well as brought in from other countries, as indicated by genetic analysis (Thaulow et al. 2014). Generally, brown trout (*Salmo trutta* Linnaeus, 1758) has been the only fish species in most high mountain lakes in southern Norway, where this species has been important for recreational, private household and commercial fishing (Somme 1941; Ovensild 2004). During the last decades, however, European minnow has increased its distribution area in this mountain region by introductions, and it is now established in a high number of lakes formerly inhabited by brown trout only (Rognerud et al. 2003; Hesthagen & Sandlund 1997; Museth et al. 2007).

According to Braaten et al. (2018a) the atmospheric input of mercury (Hg) to Norway is estimated to 3.3 tons annually, with a considerable retention in soil and lakes. Due to this long-range transport of mercury, catchments and lakes even in remote Arctic and high mountain areas are polluted with mercury (Rognerud & Fjeld 2001; Rognerud et al. 2002; Berg et al. 2006; Rosseland et al. 2007; Jenssen et al. 2010; Braaten et al. 2017). At the same time introduced invertebrates and fish may increase the length of the food chain and result in elevated mercury levels in the top predator fishes (Cabana et al. 1994; Swanson et al. 2003). European minnow may feed on the same invertebrates as brown trout, and concurrently become part of brown trout diet (Museth et al. 2003), thus elevating the trophic position of brown trout, with increasing risk of obtaining higher total mercury (THg) concentrations (Rognerud et al. 2002). Eating of fish is the main source for exposure to mercury in humans, and due to the neurotoxic effects of mercury, fish consumption is of special concern for “groups at risk”, especially pregnant women and prenatal and postnatal exposure to children (Myers et al. 2009; Okpala et al. 2017). The nitrogen stored in animals is enriched in the ¹⁵N isotope relative to the concentration in the food, and accordingly
top predators such as piscivorous fish have the highest concentration of this nitrogen isotope. Accordingly, the ratio of the stable nitrogen isotopes $^{15}$N and $^{14}$N ($\delta^{15}$N) relative to a standard (atmospheric N$_2$), and expressed per mil (‰), can be used as an estimate of trophic position (Cabana & Rasmussen 1996, and references therein). On this background, we have analysed THg concentrations and $\delta^{15}$N in brown trout from populations on the Hardangervidda mountain plateau in Norway, with two primary objectives; (i) examine the concentrations of total mercury and the trophic position (indicated by $\delta^{15}$N) of brown trout in lakes with and without coexisting European minnow, and (ii) explain the variation in THg concentrations, within and between fish populations, with respect to fish specific data (age, length), and trophic position.

**MATERIAL AND METHODS**

**The lakes and sampling procedures**

The study is based on data from eight natural lakes located on the Hardangervidda mountain plateau, in the southern part of Norway (Figure 1), of which seven of the lakes are inhabited by brown trout only, while lake Skaupsjøen is inhabited by brown trout and European minnow. This lake is situated 1158 m above sea level (a. s. l.) on the northern part of the mountain plateau, just outside the Hardangervidda national park (Figure 1). It has a mean depth of only 2.1 m, with many small islets over a large part of the 2.88 km$^2$ lake area. The other lakes are situated between 1031 and 1244 m a. s. l (Table 1, Figure 1).

![Location of the studied lakes on the Hardangervidda mountain plateau](figure1)

Figure 1. Location of the studied lakes on the Hardangervidda mountain plateau, 1) Skaupsjøen, 2) Bjornesfjorden, 3) Nordmannsågen, in the catchment area of the river Numedalsågen, and 4) Kollsvatn, 5) Litlosvatn, 6) Sandvatn, 7) Gunnleiksbuvatn, 8) Vollevatn, all in the river Kvenna. Green line delimits Hardangervidda National park, and blue lines are county and municipality borders (Map source: Kartverket.no).

In 1973, European minnow was recorded for the first time in lakes just east of Skaupsjøen (Borgstrøm 1973). The species has since been recorded in several lakes in this area, including the large reservoir Halne (Rognerud et al. 2003), from which minnows have free access to the above-lying lake Skaupsjøen where the species forms an important part of brown trout diet (Rognerud et al. 2003; Borgstrøm 2009). The establishment of European minnow in the area is most probably a result of direct spreading by man (fishermen illegally using live bait), or indirectly being stocked together with brown trout from areas where minnows may have entered the brown trout rearing facilities (Hesthagen & Sandlund 1997).

The annual precipitation on Hardangervidda declines from west towards east, illustrated by the snow depth range measured around 1 April 1943 – 2000 at the western lake, Litlosvatn (depth range 77 – 334 cm), at lake Nordmannsågen (depth range 50 – 260 cm) in central part, and at lake Skaupsjøen (depth range 40 – 190 cm) in the northeastern part of the study area (Rognerud et al. 2003). Accordingly, airborne pollutants such as mercury are expected to be highest in the western and lowest in the eastern part of the mountain area. Analyses of water quality (pH, total organic carbon (TOC) and alkalinity) of the lakes have been performed by the Norwegian Institute for Water Research (NIVA) (Skjellkvåle & Henriksen 1998; Rognerud et al. 2003). All lakes in our study are relatively shallow, oligotrophic, circum-neutral, with low acid neutralizing capacity, and TOC values in the range 0.3 – 1.5 mg L$^{-1}$ (Table 1). In boreal lakes with TOC concentrations in the range 3.6 – 20.1 mg L$^{-1}$, i.e., much higher than in lakes in the present study, a significant positive relationship between TOC concentration and mean fish THg concentration was found (Braaten et al. 2018b).

Brown trout was originally the only fish species on the Hardangervidda mountain area, being present here for at least 6,7000 years (Indrelid 2014). Recreational and household fishing for brown trout takes place in all the studied lakes, and commercial fishing has been common in some of them (the lakes Skaupsjøen, Bjornesfjorden, Nordmannsågen). The brown trout from this area is mostly marketed as fermented trout (‘rakfisk’ in Norwegian), to a price around 40 Euro per kg. Due to low annual recruitment to the brown trout population in the lake Skaupsjøen, stocking with 1+ brown trout has been performed for several years. The lakes Nordmannsågen and Bjornesfjorden have been stocked mainly with summer old brown trout (0+).

**Sampling and chemical analysis**

In August 2000-2002, brown trout were sampled by fleets of gillnets with different mesh sizes from the seven lakes where the species is still allopatric, and from the lake, Skaupsjøen, where brown trout co-exist with European minnow. Additional gillnetting of brown trout and European minnow was performed in the lake Skaupsjøen.

Table 1. Morphometric and water quality data of the studied lakes on the Hardangervidda mountain plateau (Data from Skjellkvåle & Henriksen 1998; Rognerud et al. 2003).

| Lake             | Altitude (m) | Lake area (km$^2$) | Mean depth (m) | Max. depth (m) | pH   | TOC (mg/L) | Alkalinity (µeq/L) |
|------------------|--------------|-------------------|----------------|---------------|------|------------|---------------------|
| Skaupsjøen       | 1158         | 2.88              | 2.10           | 8             | 6.9  | 1.4        | 0.144               |
| Kollsvatn        | 1182         | 0.63              | 6.5            | 13            | 6.7  | 0.7        | 0.067               |
| Litlosvatn       | 1172         | 1.51              | 10.2           | 25            | 6.6  | 0.3        | 0.054               |
| Sandvatn         | 1112         | 1.58              | 2.55           | 13            | 6.8  | 0.4        | 0.096               |
| Gunnleiksbuvatn  | 1076         | 1.27              | 2.9            | 12            | 6.8  | 0.8        | 0.062               |
| Vollevatn        | 1031         | 1.54              | 2.9            | 18            | 6.7  | 0.8        | 0.067               |
| Bjornesfjorden   | 1223         | 18.55             | 4.2            | 11            | 6.7  | 1.5        | 0.099               |
| Nordmannsågen    | 1244         | 11.09             | 4.2            | 16            | 6.9  | 1.0        | -                   |
in August 2009. Summary statistics for the sampled fish are given in Table 2. Length of the sampled brown trout and European minnow was measured in mm, and otoliths were collected for age determination. A piece of bone- and skinless dorsal axial muscle tissue were removed from each brown trout, wrapped in aluminum foil, stored in polyethylene bags, and frozen, for later total mercury concentrations (THg) and stable isotope (δ15N) analysis, following the EMERGE Fish protocol (Rosseland et al. 2001). Sampling from European minnow was done in approximately the same way, but due to the small size of the minnows, the whole fish was collected.

Analyses of the ratio between the stable isotopes 15N and 14N ratio (δ15N) and THg for fish sampled in 2009 were performed at the Isotope Laboratory, Faculty of Environmental Sciences and Natural Resource Management (MINA), Norwegian University of Life Sciences (NMBU). Samples from 2000-2002 were analysed for δ15N at Institute for Energy Technology (IFE) at Kjeller, Norway, and THg analysed at Norwegian Institute of Water Research (NIVA). All these laboratories are certified and follow the same analysis procedures. For stable isotope analysis of nitrogen, thoroughly described by Jenssen et al. (2010), the muscle tissues of the brown trout and European minnows were homogenized and freeze-dried. Stable isotopic ratios of nitrogen (δ15N/14N) were determined by combusting the homogenized freeze-dried samples in a Flash Elemental Analyzer (EA), separating the combustion gases (CO2 and N2) with a Poraplot Q column, and transferring them to a Finnigan DeltaPlus XP continuous-flow isotope ratio mass spectrometer (CF-IRMS). The isotopic ratio (δ15N/14N) was expressed as a delta-value: δ15N (%o). The house standard of brown trout was measured at the beginning of each run and repeated regularly during a run, with an average analysed value at 13.20 ± SD 0.06 %o.

According to Cabana & Rasmussen (1996), cross-system comparisons in δ15N can be complicated due to differences in δ15N at the base of the food chain, which increases markedly with the human population density in the lake watershed, likely reflecting the high δ15N of human sewage. Accordingly, δ15N should preferably be corrected to a common bottom line, for example by use of the δ15N in the snail Radix peregra (Müller, 1774) as a reference species for primary consumers, as suggested by Post (2002). However, we have no data from snails in all lakes, and therefore the analysed values have been used directly. In the catchment of the studied lakes, the local anthropogenic activity is very low, with no permanent residents, and with only a few cabins used primarily for fishing and hunting. At the lakes Litlosvatn and Nordmannsågen there are tourist cabins which are open for hikers in Easter and around 2.5 months each summer, but with strong restrictions on litter and sewage, and we consider the influence on δ15N to be disregarded. In addition, the lakes in this study are situated at nearly the same elevation, and the background δ15N is thus expected to be at the same level.

For THg analysis, described in Rognrud et al. (2002), approximately 1 g was digested in 20 mL 7 N nitric acid before being analysed for total Hg by cold vapour AAS (Perkin Elmer FIMS 400) equipped with a hydride generator. The detection limit was 0.005 μg g−1 wet weight. The analyses were run in series of 30 samples, of which one was a standard reference and three were blanks. The standard reference was a fish homogenate (DORM 2, dogfish filet of Squalus acanthias Linnaeus, 1758), a certified reference material from the National Research Council of Canada, Ottawa, and used at both laboratories.

**Age determination of fish**

The age of both brown trout and European minnow was determined by otoliths. The brown trout otoliths (sagitta) were broken through the center, and each otolith half were burnt (Power 1978). Thereafter, the burnt otolith halves were placed in a piece of modeling wax with the cut surface turned up, and soaked in propandiol, before age determination was performed under a stereomicroscope (Figure 2). The European minnow otoliths were placed whole in propandiol, and the age of both brown trout and European minnow was determined with the cut surface turned up, and soaked in propandiol, before age determination was performed under a stereomicroscope (Figure 2).

**Statistical analyses**

All descriptive statistics and statistical analyses were performed by the software JMP 16.0.0 (SAS Institute) and Canoco5 (v5.12, Ter Braak & Šmilauer 2018). Assumption-free ANOVA, t-test, linear regression and multiple linear regression with forward selection were conducted by using different set-ups of Redundancy Analysis (RDA) combined with Monte Carlo permutation tests (Šmilauer & Leps 2014). This approach is robust against violation of the assumption of a normal distribution of the modelled residuals in parametric tests. By using Monte Carlo permutation test, pseudo F-ratio calculated by
RESULTS

Mercury concentrations and $\delta^{15}$N level in brown trout and European minnow

The statistical tests revealed no differences in length (pseudo-$F<0.1$, $p>0.05$) and age (pseudo-$F<1$, $p>0.05$) of brown trout between the allopatric populations and the sympatric population (Lake Skaupsjøen) (Figure 3). In contrast, the concentrations of THg were significantly higher in brown trout from the lake Skaupsjøen compared to brown trout from the other lakes (pseudo-$F=142$, $p<0.001$). The THg concentrations in brown trout from the lake Skaupsjøen were in the range 0.02-0.41 mg/kg with mean value 0.13 (SD=±0.08), while in the other lakes with allopatric brown trout the concentrations were in the range 0.01-0.12 mg/kg, with mean value 0.04 (SD=±0.02). Likewise, there was a significant difference in uncorrected $\delta^{15}$N values between allopatric brown trout and sympatric brown trout (pseudo-$F=232$, $p<0.001$). To correct for variation in THg data attributed to age, length and uncorrected $\delta^{15}$N in the statistical tests between the different populations (i.e. allopatric vs. sympatric), we performed a partial RDA (pRDA). The pRDA revealed a statistically significant difference between the two population types (pseudo-$F=28.5$, $p<0.001$). However, the explained variation ascribed to population type dropped from 47% to 15% after the correction.

In European minnow, the concentration of THg was in the range 0.05-0.14 mg/kg, with a mean value 0.09 (SD=±0.02). Even though there was no statistically significant difference between the two species (pseudo-$F=3.1$, $p>0.05$), the variation in THg concentrations was much greater in brown trout compared to European minnow (Figure 4). The variation in uncorrected $\delta^{15}$N was also apparently
greater in brown trout compared to European minnow, and the difference between the two species was significant (pseudo-F=29.9, p<0.001) (Figure 4). In the lake Skaupsjøen, the mean $\delta^{15}N$ in brown trout was 8.47 ‰, and in European minnow 6.28 ‰, while in brown trout from the allopatric populations mean $\delta^{15}N$ was 5.92 ‰.

The age, length and uncorrected $\delta^{15}N$ explained 36% ($R^2_{adj}=0.36$, pseudo-$F=68.9, p<0.001$), 46% ($R^2_{adj}=0.46$, pseudo-$F=108, p<0.001$) and 43% ($R^2_{adj}=0.43$, pseudo-$F=94.8, p<0.001$) of the observed variation in THg in the allopatric brown trout populations, respectively (Figure 5). In the sympatric population, the age, length and uncorrected $\delta^{15}N$ explained 45% ($R^2_{adj}=0.45$, pseudo-$F=27.7, p<0.001$), 67% ($R^2_{adj}=0.67$, pseudo-$F=68.5, p<0.001$) and 31% ($R^2_{adj}=0.31$, pseudo-$F=16.1, p<0.001$) of the observed variation in THg, respectively. We also conducted a multiple regression where fish from both the allopatric and sympatric populations were included. Forward selection was applied to determine the best model to describe the observed variation. In addition to the numerical explanatory variables age, length and uncorrected $\delta^{15}N$, we included population type (i.e. allopatric/sympatric) as a nominal variable. The overall best model captured 78% ($R^2_{adj}=0.78$, pseudo-$F=140, p<0.001$) of the observed THg variation, and consisted of the explanatory variables uncorrected $\delta^{15}N$, length and population type. The output is displayed in the ordination plot in Figure 6. In all the regression models, a clear separation between the allopatric brown trout populations and the sympatric brown trout population from Lake Skaupsjøen was evident.

The amount of data on European minnow is substantially lower compared with the brown trout data, and the uncertainties in the regression models performed on the European minnow are higher. As for brown trout, there were apparently positive relationships between the THg concentrations and fish age, length and uncorrected $\delta^{15}N$ (Figure 7). However, only age was statistically significant ($R^2_{adj}=0.39$, pseudo-$F=8.5, p<0.05$).
Fauna norvegica Linnaeus, 1758 (Kjellberg & Sandlund et al.: European minnow may increase THg in brown trout Fauna norvegica 41: 41–49. 2021)

For instance, brown trout in the lake Mjøsa 2003). For instance, brown trout in the lake Mjøsa 1986; G. O. Sars, 1863 and 2020), as well as in a Total mercury concentration (THg) in European minnow from Lake Skaupsjøen captured in 2009 in relation to age (A), length (B), and δ15N (Pallas, 1793) are among the most important food 15N of the analysed populations. Factors causing mercury contamination in fish include bioavailability of methylmercury, and a food web that enhances bioaccumulation (Cabana et al. 1994; Gorski et al. 2003; Swanson et al. 2003). For instance, brown trout in the lake Mjøsa feed to a large extent on smelt Osmerus eperlanus (Linnaeus, 1758) and cisco Coregonus albula Linnaeus, 1758 (Kjellberg & Sandlund 1983; Sandlund & Næsje 1992), resulting in mercury concentrations exceeding 1 mg per kg w/w, and increasing with size and age (Fjeld & Rognerud 2002). The age of fish together with trophic position may therefore be significant predictors of mercury bioaccumulation (McIntyre & Beauchamp 2007), as also indicated in the present study. Introduced freshwater fish and invertebrate species may restructure food webs and cause major ecological changes, often at the expense of local species (Langeland 1981; Lasenby et al. 1986; Miller 1989; Spencer et al. 1991; Kolar & Logle 2002; Baxter et al. 2004). The crustaceans Gammarus lacustris G. O. Sars, 1863 and Lepidurus arcticus (Pallas, 1793) are among the most important food items for brown trout in lakes on Hardangervidda (L’Abée-Lund & Sægrov 1991; Borgstrøm 2016; Qvenild et al. 2020), as well as in other mountain areas in southern Norway (Aass 1969; Lien 1978). European minnow feed on the same prey species (Borgstrøm et al. 1985; Museth et al. 2010), also indicated by the δ15N of the analysed European minnow from lake Skaupsjøen being nearly in the same range as found for brown trout in the analysed allopatric populations. Because European minnow is included in the diet of brown trout in the lake Skaupsjøen (Rognerud et al. 2003; Borgstrøm 2009), the food web becomes longer, and this is probably the main reason for the elevated mercury concentrations in individuals from this population. In aquatic food webs, the mean δ15N of a consumer is typically enriched by 3-4 % relative to its diet (Vander Zanden & Rasmussen 1999; Post 2002; and references therein). The difference was ca 2.55 % (unadjusted values) between brown trout from Skaupsjøen (mean δ15N = 8.47 ‰) and brown trout from the allopatric populations (mean δ15N = 5.92 ‰), i.e., less than one trophic level, indicating a mixed diet of brown trout from the lake Skaupsjøen, consisting of both invertebrates and minnows. In a similar fish community, with brown trout and European minnow, in the Norwegian subalpine lake, Øvre Heimdalsvatn (1095 m a. s. l.) on the eastern slope of the Jotunheimen mountains, European minnow was mainly preyed upon during the minnow spawning period, i.e., in June-July (Lien 1981; Museth et al. 2003, Jenssen et al. 2010), probably a result of higher vulnerability of minnows at this time. Although the THg concentration in European minnow from the lake Øvre Heimdalsvatn was even higher than in the lake Skaupsjøen (range 0.014 – 0.16 mg/kg w/w) (Jenssen et al. 2010), the average THg in brown trout was low (0.05 mg/kg w/w). The average δ15N in brown trout was 6.5 ‰ (Jenssen et al. 2010), i.e., indicating a lower trophic level than in the lake Skaupsjøen, probably reflecting a lower total consumption of minnows. Both the δ15N and THg concentration were nevertheless higher in brown trout from the lake Øvre Heimdalsvatn than in brown trout from the allopatric populations included in our study. This may illustrate the effect on the mercury contamination in a piscivore as a result of the actual annual quantity of prey fish in the diet.

Seasonal studies of brown trout diet in the lake Skaupsjøen have not been performed, but minnows were an important part in both August 2009 (Borgstrøm 2009), and August 2001 (Rognerud et al. 2003), i.e., after the spawning season of minnows. The lakes Øvre Heimdalsvatn and Skaupsjøen differ in morphometry, with Skaupsjøen being very shallow, with lots of islets, probably increasing the availability of minnows to brown trout in this lake in comparison with the conditions in the lake Øvre Heimdalsvatn. Predation on minnows, and thereby the transfer of mercury to brown trout, may according to these examples show considerable variations between lakes, most probably depending on availability of minnows as prey for

**DISCUSSION**

The studied lakes are all low-productive, with low total organic carbon (TOC) values and nearly similar high pH-values and alkalinity, and with minimal human activity in the catchment areas of all the lakes. However, the mean THg concentration in brown trout from Skaupsjøen was around three times higher than in brown trout from the allopatric populations. Factors causing mercury contamination in fish include bioavailability of methylmercury, and a food web that enhances bioaccumulation (Cabana et al. 1994; Gorski et al. 2003; Swanson et al. 2003). For instance, brown trout in the lake Mjøsa feed to a large extent on smelt Osmerus eperlanus (Linnaeus, 1758) and cisco Coregonus albula Linnaeus, 1758 (Kjellberg & Sandlund 1983; Sandlund & Næsje 1992), resulting in mercury concentrations exceeding 1 mg per kg w/w, and increasing with size and age (Fjeld & Rognerud 2002). The age of fish together with trophic position may therefore be significant predictors of mercury bioaccumulation (McIntyre & Beauchamp 2007), as also indicated in the present study. Introduced freshwater fish and invertebrate species may restructure food webs and cause major ecological changes, often at the expense of local species (Langeland 1981; Lasenby et al. 1986; Miller 1989; Spencer et al. 1991; Kolar & Logle 2002; Baxter et al. 2004). The crustaceans Gammarus lacustris G. O. Sars, 1863 and Lepidurus arcticus (Pallas, 1793) are among the most important food items for brown trout in lakes on Hardangervidda (L’Abée-Lund & Sægrov 1991; Borgstrøm 2016; Qvenild et al. 2020), as well as in other mountain areas in southern Norway (Aass 1969; Lien 1978). European minnow feed on the same prey species (Borgstrøm et al. 1985; Museth et al. 2010), also indicated by the δ15N of the analysed European minnow from lake Skaupsjøen being nearly in the same range as found for brown trout in the analysed allopatric populations. Because European minnow is included in the diet of brown trout in the lake Skaupsjøen (Rognerud et al. 2003; Borgstrøm 2009), the food web becomes longer, and this is probably the main reason for the elevated mercury concentrations in individuals from this population. In aquatic food webs, the mean δ15N of a consumer is typically enriched by 3-4 % relative to its diet (Vander Zanden & Rasmussen 1999; Post 2002; and references therein). The difference was ca 2.55 % (unadjusted values) between brown trout from Skaupsjøen (mean δ15N = 8.47 ‰) and brown trout from the allopatric populations (mean δ15N = 5.92 ‰), i.e., less than one trophic level, indicating a mixed diet of brown trout from the lake Skaupsjøen, consisting of both invertebrates and minnows. In a similar fish community, with brown trout and European minnow, in the Norwegian subalpine lake, Øvre Heimdalsvatn (1095 m a. s. l.) on the eastern slope of the Jotunheimen mountains, European minnow was mainly preyed upon during the minnow spawning period, i.e., in June-July (Lien 1981; Museth et al. 2003, Jenssen et al. 2010), probably a result of higher vulnerability of minnows at this time. Although the THg concentration in European minnow from the lake Øvre Heimdalsvatn was even higher than in the lake Skaupsjøen (range 0.014 – 0.16 mg/kg w/w) (Jenssen et al. 2010), the average THg in brown trout was low (0.05 mg/kg w/w). The average δ15N in brown trout was 6.5 ‰ (Jenssen et al. 2010), i.e., indicating a lower trophic level than in the lake Skaupsjøen, probably reflecting a lower total consumption of minnows. Both the δ15N and THg concentration were nevertheless higher in brown trout from the lake Øvre Heimdalsvatn than in brown trout from the allopatric populations included in our study. This may illustrate the effect on the mercury contamination in a piscivore as a result of the actual annual quantity of prey fish in the diet.

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brown trout. The results from the lake Skaupsjøen can consequently not be asserted to all localities with brown trout and European minnow, but still be a predictor of the risk of mercury contamination in brown trout following establishment of European minnow in shallow lakes in this mountain region.

In addition to elevated mercury concentrations in brown trout after establishment of European minnow, both brown trout and European minnow feed on the same invertebrates (Borgstrøm et al. 1985; Museth et al. 2010), thus being potential competitors. In the lake Skjerjøvatn, also on the Hardangervidda mountain plateau, annual harvest of brown trout was around 450 kg (2.9 kg/ha) previous to European minnow introduction (Taagbol et al. 2002). After establishment of European minnow in the 1980ies, large shoals of minnows could be observed in shallow water, as well as in the spawning and rearing habitats of brown trout in the streams. In 1995 the brown trout population had become heavily reduced, and by a corresponding gillnet effort as used previously, the annual harvest was reduced to 60 kg (Taagbol et al. 2002). This change in brown trout population density was probably a combined effect of competition and reduced annual recruitment to the brown trout population, following the European minnow establishment, as also indicated by studies in the lake, Øvre Heimdalsvatn (Borgstrøm et al. 2010; Brittain et al. 2019).

By introducing a new species of fish which can act as a prey for piscivore species in the same lake, the risk of increase in environmental contaminants like mercury in the top predator is high. Although the level of THg in the sympatric brown trout population in Skaupsjøen was not extremely high, the levels in old fish were still above the advisory levels for “consumers at risk”, i.e., pregnant and lactating women and young children. European Food Safety Authority (EFSA) (2018) has set a Tolerable Weekly Intake (TWI) of organic mercury (near 100% in fish) to 1.3 µg/kg body weight, instead of a former use of mercury concentration in the fish filet. Norwegian Scientific Committee for Food and Environment (VKM) uses the same TWI-level, and in addition categorized the concentrations in fish filet as either “low” (< 0.051 mg Hg/kg) or “high” (> 0.33 mg Hg/kg). A 150 g weekly fish meal of category “high” will accordingly exceed the TWI level (Amlund et al. 2019). With a level of up to 0.41 mg THg/kg in brown trout from Skaupsjøen, it is clearly in the category “high”, demonstrating a risk for the most sensitive consumer group. This also illustrate a need for further studies in mountain lakes with introduced prey fish species to establish local food advisory levels.

CONCLUSION

In addition to reduced brown trout production, the establishment of European minnow in mountain lakes formerly inhabited by allopatric brown trout may result in increased mercury contamination of brown trout, causing a possible health risk for those who use such fish regularly in their household. Thus, the European minnow-brown trout interaction revealed in the lake Skaupsjøen may illustrate the risk connected to the extensive spreading and establishment of European minnow in mountain areas.

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