Catch per unit effort by repeated gillnetting; a useful method for direct estimation of brown trout abundance in small lakes

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Samandrag

Fangst pr innsatsenhet ved gjentatt garnfiske; en anvendelig metode for estimering av populasjonsstørrelse hos ørret i små innsjøer. I dette studiet er det gjennomført ein estimering av populasjonsstorleiken av ein aurebestand ved repetert fiske med garn i fire netter i eit lite vatn på Hardangervidda. Lokaliteten er eit av dei klassiske vatna som I. D. Sømme dreiv tilsvarande forsøk i på tjue- og trettitalet. Resultata tyder sterkt på at metoden gjev sikre bestandsestimat, i det minste når det i utgangspunktet er låg fisketettleik og stor fisk til stades, dvs. fisk med høg symjeaktivitet per tidseining. Garninnsatsen som er brukt i desse forsøka har ført til høg fangstdødelegheit etter få netters fiske. Restbestanden er difor dominert av ung fisk, med få eldre fisk til stades. Garnfiske i slike bestandar er med andre ord svært destruktivt, sidan meir eller mindre all fangbar fisk vert teke ut, sjølv med ein relativt låg garninnsats. Maksimum storleik og alder på aure i slike bestandar vil vera avhengig av garnmaskevidda og garninnsatsen. Generelt vil aldersstrukturen i aurebestandar i innsjøar gje verdifull informasjon om fiskeinnsats og fangstdødelegheit, og gje viktig grunnlag for forvalting av fisket i slike bestandar.

Summary

In the present study, a population estimation of brown trout was performed by repeated gillnetting during four nights in a small lake on the Hardangervidda mountain plateau. The locality is a 'classic' one, i.e. one of the lakes I. D. Sømme performed similar gillnetting experiments in 1925 and 1933. The results indicate that this gillnetting method gives highly reliable stock estimates, at least given a low fish density and large individual fish size, i.e., specimens with high swimming activity per unit time. The gillnet effort used resulted in high fishing mortality after few nights of gillnetting, rendering a population dominated by young fish, with few old individuals present. Gillnetting in such brown trout populations is thus destructive, since practically the whole stock of catchable fish may be removed, even with a relatively low fishing effort. Maximum size and age of the fish is dependent on mesh size of the gillnets used. In

general, the age structure of brown trout populations gives valuable information concerning the exploitation effort and fishing mortality, which may be used in fisheries management.

Introduction

Catch per unit effort is commonly used for estimation of relative fish abundance, both in lakes and streams (DeLury, 1951; Ricker, 1975; Bohlin et al., 1989; Emmrich et al., 2012; Guzzo et al., 2014). In lakes, catch per unit effort is most frequently used for obtaining a relative measure of population abundance or relative size of year-classes, length-classes etc (Jensen, 1977; Hesthagen et al., 1993; Guzzo et al., 2014). Jensen (1977) used catch per unit effort in a study of allopatric brown trout abundance in a small subalpine lake by sampling with a pilot gillnet fleet consisting of separate gillnets with mesh sizes 24, 26, 28, 30, 32, 34, 36 og 38 mm (knot-to-knot). He demonstrated that catch of each age-class was significantly related to the abundance in the population.

Estimation of absolute numbers of fish by use of catch per unit effort in multiple catches is also possible, but presupposes that effort per fishing operation gives a marked decrease in population number, i.e., a high fraction of the population is captured per fishing effort (Ricker, 1975; Robson & Spangler, 1978). Furthermore, an important condition is that catchability is constant during all sampling intervals (Zippin, 1958). Thus, to minimize variation in catchability between samplings, the estimation has to be carried out during a period with more or less constant environmental conditions (Ricker, 1975), such as constant discharge in streams (Zalewski & Cowx, 1990), or under the same weather and light conditions when sampling in lakes (Jensen, 1972). The conditions for using catch per unit effort in multiple catches for estimating population abundance seem to be met in small mountain lakes inhabited by brown trout. The traditional harvest method of brown trout in small lakes and tarns both on the Hardangervidda mountain plateau in southern Norway and in other areas of the country has been performed with a high number of gillnets. However, it usually takes place only for a few nights, because there is commonly a rapid decline in catch, often after the first night, as described by Dahl (1943) from several lakes in this area. According to Dahl (1943), the catch per gillnet showed a rapid decline, and after a few nights' gillnetting, the catch might be only a tenth of what is obtained after the first fishing night. Sømme (1934) used this marked decline in catch per night to estimate the population of catchable brown trout in two small lakes in the same mountain area. The significant decrease in catch from one night to the next, resulted in population estimates with small confidence limits. The method has been used in other lakes as well (Ricker, 1975; Qvenild & Aasheim, 1982). However, still there are few examples of its use, probably because the method is destructive, since a substantial fraction of the catchable fish may be removed from the population. In situations where landowners or others operate a commercial fishery, there is an opportunity to obtain a population estimate based on multiple fishing during a short period of time. In cooperation with the landowners of one of the lakes where Sømme (1934) carried out his studies, we repeated the experiment about 80 years later. The aim was to test the method of repeated catch per unit effort, and to focus upon the use of the method which may be valuable in studies of population dynamics and fish productivity in small lakes.

Materials and Methods

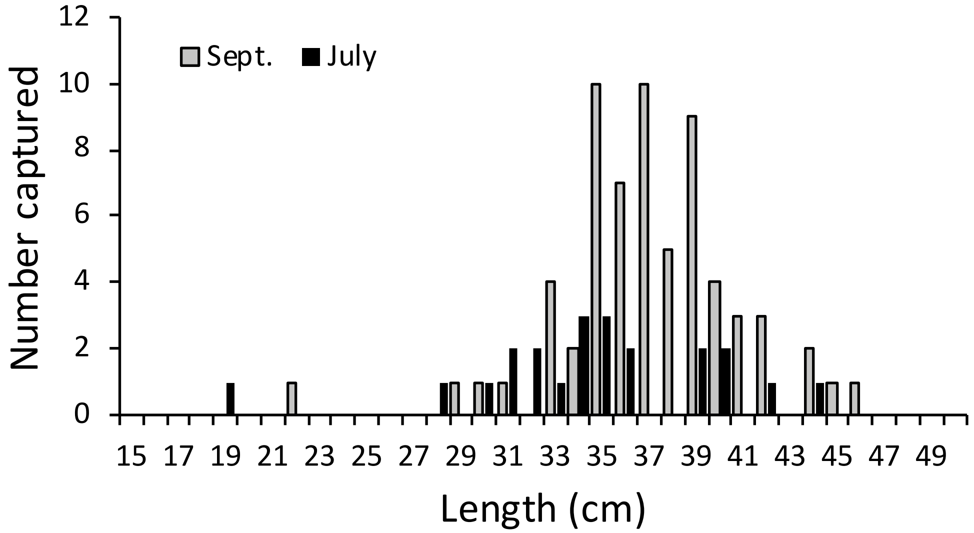
The study was performed in the 0.265 km^2 lake Langesjøtjønne, situated 1209 m a. s. l. in Nore and Uvdal municipality, within the Hardangervidda national park. The lake drains to the 11.07 km^2 lake, Langesjøen, via a small, short stream (Figur 1). Langesjøtjønne is shallow, with maximum depth around 2 m. The drainage area is 3.67 km^2 (NVE Atlas 2020). The lake is ice-covered usually from October, with ice breakup most often in middle of June. In 2012, the mean temperature during the period 18 July to 7 September was 12.1 ^{o}C, measured by a TinyTag[12] logger placed at 0.5 m below surface, in the

Figur 1. Location of the study site, the lake Langesjøtjønne, and the lakes Langesjøen and Flotatjønne on the Hardangervidda mountain plateau.

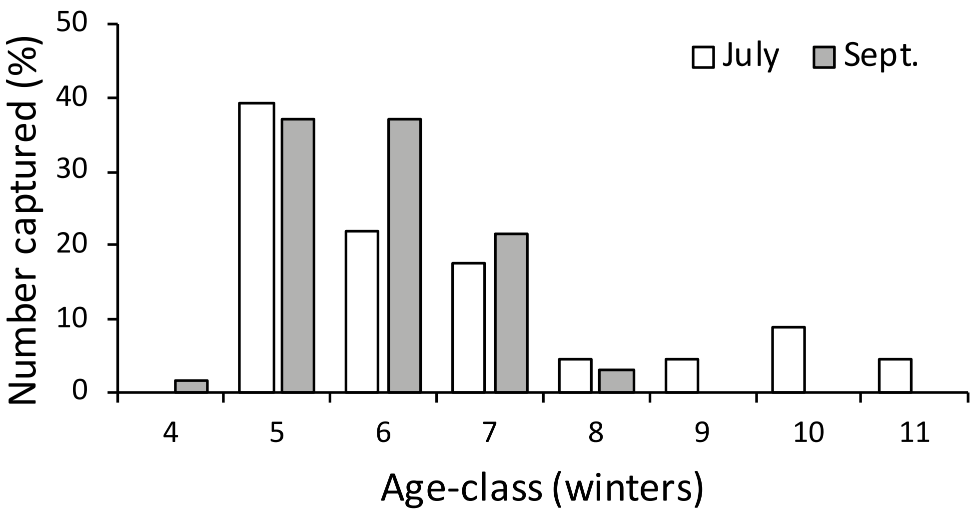
northern part of the lake. Maximum temperature during this period was 16.8 °C, recorded in middle of August, and minimum temperature 8.5 °C recorded 31 August. A black-throated loon, *Gavia arctica*, with one brood, was observed in the lake during July 2012.

During autumn, the landowners operate a commercial fishery in the lake Langesjøtjønne, as well as in other lakes in the area. Brown trout is the only fish species present, and the captured fish during autumn is mainly used for production of 'fermented' trout (rakaure), a Norwegian food specialty which is mainly marketed before Christmas. Gillnetting has been performed nearly all years during the last decades, but catch reports are missing for several years. Annual catch has varied between 9 and 98 kg according to the landowners, with mean weight of captured fish around 680 g.

The sampling in the lake during 2012 was carried out by an experimental gillnet fleet in July and by a multiple catch connected to the commercial fishery in September. The experimental fishing was restricted to gillnetting one night, 18 -19 July, with a fleet consisting of 10 gillnets with the following mesh sizes: 16.5, 19.5, 22.5, 26, 29, 31, 35, 39, 45, and 51 mm (knot to knot). The gillnets were set in the evening and lifted the next morning. Length and weight of captured fish were recorded, and scales and otoliths sampled for age determination. Back-calculation of length by use of scales was performed according to the method described by Dahl (1910).The commercial fishery by the landowners was accomplished during the period 6 – 10 September 2012, by the use of 20 gillnets during each of four nights, i.e., a total effort of 80 gillnet nights. The gillnet fleet consisted of nets with the mesh sizes 39 and 45 mm (knot to knot). The daily catches were recorded by the present authors. Because the landed fish should be conserved as fermented trout, otoliths were not allowed to be removed, and only fish length was recorded, and scales sampled for use in age determination. The catch per unit data from this fishery was used for estimation of the number of catchable fish in the lake at start of the fishing experiment, and the result compared with data from the fishery made by Sømme (1934) in 1925 and 1933. The gillnet effort used by Sømme in both years was around 30 gillnets per night for three following



Figur 2. Length distributions of captured brown trout by the experimental gillnet fleet in July 2012, and by the multiple capture during September 2012, in the lake Langesjøtjønne.



Figur 3. Age distribution of captured brown trout in the lake Langesjøtjønne, during July and September 2012.

nights. Estimations of population size, standard error (SE) and confidence limits are carried out according to the method described by Zippin (1958). In addition, we plotted catch against accumulated catch in successive samplings, according to the Leslie method (Ricker, 1975). It should be stressed that some important conditions have to be fulfilled when population size is estimated by use of catch per unit effort in repeated catches, such as constant catchability during all sampling intervals, and that a high fraction of the population is captured per total fishing effort (Ricker 1975; Robson & Spangler 1978).

Results

Length and age distribution

In July, the total catch by the experimental gillnet fleet was 23 brown trout in the length-range 19 – 44 cm, but with only one fish below 28 cm (Figur 2). The total catch by the commercial gillnetting

Table 1. Back-calculated length (mm) ± standard deviation of brown trout captured during the commercial fishery in the lake Langesjøtjønne, September 2012.

		Length at age							
Age (winters)	Number of fish	L1	L2	L3	L4	L5	L6	L7	L8
4	1	32	100	150	200				
5	24	48±10	111±24	181±33	249±43	330±42			
6	23	41±8	88±16	142±27	207±27	270±35	337±31		
7	14	33±6	81±22	137±27	193±32	247±41	313±35	360±40	
8	2	39±2	98±11	131±25	189±49	226±51	280±75	323±98	379±63

Table 2. Daily catches of brown trout in the lake Langesjøtjønne, with estimates of number of catchable fish, standard error (SE) and confidence limits, based on the method described by Zippin (1958). Data from 1925 and 1933 after Sømme (1934).

År	Day 1	Day2	Day 3	Day 4	Estimated number	SE	95 % Confidence limits	Estimated catch rate
1925	54	21	9		89	3.7	82-96	0.944
1933	42	12	6		62	2.1	58-66	0.968
2012	49	14	3	4	71	1.2	69-73	0.986

in September consisted of 70 fish in the length range 22 – 46 cm, of which 65 were aged (Figur 2).

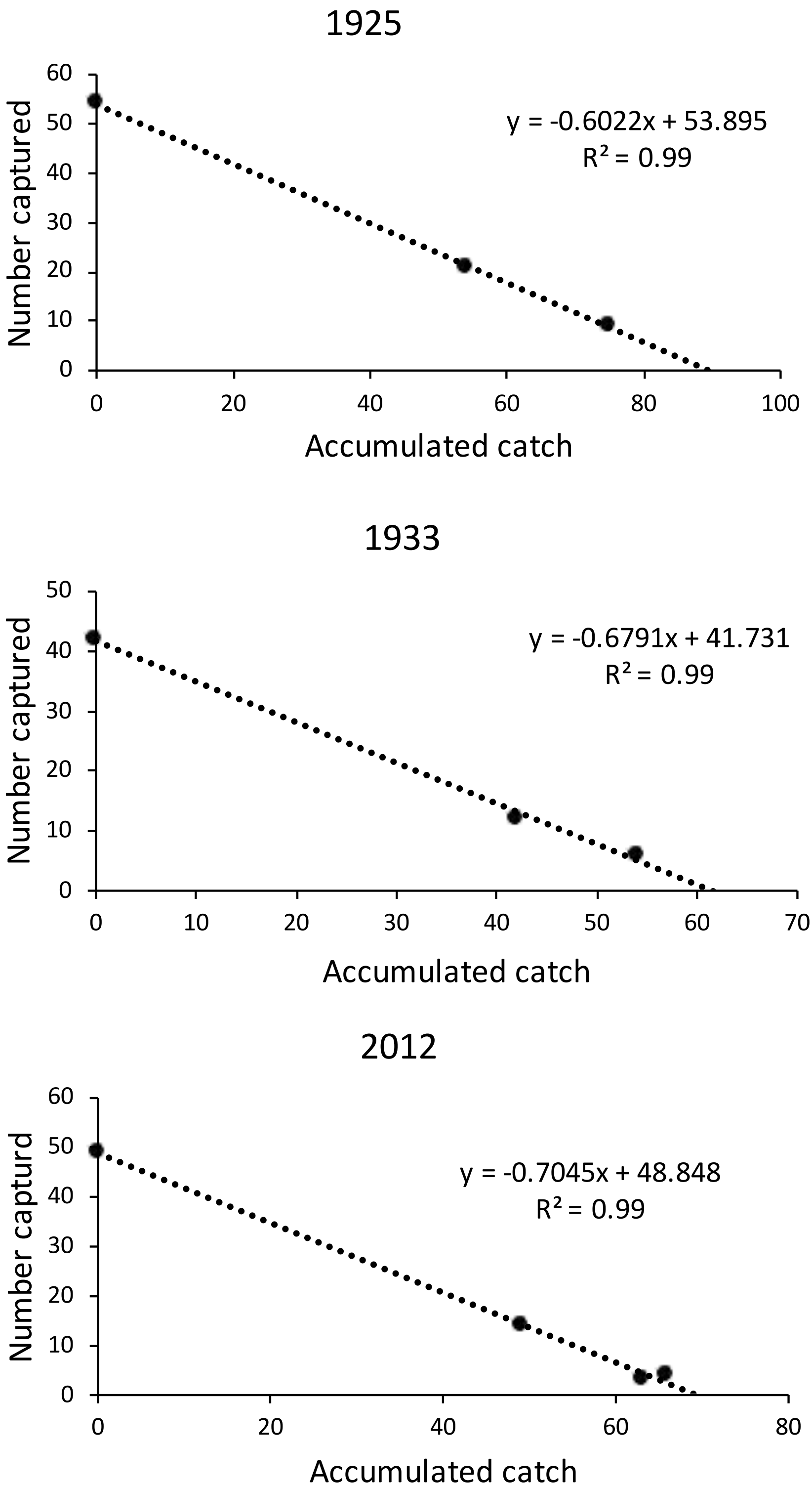
The age-classes 5-7 dominated in both the experimental catch in July and in the commercial catch in September (Figur 3). The small differences in average length between 5 and 8 winters old fish in September are in contrast to the length increment of the same year-classes during the 2011 season, which showed an average increment of 8.1, 6.7, 4.7, and 5.6 cm, based on the difference in back-calculated lengths between the growing seasons 2011 and 2012, respectively (Table 1). As an example, the back-calculated mean length at age 5 winters declines from 33.0 cm starting with age-class 5 to 22.6 cm when back-calculated from age-class 8, i.e., length at a given age decline by 'back-calculation' from older fish, compared to back-calculation from fish in younger age-classes (Table 1).

Estimated stock size

The catch data based on repeated gillnet samplings in the lake Langesjøtjønne in 2012, as well as in 1925 and 1933, give a catchable stock between 62 and 89 fish based on the Zippin method, and with relatively narrow confidence limits (Table 2). In 2012, the catchable stock was estimated to 71 fish. The catch mortality after four nights of fishing was 98.6 % (Table 2). The catchable stock in 1925 and 1933 was estimated to 89 and 62 fish, respectively, with corresponding catch mortalities at 94.4 and 96.8 % after three nights of fishing (Table 2). The Leslie method gives nearly identical population estimates as with the Zippin method, varying between 62 and 90 fish (Figur 4). The average weight of the captured fish in 2012 was 600 g, giving a stock biomass of 1.6 kg/haa. According to the daily catches during the three years (Table 2), the gillnet effort used resulted in a catchability in the range 0.60 – 0.70, despite a lower gillnet effort in 2012.

Discussion

The marked decrease in catch per gillnet effort from one night to the next during three independent experimental gillnettings in the lake Langesjøtjønne in 1925, 1933, and in 2012, each with 3-4 nights' samplings, can hardly be a result of coincidence, but ratherreflect an absolute de-



Figur 4. Number of brown trout captured in the lake Langesjøtjønne plotted against accumulated catch in the years 1925, 1933, and 2012, with regression lines (Data from 1925 and 1933 after Sømme, 1934)

crease in stock size. Sømme (1936) performed an additional gillnet experiment in this lake in 1935. During four nights, from 16 July to 20 July, he used 20 gillnets per night, resulting in a total catch of 89 fish, in addition to six specimens captured by rod. All fish were in the length range 38 – 54 cm. Catch per night was not given, but he gave a population estimate of 165 catchable fish at the start of the experiment. During the next days, from 21 July to 26 July, he continued the gillnetting, but now with 30 gillnets per night. The total catch was 60 fish, i.e. the total gillnetting resulted in a catch of 149 fish from a population consisting of 165 catchable fish. Thus, he once more demonstrated a high catch efficiency by gillnetting in this lake in 1935, although the catchability per gillnet per night was lower than in 1925, 1933, and 2012. The fishing experiment in 1935 took place in July (Sømme 1936), while Sømme (1934) does not give date of his fishing experiments in 1925 and 1933. Our sampling in 2012 was performed in September, i.e., during dark nights, which may explain the very high catchability despite a much lower gillnet effort compared to the effort used in 1925 and 1933.

The use of gillnets presupposes that the fish is active, implying that the probability of hitting a gillnet increases when swimming activity per time unit increases (Rudstam et al., 1984). An increase in catchability with increasing fish size and mesh size is demonstrated for several fish species (Hamley & Regier, 1973; Borgstrøm, 1989; Borgstrøm et al., 2015), most probably due to a positive relationship between fish size and swimming distance per time unit (Rudstam et al., 1984). Thus, the high catchability of fish in the lake Langesjøtjønne may partly be related to the relatively large size of the brown trout and thus a high swimming activity. This was also pointed out by Sømme (1941), who postulated that practically the whole stock of catchable fish at least once passed a small part of the 0.77 km^2 lake Flotatjønne, during a period of 8 – 10 days. In brown trout populations with high density, the catchability is considerably lower, probably due to the stationarity of the fish (Jensen, 1977; Borgstrøm, 1992). Jensen (1986) estimated that a gillnet effort corresponding to 30 gillnets per haa was needed to obtain a fishing mortality of 75 % in the lake Øvre Heimdalsvatn. This 0.78 km^2 lake was at that time inhabited by a dense brown trout population, with a biomass of 8 - 19.5 kg/haa. In the present study, three gillnets per haa were sufficient to obtain a fishing mortality at 98.6 %, i.e., by only a tenth of the effort used in the lake Øvre Heimdalsvatn, i.e. practically the whole stock of catchable fish was captured. According to the population estimation in 2012, the density of catchable fish was 1.6 kg/haa in the lake Langesjøtjønne, or 2.7 fish/haa, i.e., a much lower density and number of fish than in Øvre Heimdalsvatn. In the lake Flotatjønne which has the same surface area as the lake Øvre Heimdalsvatn, a total gillnet effort of 1.5 gillnets per haa produced a gillnet exploitation mortality of 96.5 %, in a population consisting of 206 fish, corresponding to 2.7 fish/haa (Sømme, 1934), or similar to the high fishing mortality found in the present study.

Brown trout on Hardangervidda mountain plateau may reach a high age, as documented by, i.e., Svalastog (1991), who captured two individuals with age 34 and 38 winters in one gillnet set in the lake Viuvatn. Especially in lakes with low gillnet exploitation, individuals with age up to around 30 winters seem to be common in this mountain area (Borgstrøm, 2016). In contrast to this, the age composition in lakes with heavy and regular gillnet exploitation, consists of relatively young fish. Jensen (1977) documented the marked effect of high gillnet effort on the age composition of brown trout in lake Øvre Heimdalsvatn, where the number of fish ≥7 winters fell from 5323 individuals at the start of his project in 1958 to only 468 fish ≥ 7 winters in 1965, after an annual high gillnet exploitation, resulting in 0.25 – 0.44 annual survival rates. The oldest brown trout captured in lake Langesjøtjønne in 1933 was 10 winters (Sømme, 1934), and the absence of fish older than 11 winters in this lake in 2012 are both clear indications of a very high annual mortality of fish in catchable size. Actually, according to the estimated annual fishing mortality, it is not expected that fish older than 7 – 8 winters should be present in the lake if gillnetting was performed every year. According to Dahl (1943), brown trout populations in lakes situated in the uppermost part of a catchment, without any large rivers or streams, foremost in socalled 'end' lakes, are characterized by low fish density and a high individual growth rate. The lakes Langesjøtjønne and Flotatjønne are typical examples of such lakes, inhabited by brown trout populations having low annual recruitment, low fish density, and relatively fast individual growth rate. Such populations seem to be highly vulnerable to gillnetting. As a consequence, a low fish density gives a substantial increase in catch probability, and the combination of high catchability and high gillnet effort will substantially influence the age and size structure of the population. The age composition of allopatric brown trout may consequently give indirect information of the annual exploitation rate.

Age-class 5 winters was the youngest cohort captured by the experimental gillnet fleet used in the lake Langesjøtjønne in July 2012, and only one individual in age-class 4 winters was captured during the commercial fishing in September in the same year, indicating a low recent recruitment to the stock. Recruitment to brown trout populations on the Hardangervidda mountain plateau seems to be highly influenced by snow conditions and summer temperature (Borgstrøm & Museth, 2005), implying that large cohorts originate in summers with long growing seasons, i.e. early snow and ice melting in streams, and high temperatures. Since snow conditions and temperatures show large annual variations in this mountain area (Rognerud et al., 2003; Borgstrøm, 2019), strength of brown trout cohorts may also vary considerably, especially in the western parts where snow cover is deeper and summer temperature lower than in the eastern part (Rognerud et al., 2003). The low occurrence of fish with age below five winters both in the experimental catch and the commercial catch from the lake Langesjøtjønne might still hardly be a result of the previous summer conditions, because four winter old fish dominated in the experimental catch from the nearby lake, Langesjøen, in July 2012 (Myrvang & Slettebø, 2013). The low number of young fish might on the other hand be connected to the occurrence of black-throated loon with one young in the lake this year, indicating breeding at the lake. Black-throated loon typically breed at small lakes and ponds, and often on small islands (Dunker & Elgmork, 1973; Petersen, 1979). A pair of the larger common loon *Gavia immer* needs around 200 kg of prey fish during summer, including the feeding of two fullfledged chicks (Kerekes, 1989). Accordingly, a pair of the black-throated loon may also need a considerable mass of prey fish, probably corresponding to some thousands of small brown trout. This high number of prey fish is not found in the small lake Langesjøtjønne, and most probably the main foraging is undertaken in the nearby much larger lake, Langesjøen. Similar foraging strategies are described by Dunker & Elgmork (1973) from several other Norwegian localities. Nevertheless, foraging by black-throated loon in Langesjøtjønne may also occur, partly explaining the low number of fish with length below 30 cm captured by the experimental gillnetting. Breedings of black-throated loons may take place in several small undisturbed lakes on the Hardangervidda mountain area, probably contributing to low densities of brown trout in such lakes, resulting in populations with high individual size and growth rates. As demonstrated in the present study, such populations may be highly vulnerable to gillnetting, but also of high value both for sport and commercial fishing.

The high gillnet catchability leads to an early removal of the most fast-growing individuals in a given cohort, and when the removal of faster-growing individuals is at a higher rate than removal of slower-growing fish, the surviving fish will be dominated by slower-growing individuals (Kraak et al., 2019), i.e., a typical example of the Rosa Lee phenomenon (Lee, 1912). This is clearly demonstrated by the back-calculations of length of brown trout from the lake Langesjøtjønne. Length of remaining old individuals in such populations give consequently little information concerning the growth potential when annual mortality of catchable fish is very high.

As a conclusion, we state that repeated gillnetting for at least three-four nights seems to be a reliable method for estimating stock size of allopatric brown trout populations in small high mountain lakes, given a low fish density and large individual fish size. Since the method is based on a high fishing mortality, rendering an age structure dominated by young fish, the maximum size and age become dependent on mesh size of the gillnets used. Thereby, the age structure of brown trout populations in this mountain area may give valuable information concerning the exploitation effort which in turn may be used in management of the fishery. The study also demonstrates that gillnetting in a brown trout population with low fish density may be destructive, since more or less the whole stock of catchable fish is removed, even with a relatively low fishing effort. An alternative to commercial gillnetting in such small brown trout populations as performed in the lake Langesjøtjønne, might be that the fishery is let out on hire to sport fishermen, resulting in increased number of old and large fish, and probably a higher income to the landowners than their own gillnet fishery.

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