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MANAGEMENT AND ECOLOGY OF ARCTIC CHARR POPULATIONS IN WINDERMERE

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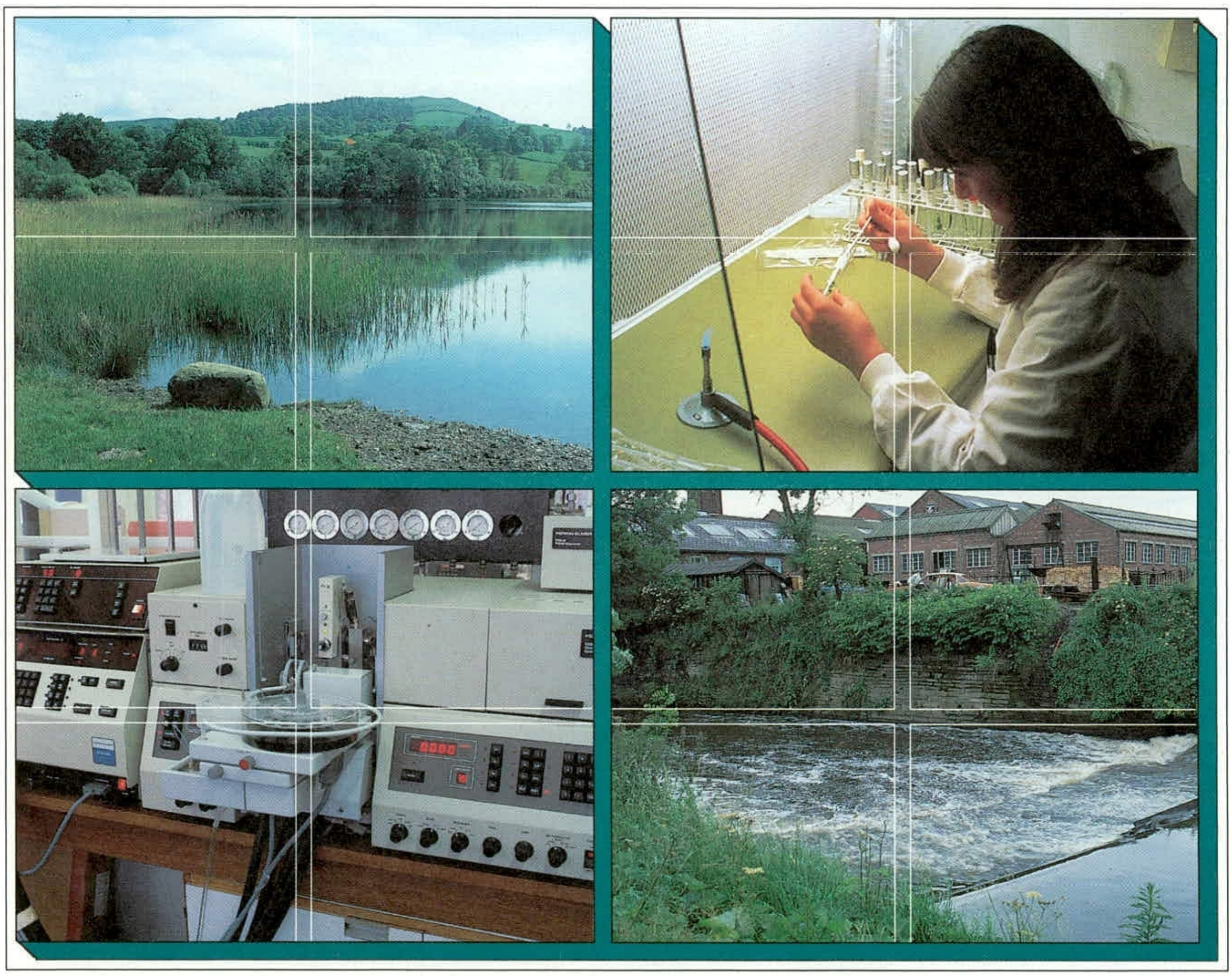

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SUMMARY

1. This interim report summarises the origins of the present investigation from previous work on the effects of enrichment on the water quality of Windermere, and especially on the population of Arctic charr in the lake. Previous work on the ecology of Windermere charr is also summarised. There are at least four races of charr in the lake with the North and South Basins each containing two distinct races that spawn in spring and autumn respectively. Most of the charr are autumn spawners (94 - 96% of adult population).

2. The present investigation commenced on 1 April 1990 and is a three-year study with the following objectives:

   (i) To provide an adequate basis for comparison between spring and autumn races of charr in the north and south basins of Windermere, and to survey their spawning sites.

   (ii) To investigate, experimentally, the sensitivity of juvenile stages of the different races to elevated temperatures and low oxygen concentrations.

   (iii) To integrate this information for the purposes of the future management of the Windermere charr fishery.

3. The methods used to obtain field data are:

   (i) Echo sounding to survey both basins every two weeks throughout most of the year.

   (ii) Gill netting at the long-term site for autumn spawners in the North Basin (annual records from 1939 to present), and at other autumn and spring spawning sites in the North and South Basins of the lake.

   (iii) Angler's catches from both basins (records from 1966 to present).

4. Tolerance and resistance to thermal stress are being investigated in the laboratory, using different life stages (alevins, fry, parr) for the different races. Tolerance and resistance to low oxygen levels are also being investigated in the laboratory, but on a more limited scale than the work on thermal stress.

5. In the experiments on thermal tolerance, there appeared to be little difference between mean values for either alevins or parr of different racial origin, but values for fry reared from spring spawners were higher than those for fry from autumn spawners. This discrepancy could be due to the much smaller sample size for spring spawning fry and their selection for higher temperature tolerance after a period of high mortality in the hatchery. At low, but not high, acclimation temperatures, there were clear differences between life-stages, alevins being less temperature tolerant than older fish. Apart from alevins at an acclimation temperature of 5°C, none of the upper survival temperatures was below 24°C and therefore it is unlikely that water temperatures in the open water of Windermere would ever be lethal for charr. Upper temperature limits for charr are about 2-3°C and 5-6°C lower than those for juvenile brown trout and Atlantic salmon respectively.

6. There was good, if not excellent, agreement between the angler's catches and the gill-net catches. The gill-net catch in the North Basin was higher in 1990 than in the three previous years, but then declined again in 1991. A similar pattern was shown in angler's catches for the whole lake, that for 1990 being the highest since 1983. The ratio of angler's catches in the North and South Basins showed that catches have been relatively low in the South Basin from 1984-1988. There was a clear improvement in 1989 with similar catches in both basins but the decline in 1990 and 1991 to earlier low values indicated that the 1989 improvement was temporary, not permanent.

7. There has been an increase in the percentage of brown trout in the total catches of the anglers fishing for charr, especially in the South Basin. This increase commenced in 1984, the same year which marked the onset of changes in the ratio of charr catches in the two basins of Windermere. Comparisons of catches of charr with those of charr plus trout showed that the increases in trout catches in the South Basin were not responsible for the lower charr catches.

8. Comparisons of monthly catches in the fishing season (March/April to September) in 1989, 90, 91 showed that brown trout were frequently taken in the South Basin, especially in spring and early summer, but were rarely taken in the North Basin. In most months, charr catches were lower in the South Basin than in the North Basin.

9. Estimates of fish densities with an echo sounder were first restricted to fish > 20cm at depths down to 20m, this being roughly the stock available to the angler. In the North Basin, there was a similar pattern in the fluctuations in fish density and angler's catches. Similarities were less evident for the lower numbers in the South Basin, but more fish were usually available during the day in months in which anglers fished. These comparisons showed that the results obtained with the echo sounder were generally comparable to angler's catches.

10. The echo sounder also provided monthly estimates of pelagic fish densities (all sizes, all depths) in both basins. Results for day samples confirmed the higher numbers in the North Basin and the lower numbers in winter in both basins. There were distinct spring and autumn peaks in numbers in the North Basin but only an autumnal peak in the South Basin. Results for night samples confirmed these conclusions but showed that in most months, more fish were present in the open water at night than during the

day. There is a wealth of information in the data obtained with the echo sounder and analysis of these data will be one of the major tasks in the next few months.

1. INTRODUCTION

1.1. Origins of present investigation

Windermere is the largest natural lake in England and is a Site of Special Scientific Interest situated in a National Park. The lake provides part of the water supply to North West England and is a focus for tourism and recreation. Windermere is divided by shallows and islands into a north basin (area 8.1 km^2) and a south basin (area 6.7 km^2).

Since 1945, regular measurements from both basins have shown that the lake has become nutrient enriched (Lund 1972, Sutcliffe et al. 1982, Heaney et al. 1988, Talling & Heaney 1988). The Freshwater Biological Association (FBA, now Institute of Freshwater Ecology, IFE) was commissioned by North West Water to provide a general assessment of environmental and biological features of Windermere and their susceptibility to change. The unpublished report (Atkinson et al. 1986) showed that since 1945 there has been a c.20-fold increase in the mean winter concentration of soluble reactive phosphorus in the south basin, rising to more than 20 $\mu g\ l^{-1}$, but smaller increases have occurred in the north basin, rising to less than 10 $\mu g\ l^{-1}$. the report also highlighted hypolimnetic deoxygenation during summer and autumn in the south basin, first recorded during 1981. It was indicated that the charr population might be particularly sensitive to the development of deep water anoxia.

Following this report, NWW commissioned a two year study of Windermere to provide further information on its water quality, a more refined phosphorus budget and an investigation of the biology and population structure of charr. The final report (Heaney, Mills & Corry 1989) showed that hypolimnetic deoxygenation was particularly severe during 1988. In the South Basin, anoxia occurred for a prolonged period between the end of September and mid-November, and extended upwards to a depth of about 25 m. Complete anoxia does not occur in the North Basin, but oxygen concentration fell to less than 20% saturation below 30 m depth during the first half of November 1988, this being the most severe on record.

Although nutrient enrichment is not directly harmful to charr, the associated anoxia will restrict the water volume available to the charr and this will be reduced further in hot summers when surface temperatures may be higher than the preferred values for the charr. It is also possible that summer water temperatures will increase as a result of climate change. Evidence from other European lakes indicates that increasing enrichment can lead to a reduction and eventual extinction of charr populations (Mills et al. 1990).

Following the IFE report, North West Water started work to reduce phosphate discharged in treated sewage from the Windermere and Ambleside sewage works. The new sewage treatment plants should markedly reduce the quantity of phosphates entering both the north and south basins of Windermere. However, evidence from other lakes suggests that recovery may be slow (the sediments accumulate phosphorus which may be released back into the water column over many years) and it is therefore important to continue studies on the status of Windermere charr. North West Water Limited, a subsidiary of North West Water Group PLC, therefore agreed to support a two-year study, now extended to three years (25% funding from NWW Ltd., 75% funding from NERC).

The chief objectives of this investigation are:

(i) To provide an adequate basis for comparison between spring and autumn races of charr in the north and south basins of Windermere, and to survey their spawning sites.

(ii) To investigate, experimentally, the sensitivity of juvenile stages of the different races to reduced oxygen concentrations and to elevated temperatures.

(iii) To integrate this information for the purposes of the future management of the Windermere charr fishery.

1.2. Ecology of Windermere charr

The Arctic charr, Salvelinus alpinus (L.), is a holarctic species that is frequently anadromous in northern latitudes higher than 65°N. At lower latitudes, this species forms numerous land-locked populations. There are several populations in Ireland and Scotland, only four recorded in Wales and all the English populations are restricted to the Lake District. Charr are present in eight lakes (Buttermere, Coniston, Crummock, Ennerdale, Haweswater, Thirlmere, Wastwater, Windermere). They also used to be present in Ullswater but have now disappeared, possibly because their spawning grounds in Glenridding Beck were polluted by suspended solids and lead from mine washings.

There are at least four races of charr in Windermere with the north and south basins each containing two distinct races that spawn in spring and autumn respectively (Frost 1965, Child 1984, Partington & Mills 1988). By using a combination of the number and length of gill rakers, a discriminant function can be used to predict with more than 95% accuracy whether an individual charr is a spring or autumn spawner (Partington & Mills 1988). There are also differences in growth rates; north basin autumn spawners grow relatively slowly, north basin spring spawners and south basin autumn spawners are intermediate and south basin spring spawners grow fastest (Mills 1989).

Mark-recapture studies have shown that adults return each year to the same spawning site (Frost 1963, Le Cren & Kipling 1963). Differences in allele frequencies at esterase and malate dehydrogenase loci have been found between fish spawning at similar times but on different sites. It is therefore possible that each of the autumn and spring spawning sites (Fig. 1) could maintain separate stocks. Recent surveys have shown that spawning still occurs on at least seven of the autumn sites (3 in north basin, 4 in south basin) and four of the spring sites (2 in each basin). Most of the charr are autumn spawners with spring spawners representing less than 4-6% of the adult population (Mills 1989, Mills & Hurley 1990).

The mean age of spawning females (c. 8 years for autumn spawners, c. 9 years for spring spawners) is higher than that of spawning males (6-7 years). Most male charr mature at an age of 5 years whereas females mature at six years or older and live longer than males. About 80% of charr between 9 and 14 years old are female. There are no obvious differences in age structure between basins and male and female charr grow at similar rates. These conclusions are based on recent information (Partington & Mills 1988, Mills 1989, Mills & Hurley 1990). Comparison with earlier data is difficult because the previous use of scales for ageing (Frost 1978) led to marked underageing of older fish when compared with the use of otoliths for ageing in recent years. As there is a high proportion of old charr in both basins, mortality through angling cannot be high or few fish would survive to reach such ages.

Crude estimates of the total adult charr populations are 132,000 autumn spawners and only 8,000 spring spawners with a total biomass of 30-35 Mg (tonnes) (Mills & Hurley 1990).

2. METHODS

2.1. Laboratory experiments

Charr were reared from freshly fertilized eggs taken from fish caught in gill nets on the spawning sites in Windermere. Eggs were incubated and young fish reared in the IFE hatchery on the shore of the lake. Eggs and juveniles from each of the four races of charr were always kept separate so that comparisons could be made between these races.

Tolerance and resistance to thermal stress were investigated for different life stages: alevins (newly-hatched fish that are still dependent on yolk for their food), fry (newly-emerged fish that have just started to feed on external food) and juvenile parr (older fish that are immature). The experiments were performed in constant-temperature tanks. Alevins and fry were kept in small jars containing water that was stirred and aerated by compressed air (oxygen concentration in water > 85% saturation). Juvenile parr were kept in larger aquaria through which circulated water of a constant temperature. Oxygen concentrations always remained higher than 85% saturation.

Young charr of similar size were acclimated to the same constant temperature (either 5, 10, 15 or 20°C) for 1-2 weeks. The water temperature was then raised at about 1°C/30 min to a final temperature. Records were kept of the highest temperatures, for survival over 10 min, 100 min, 1000 min and 7 days at each acclimation temperature. This methodology and protocol is basically the same as that used to investigate the effects of thermal stress on brown trout, Salmo trutta L., and Atlantic salmon, Salmo salar L. (Elliott 1981, 1991).

Tolerance and resistance to low oxygen levels have been investigated only with alevins at present. These were subjected to different oxygen levels at 5°C and 9°C. The oxygen tolerance experiments were limited because a closed system had to be used in order to prevent oxygen exchange between the low oxygen concentrations in the water and higher levels in the atmosphere. Oxygen uptake by the fish also had to be taken into account, and varied considerably between fish. A large number of replicates was therefore necessary to obtain meaningful results. Records were kept of the lowest oxygen levels for survival over 10 min, 100 min, 1000 min and 7 days at each temperature.

2.2. Gill netting and angler's catches

The long-term FBA/IFE data for autumn spawning charr in the north basin were obtained by regular gill netting with 32 mm (bar) mesh during each November from 1939 to the present. The results are expressed as catch-per-unit-effort (CPUE) which is the mean catch per gill-net day. Mature charr were all gill netted on their spawning sites using mesh sizes ranging from 19 mm to 46 mm(bar). Nettings for spring spawners were performed in deep (15-30 m) water above the spawning sites, and those for autumn spawners were performed in shallow (2-4 m) water above the spawning sites.

Charr were last commercially netted in Windermere in 1921 but they are still caught by fishermen using plumb lines (Kipling 1984). The fishery for charr in Windermere is worth at least £24 K. Anglers catch-per-unit-effort (CPUE) data were expressed as mean catch per boat per hour. Data are now available from 1966 to the present.

2.3. Echo sounding

The Simrad EY-M echo sounder was used to provide information on fish numbers, size and distribution. Surveys of both basins during daylight were performed once every two weeks throughout most of the year, and every week during the spawning seasons. Night surveys were also performed in each month from October 1990. A survey was postponed on some occasions because of dangerous weather or the absence of the boat during its annual refit and maintenance (the echo sounder is mounted on the hull of the boat).

The operation principle of the echo sounder can be summarised as follows. Sound waves are generated at the face of a transducer until switched off by a timer. The sound pulse travels through water away from the transducer. A target in the path of the sound pulse will return an echo to the transducer. The transducer consequently reverses its transmitting mode function. The received 'echo' is converted from pressure oscillations to electrical oscillations that are picked up by a receiver, amplified and converted into a visible sign on a display device.

The electrical oscillations picked up and displayed provide qualitative rather than quantitative information. The echo signal must be processed to provide quantitative information about fish appearing in the water column. Hardware and software supporting the hydro-acoustic data acquisition system (HADAS) provide the quantitative information required about the fish in the water column. The hardware allows for the communication between echo-sounder recordings in the field and the computer. The software allows the analysis and storage of data received from the echo-sounder. The received echo needs to be transformed to provide information on fish quantity. Fish at varying distances from the transducer produce different echo intensities. In order to obtain echo signals depending only on the properties of the target, compensation for the decrease in sound intensity due to propagation laws is required. This is achieved by having in the echo receiver an amplifier whose effect varies with time.

Where fish are targets, the sound pulse is reflected mainly from the swim bladder, but also from the scales, flesh and bones. It is estimated that half the signal comes from the swim bladder which occupies about 5% of the volume of the fish. The signal coming from a single fish is proportional to its weight, and it is therefore possible to construct size frequency distributions for all recorded fish.

Comparisons have been made in Scandinavia between acoustic surveys using a Simrad EY-M echo sounder and a trawl (e.g. Bagenal 1981). The results were comparable but the echo sounder recorded considerably fewer fish than the trawl catch near the lake surface, and higher numbers than the trawl in deeper water. The precision of the results from the echo sounder was high with replicate estimates of fish numbers differing by only 0.4% from their mean value in deep water and by only 8.5% in surface waters (depth 4-8 m). Length frequencies for fish from the trawl catches agreed with the frequency distribution of records from the echo sounder and therefore the latter provides information on the size distributions of the fish.

The chief advantage of the echo sounder is that it provides a rapid method for estimating fish populations in a lake. The chief disadvantage is that it cannot identify fish species and therefore it must be supplemented by conventional methods of sampling, such as gill nets.

3. RESULTS

3.1. Laboratory experiments

Some of the preliminary results from the experiments on temperature tolerance are summarised in Figs 2 and 3.

These results are first presented in terms of the different life-stages (Fig. 2): alevins (newly-hatched fish that are still dependent on yolk for their food), fry (newly-emerged fish that have just started to feed on external food) and juvenile parr (older fish that are immature). The effect of the acclimation temperature on the survival temperature was more marked for alevins than for fry and especially parr. There appeared to be little difference between mean values for alevins of different racial origins or parr of different origin (cf. values for North/South Basin spring spawners, South Basin autumn spawners, North Basin autumn spawners in Fig. 2). This was clearly not the case for fry, with consistently higher values for spring spawners. The results for fry from spring spawners must be treated with caution because only four fish were used in the experiment at each acclimation temperature (ten or twelve fish were used in all other experiments), and the fish were the survivors after a period of high mortality, probably due to high temperatures in the hatchery.

The results are next presented in terms of racial origin (Fig. 3): North/South Basin spring spawners, South Basin autumn spawners, North Basin autumn spawners. At low, but not high, acclimation temperature, there were clear differences between life stages, alevins being generally less temperature tolerant than older fish.

These upper temperature tolerance limits appear to be about 2-3°C lower than those for brown trout and 5-6°C lower than those for Atlantic salmon.

The experiments on tolerance and resistance to low oxygen levels at 9°C was not very successful because neither the experimental fish nor the controls survived the 7 days of the experiment. At 5°C, all controls survived and some alevins (12.5%) survived for 7 days in water with an oxygen equivalent to 30% saturation. As % saturation increased, the number of survivors over 7 days also increased, being 25% at 50% saturation, 62.5% at 69% saturation and 100% at 75% saturation.

All alevins survived for 1000 min at oxygen levels above 17% saturation, few alevins survived below 15% saturation, and alevins survived for 10 min or less at levels below 10% saturation.

3.2. Gill netting and angler's catches

Gill netting of autumn and spring spawners has confirmed that both races are present in both basins. There is no evidence to suggest that age structure and the mean age of the spawning males and females has changed significantly since the earlier surveys in 1986, 1987, 1988 (Mills 1989).

The gill-net catch in the North Basin was higher in 1990 than in the three previous years, but then declined again in 1991 (Fig. 4a). A similar pattern was shown in an angler's catch-per-unit-effort (CPUE) for the whole lake, the catch for 1990 being the highest since 1983 (Fig. 4b). Comparisons between gill-net and angler's catches showed that they generally followed a similar pattern but there was a marked discrepancy about 1980 when the relative catches crossed (note that both sets of catches are scaled in Fig. 4b so that their overall means coincide). There was a positive relationship between the two sets of catches when the periods 1966-80 and 1981-1991 were treated separately (Angler A in Fig. 5). A similar relationship was not obtained for a second angler, probably because fewer data points were available

(Angler B in Fig. 5). This explanation is supported by the strong positive relationship between catches by the two anglers even though the CPUE for Angler B was generally lower than that for Angler A (Fig. 5). It was therefore concluded that there was good, if not excellent, agreement between the angler's catches and the gill-net catches.

As the angler's catches generally reflected changes in charr abundance, they could be used to compare population changes in the two basins of the lake. A simple, but useful, index of these changes was provided by the ratio of mean catch in the South Basin to mean catch in the North Basin. Values for one angler's catches from 1966 to the present showed that, prior to 1983, catches were similar in both basins or were higher in the South Basin (Fig. 6). The marked decrease in the ratio for the next five years indicated the relative decline in South Basin catches from 1984 to 1988. The ratio of catches for a second angler over a shorter period (1975 to 1988) followed a similar pattern (Angler B in Fig. 6). There was a clear improvement in 1989 with similar catches in both basins (ratio $\approx$ 1) for both anglers, - but the decline in 1990 and 1991 to earlier values indicated that the 1989 improvement was temporary, not permanent.

Charr fishermen on Windermere have expressed the general, but subjective, view that more brown trout, Salmo trutta L., have been taken on charr tackle in recent years. Records were obtained from the two anglers and these confirmed an increase in the percentage of trout taken in the catches, especially in the South Basin (Fig. 7). It is notable that the latter increase commenced in 1984, the same year which marked the onset of changes in the ratio of catches in the North and South Basins of Windermere (cf. Fig. 6). The change in the latter ratio could have been due to the increased proportion of trout in the catches, but a comparison of the ratio for total catches (charr + trout) in both basins revealed little change in the temporal pattern (Fig. 8) from that obtained for charr alone (cf. Fig. 6). Further comparison of the two ratios revealed few differences but the presence of trout slightly increased the ratio in a few years (e.g. 1988, 1990, 1991 in Fig. 9). However, the general conclusion must be that the increases in the catches of trout in the South Basin were not responsible for the lower catches of charr relative to those of the North Basin.

Monthly catches were compared for both anglers in the fishing season (March/April to September) in 1989, 1990, 1991. These years were chosen for more detailed examination because the angler's catches could also be compared with fish density estimated by the echo sounder (Fig. 10).

Apart from one large catch by Angler B in April 1991, brown trout were rarely taken by both anglers in the North Basin. They were, however, frequently taken in the catches in the South Basin, especially in spring and early summer. These comparisons also show that in most months, catches were lower in the South Basin than in the North Basin. Comparisons with the results from the echo sounder are made in the next section.

3.3. Echo sounding

The echo sounder provides estimates of the total number of fish present in the open water of the lake but cannot identify the species. Shoaling fish recognized with the echo sounder were undoubtedly perch, Perca fluviatilis L., and these fish could be easily deleted from the records. Pike, Esox lucius L., were probably rare in the open water of the lake. It was impossible to separate charr from pelagic brown trout and the echo sounder therefore provided estimates of the total number of pelagic salmonids (charr + trout) in the North and South Basins of Windermere.

The methods used by anglers to catch charr in Windermere take fish at water depths from about 1m to no more than 20m. Charr taken from the lake have a fork length greater than about 20cm. For these reasons, the results from the echo sounder were filtered to leave those from water depths down to 20m and fish longer than 20cm. The final estimates of fish density were therefore for those fish that should, in theory, be available to the angler (Fig. 10).

The results confirmed the earlier conclusion from the angler's catches that the density of fish was consistently higher in the North Basin. In the North Basin, there was also a similar pattern in the fluctuations in fish density and angler's catches, e.g. a late summer peak (August), especially in 1989, 1990. Similarities were less evident for the lower numbers in the South Basin, but more fish were usually available during the day in months in which anglers fished.

Estimates of fish density at night were usually higher than the corresponding estimates during the day but there were three exceptions in which the reverse was true (October 1990, September, October 1991).

These comparisons are generally encouraging because they show that the results obtained with the echo sounder are generally comparable to angler's catches.

Finally, estimates of total pelagic fish (all sizes at all depths) are compared on a monthly basis in the two basins of Windermere, both during the day (Fig. 11) and at night (Fig. 12). Results for the day samples again confirmed the generally higher numbers in the North Basin compared with the South Basin, and the lower numbers in the winter months. There were distinct spring and autumn peaks in numbers in the North Basin but only an autumnal peak in the South Basin. The reasons for these differences are unknown at present. Results for the night samples confirmed the higher numbers in the North Basin, the presence of spring and autumn peaks in the North Basin, and the single autumnal peak in the South Basin.

These results are also encouraging because they show clear differences between the two basins and consistent patterns of abundance within each basin.

4. DISCUSSION

The laboratory investigations are essential to determine the tolerance limits of the different life stages of the charr to extremes of temperature and low levels of oxygen. It is perhaps surprising that these limits have not been determined before but there is little quantitative information on either the temperature or oxygen requirements of charr.

The upper temperature limits for charr are about 2-3°C lower than the values obtained in similar experiments on brown trout (Elliott 1981), and about 5-6°C lower than those obtained for juvenile Atlantic salmon (Elliott 1991). It is interesting that there appear to be no consistent differences between the different races of charr in Windermere. This suggests that although they differ morphologically, meristically and genetically, their physiological response to thermal stress is similar.

The long-term records for gill-net catches are essential for the assessment of the relevance of short-term change. Low catches were obtained in 1987, 1988 and 1989, but the higher catch in 1990 demonstrates that there has been no permanent decline in catches. The 1990 value is similar to values obtained in the early 1980's (Fig. 4).

The good agreement between angler's catches and gill-net catches reinforces the conclusion that both reflect accurately the fluctuations in the number of adult charr in the lake. The ratio of angler's catches in the South and North Basins of the lake clearly identifies the persistently low catches in the South Basin from 1984 to 1988, and demonstrates that the improvement in 1989 was temporary, not permanent (Fig. 6). Such comparisons highlight the need for long-term records but, unfortunately, it is becoming increasingly difficult to find financial support for the collection of such records.

The increase in brown trout in the angler's catches in the South Basin from 1984 to the present (Fig. 7) is intriguing. There could have been a general increase in the density of trout in the South Basin and/or a shift in the habitat frequented by the trout. Trout have been traditionally thought to inhabit the shallow littoral regions of the lake but if the shore areas become unsuitable for some unknown reason, then the fish would move to the open water to join the pelagic charr. Such speculations indicate a need for further research to determine why brown trout appear to have become more numerous in the open water of the South Basin, but not the North Basin, in recent years.

The echo sounding technique provides, for the first time, estimates of the total number of fish present in the open water of the lake. Previous methods all used nets or traps, and usually provided an index of abundance, most frequently of spawning adults. Such methods cannot provide estimates of absolute numbers. Echo sounding not only overcomes this problem but also provides frequent estimates of the number of fish present at different water depths and the size frequency distribution of the fish in the water column. The chief disadvantage of echo sounding is that it cannot separate charr from pelagic brown trout in Windermere.

In spite of the latter problem, the results from the echo sounder are encouraging. Comparisons with the angler's catches produced no major problems in interpretation (Fig. 10). Seasonal changes in the estimates of fish density exhibited consistent patterns in each basin of the lake and also revealed consistent differences between basins (Figs. 11,12). There is a wealth of information in the data obtained with the echo sounder and analyses of these data to answer pertinent questions will be one of the major tasks in the next few months.

The work described in this interim report will continue for at least another year and should provide greater insight into the ecology of charr stocks in Windermere. Such information will be valuable for making future decisions on the management of the lake and its charr.

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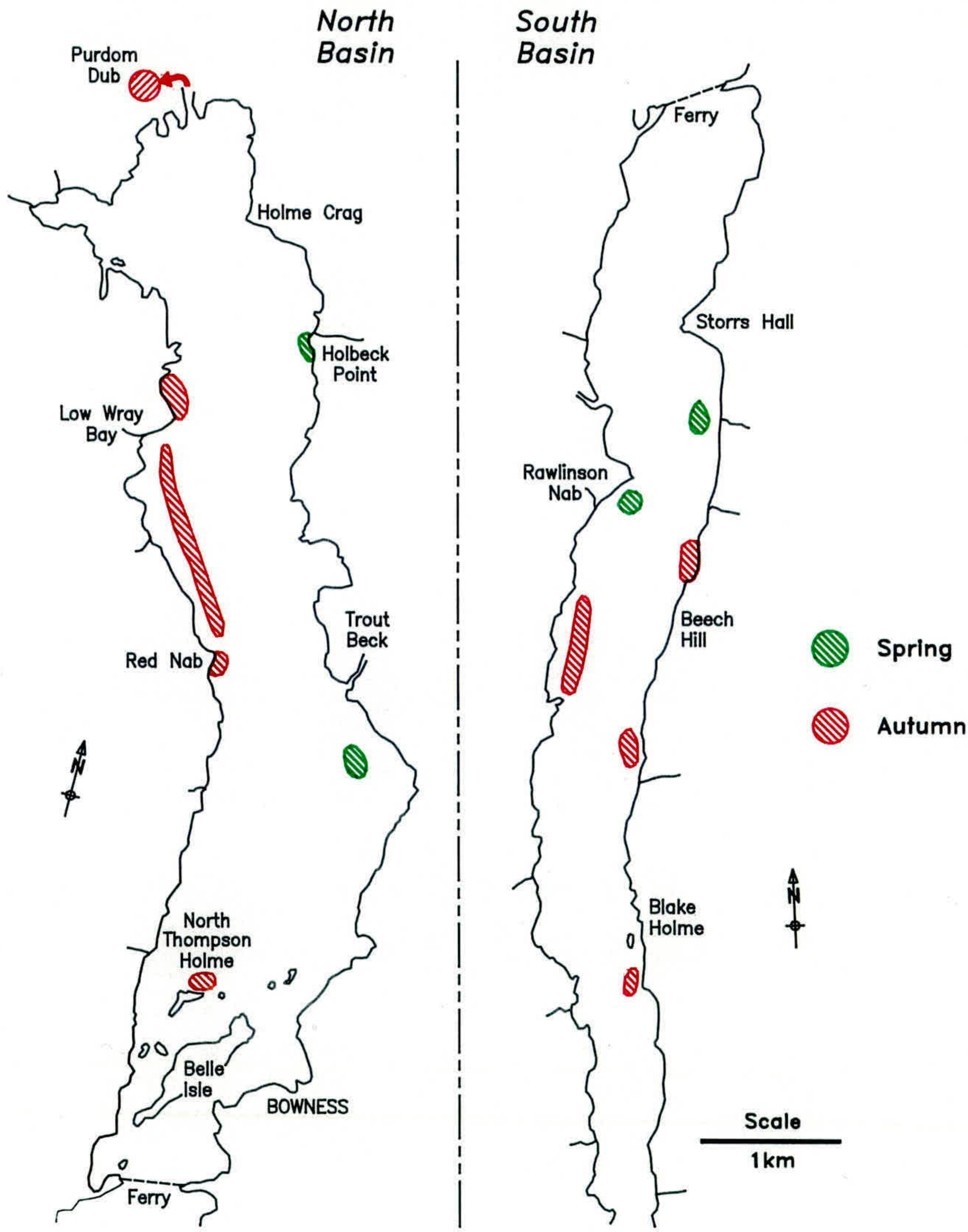

Fig. 1. Map of North and South Basins of Windermere showing positions of spawning sites for spring and autumn charr.

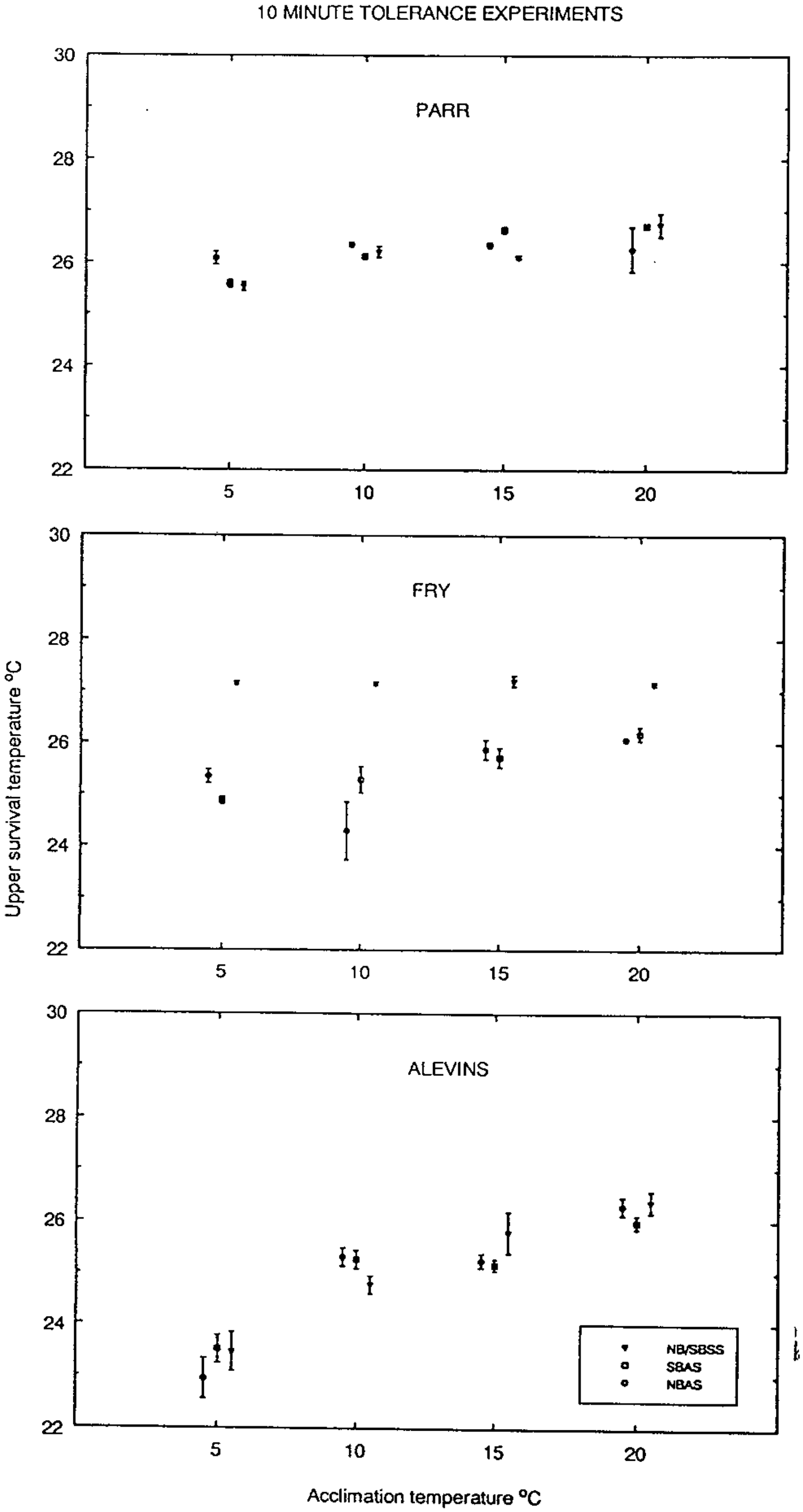

Fig. 2. Comparison of highest mean temperatures (with 95 % C.L. indicated by vertical bars) for survival of charr over 10 min after being kept at acclimation temperatures of 5, 10, 15 20°C; data are grouped according to life stage (alevins, fry, parr).

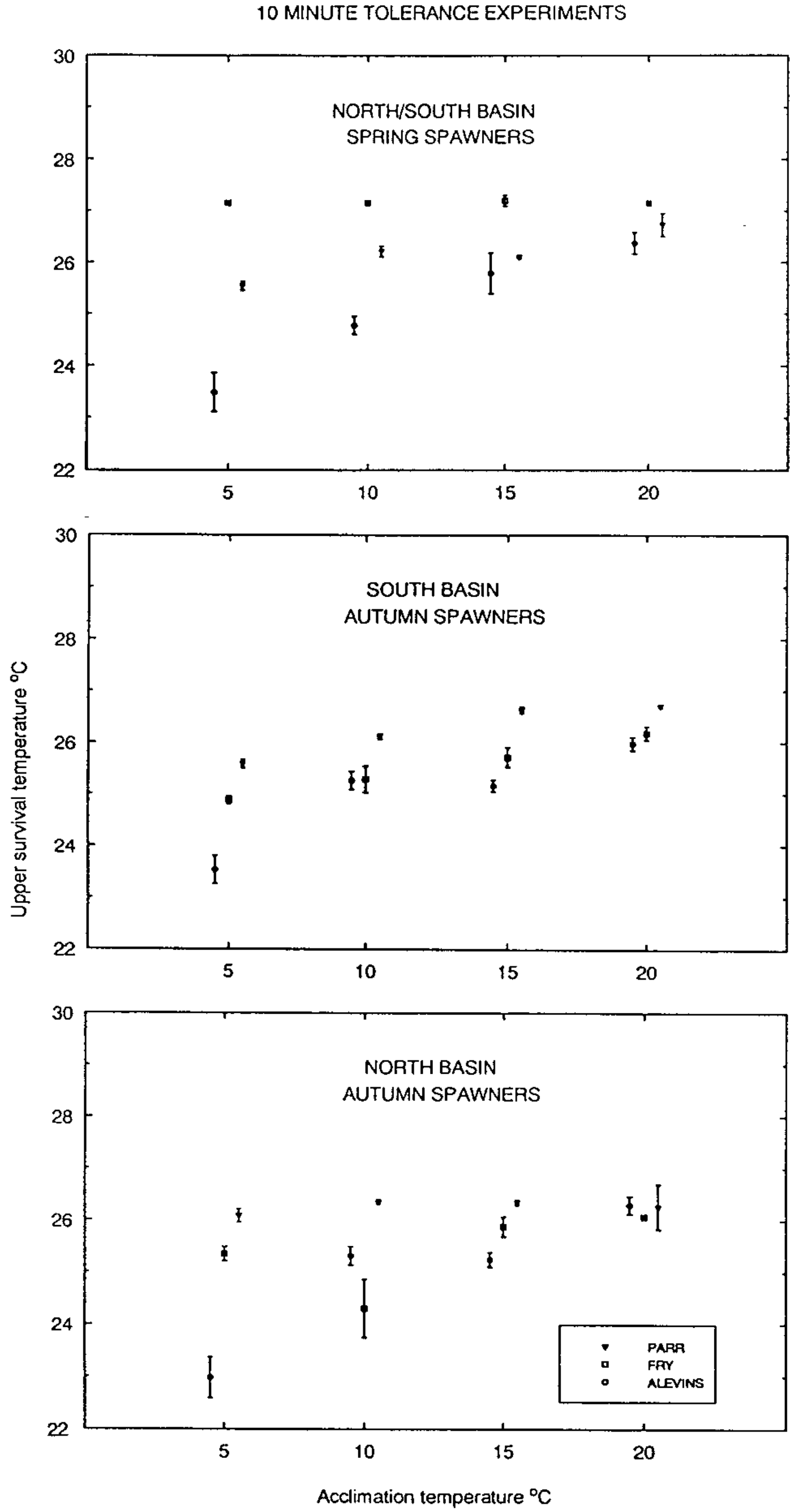

Fig. 3. Legend as in Fig. 2. Data are grouped according to race of charr (North/South Basin spring spawners, South Basin autumn spawners, North Basin autumn spawners).

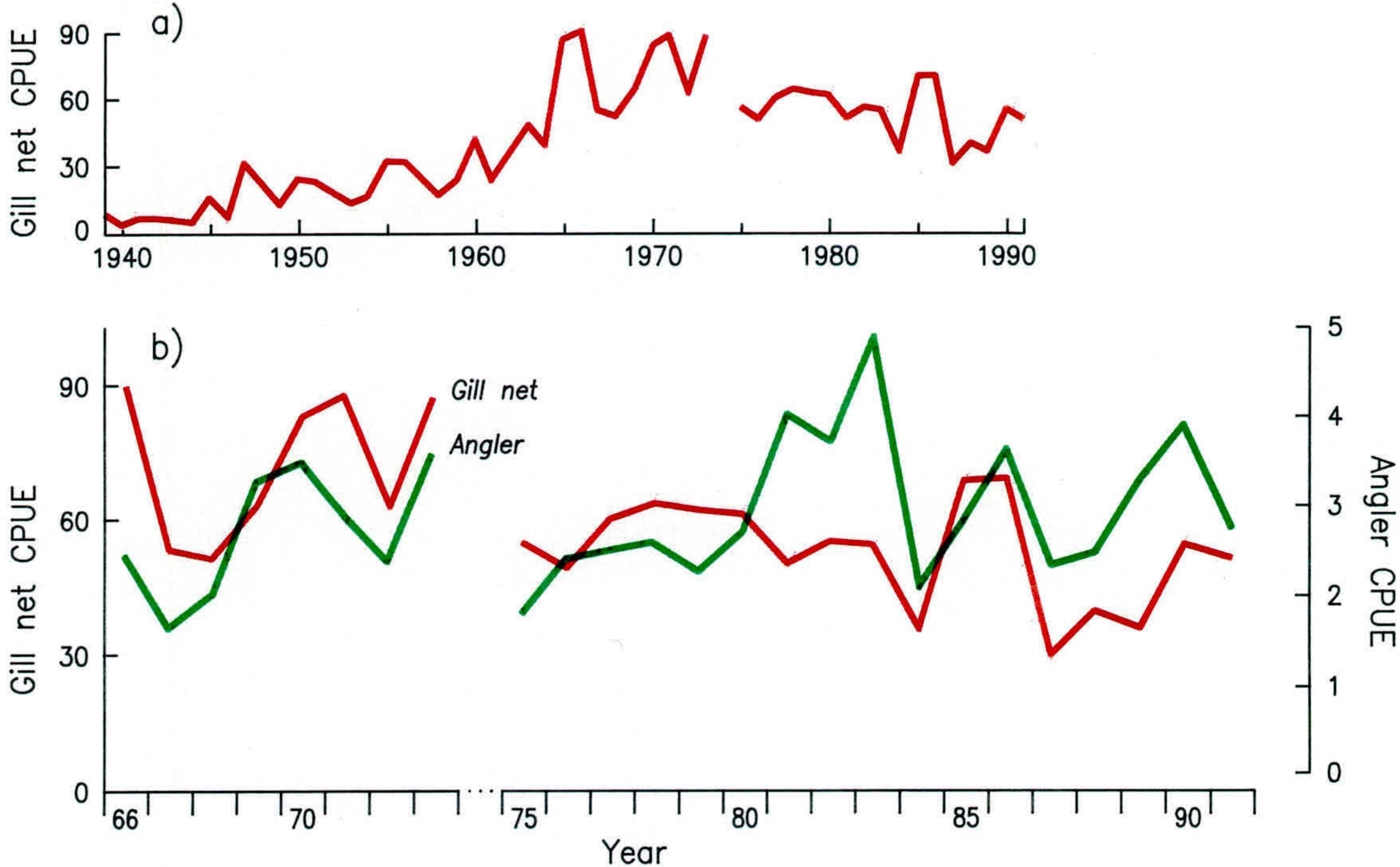

Fig. 4. (a) Gill - net catch per unit effort (CPUE) for charr at Windermere North Basin spawning sites from 1939-1991. CPUE is the mean catch per gill-net day in November at Low Wray Bay (1939-1973) and North Thompson Holme (1975-1991) spawning sites. (b) Gill net CPUE (red line) and angler CPUE (green line) from 1966 to 1991. Angler CPUE is the mean catch per boat per hour. The scales for gill-net and angler CPUE have been arranged so that the overall means for each coincide.

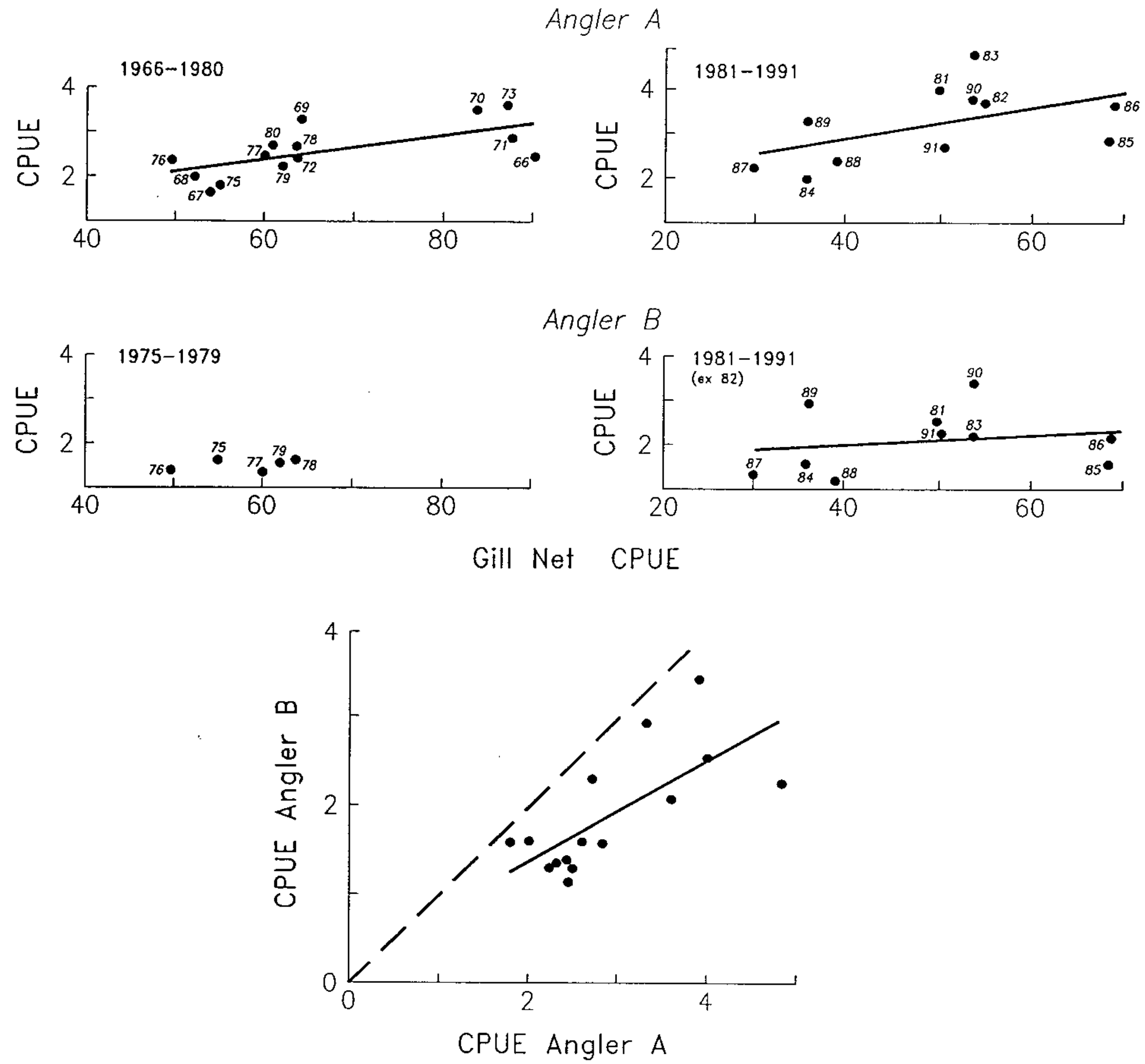

Fig. 5. Relationship between angler catch-per-unit-effort (CPUE) and gillnet CPUE for the periods 1966-1980 and 1981-1991 for Angler A, and for the periods 1975-1979 and 1981-1991 (excluding 1982) for Angler B, together with the relationship between CPUE for Anglers A and B (angler CPUE is the mean catch per boat per hour, gillnet CPUE is the mean catch per gillnet day).

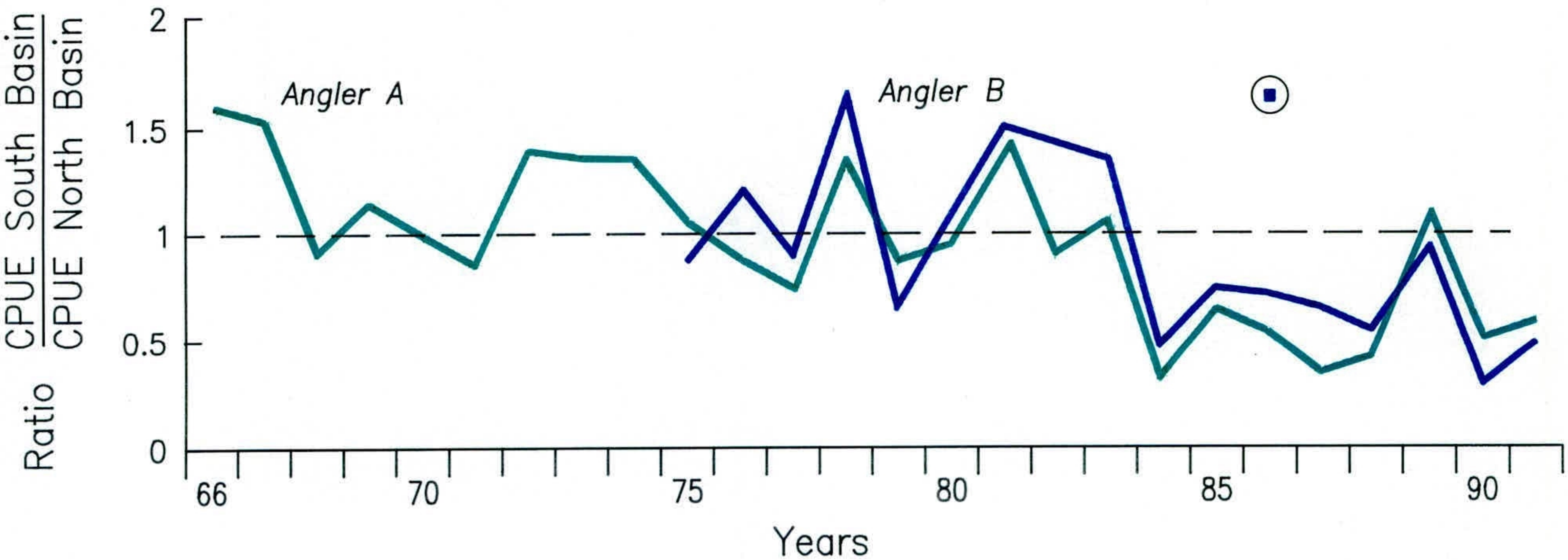

Fig. 6. Ratio of angler CPUE for South Basin for angler A (geen line) from 1966-1991 and angler B (blue line) from 1975 to 1991. (Note: the high encircled value for angler B in 1986 was due to the inclusion of one exceptionally high catch in the South Basin; when this was excluded from the analysis the estimated ratio was very similar to adjacent values.

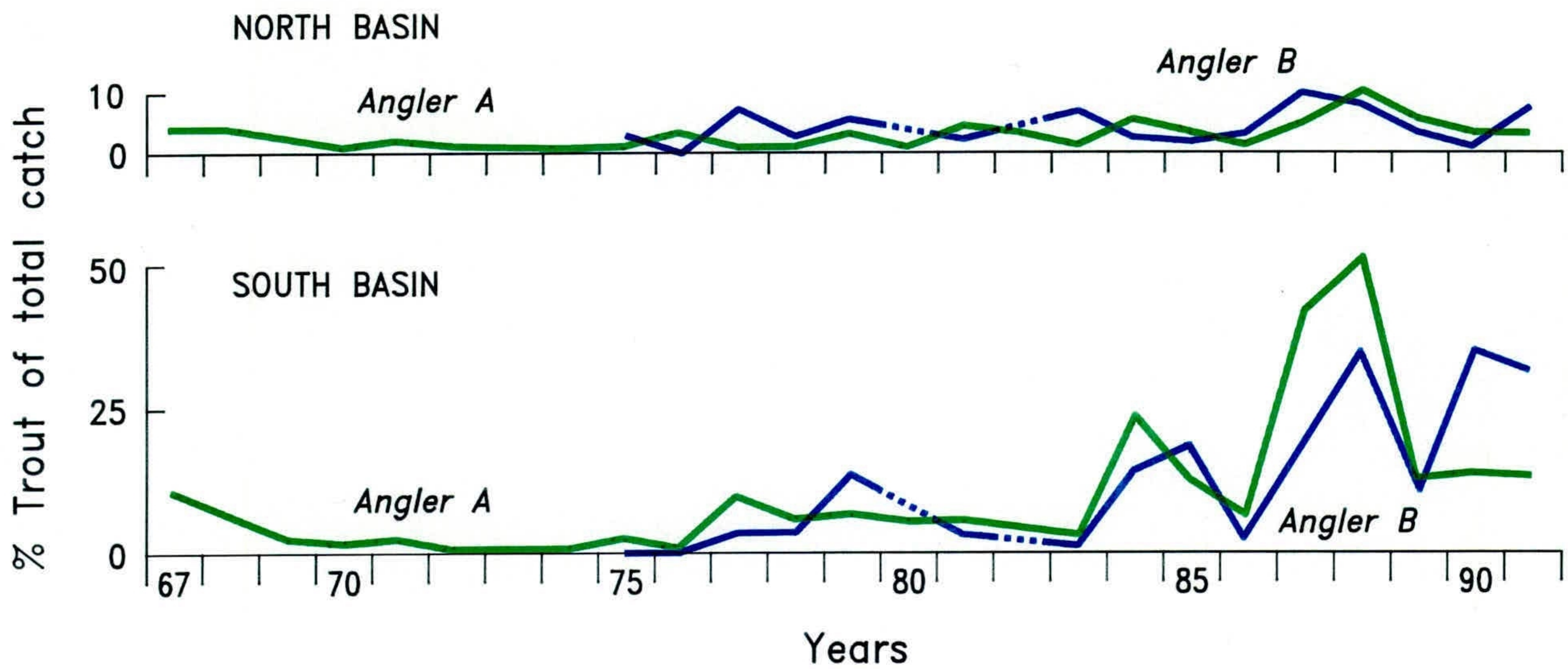

Fig. 7. Percentage of brown trout taken in the North and South Basins in annual catches by anglers A and B.

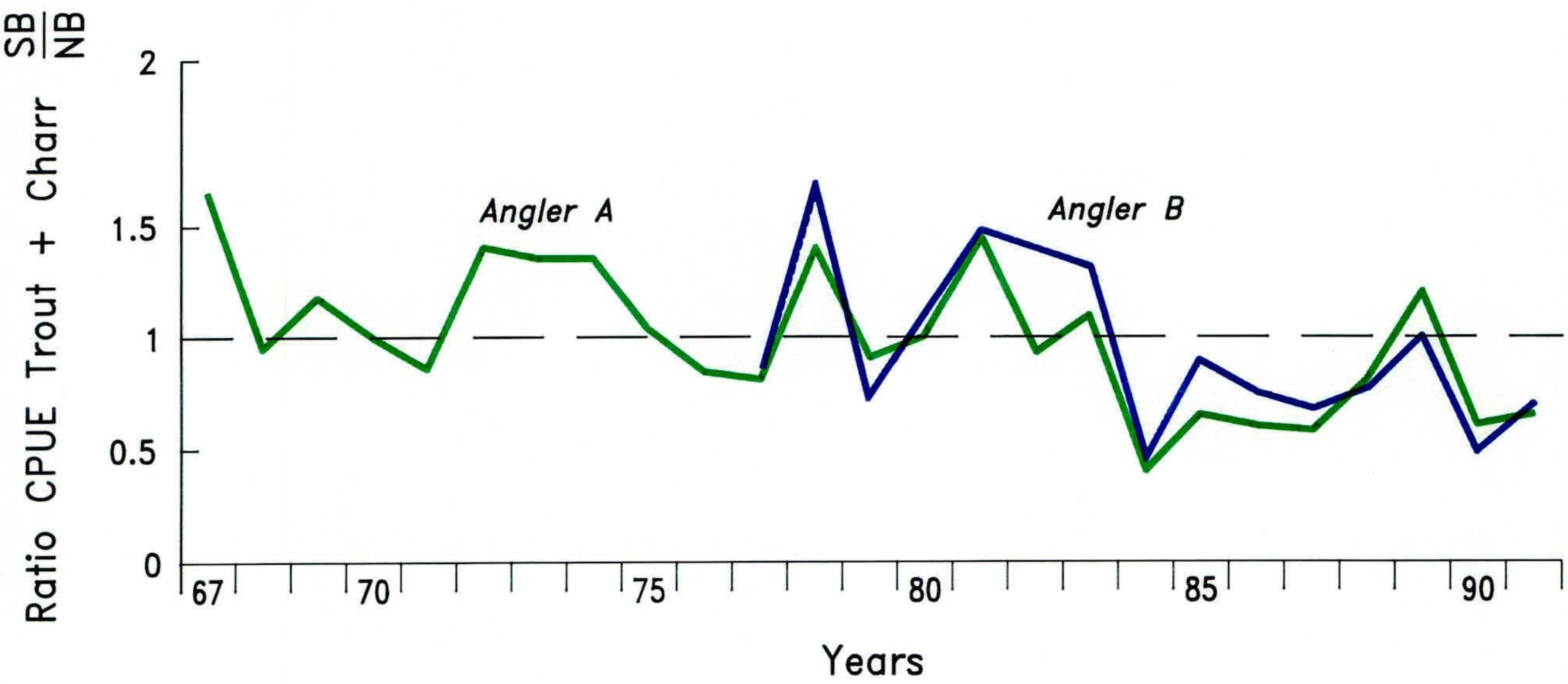

Fig. 8. Ratio (South Basin : North Basin = SB/NB) of angler CPUE for total catch (charr + trout) for Angler A from 1967 to 1991 and Angler B from 1977 to 1991.

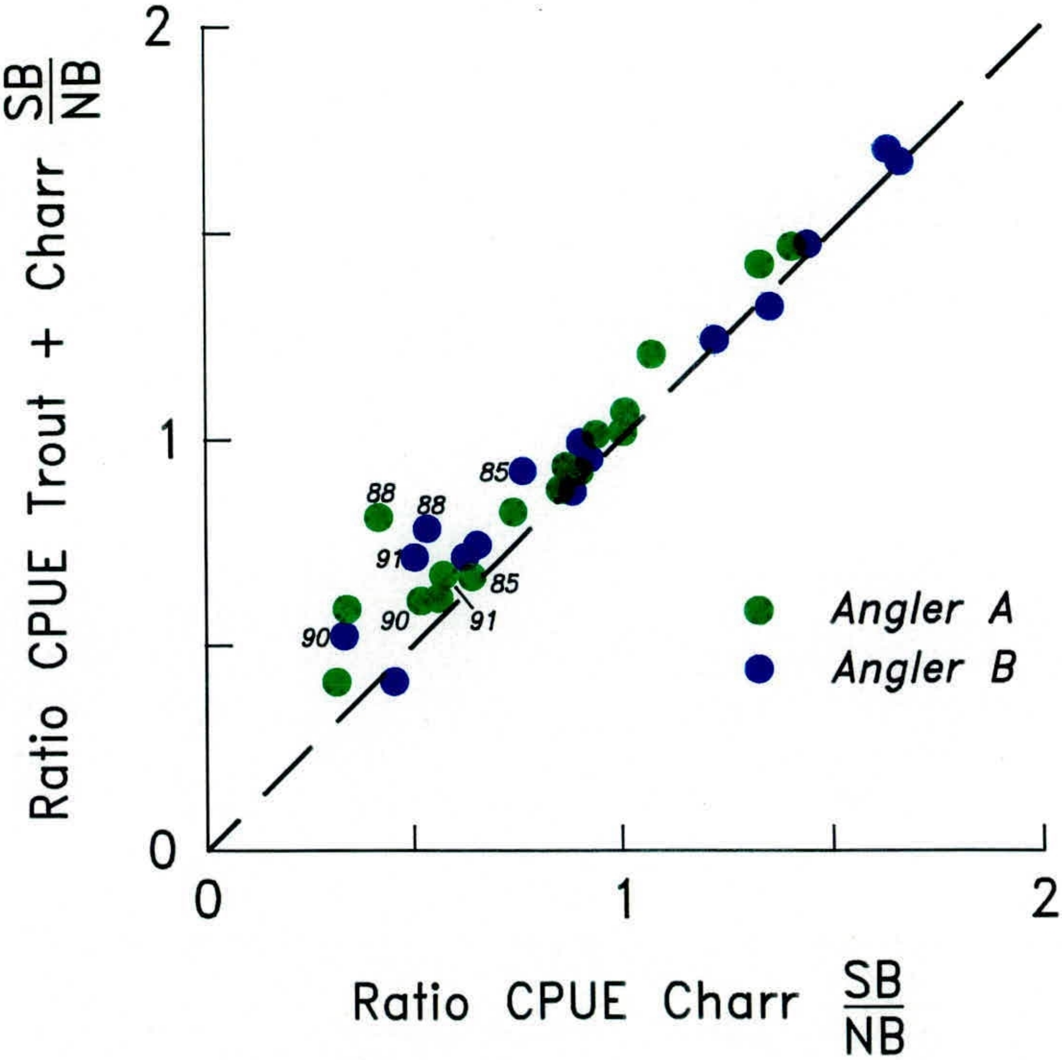

Fig. 9. Comparison between ratios (South Basin : North Basin = SB/NB) of CPUE for Anglers A and B, using total catch (charr + trout) and charr only.

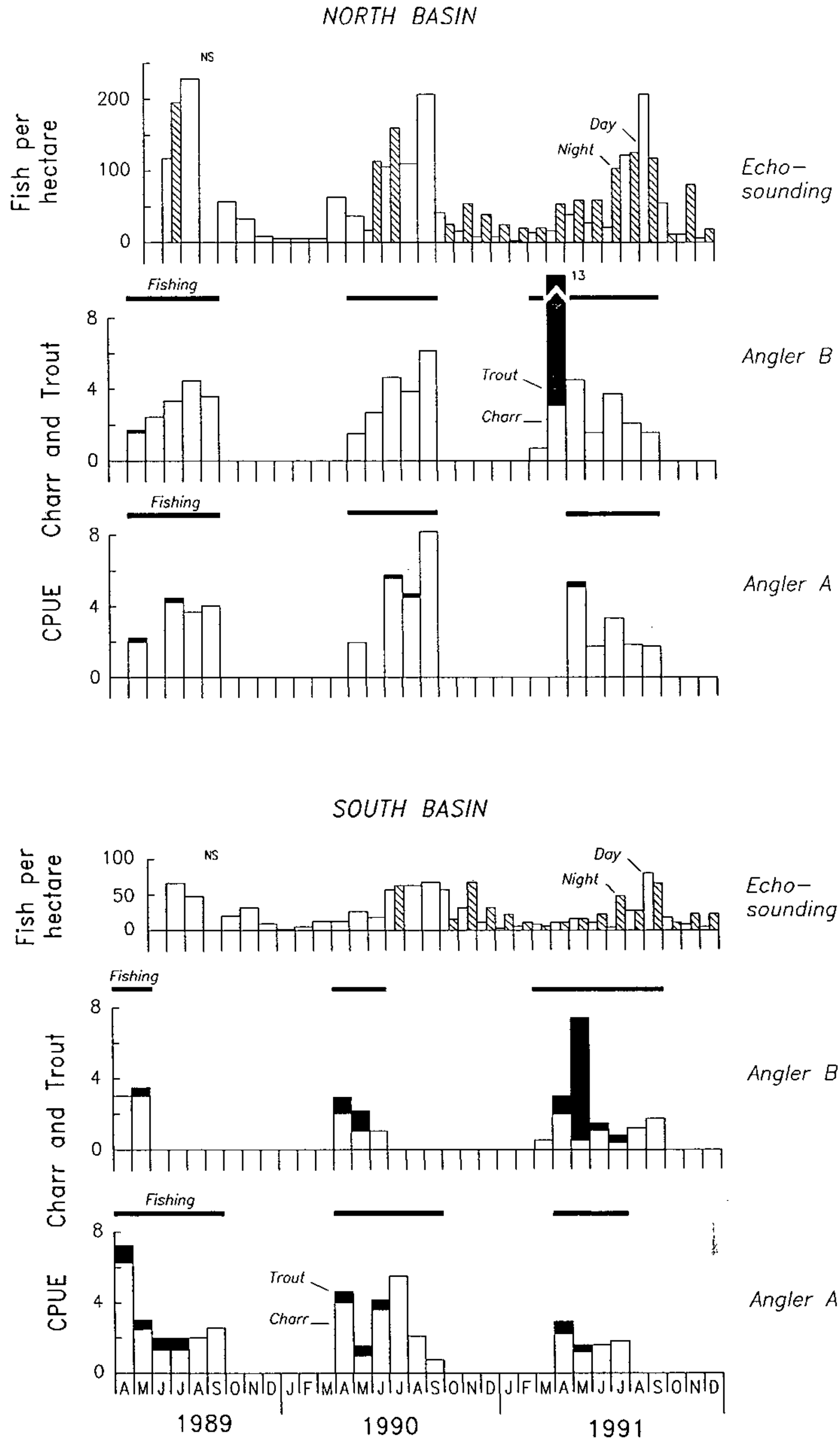

Fig. 10. Comparisons of monthly CPUE for charr (open columns) and trout (black portion of columns) taken in North and South Basins by Anglers A and B; estimates of fish density from echo-sounding are also provided.

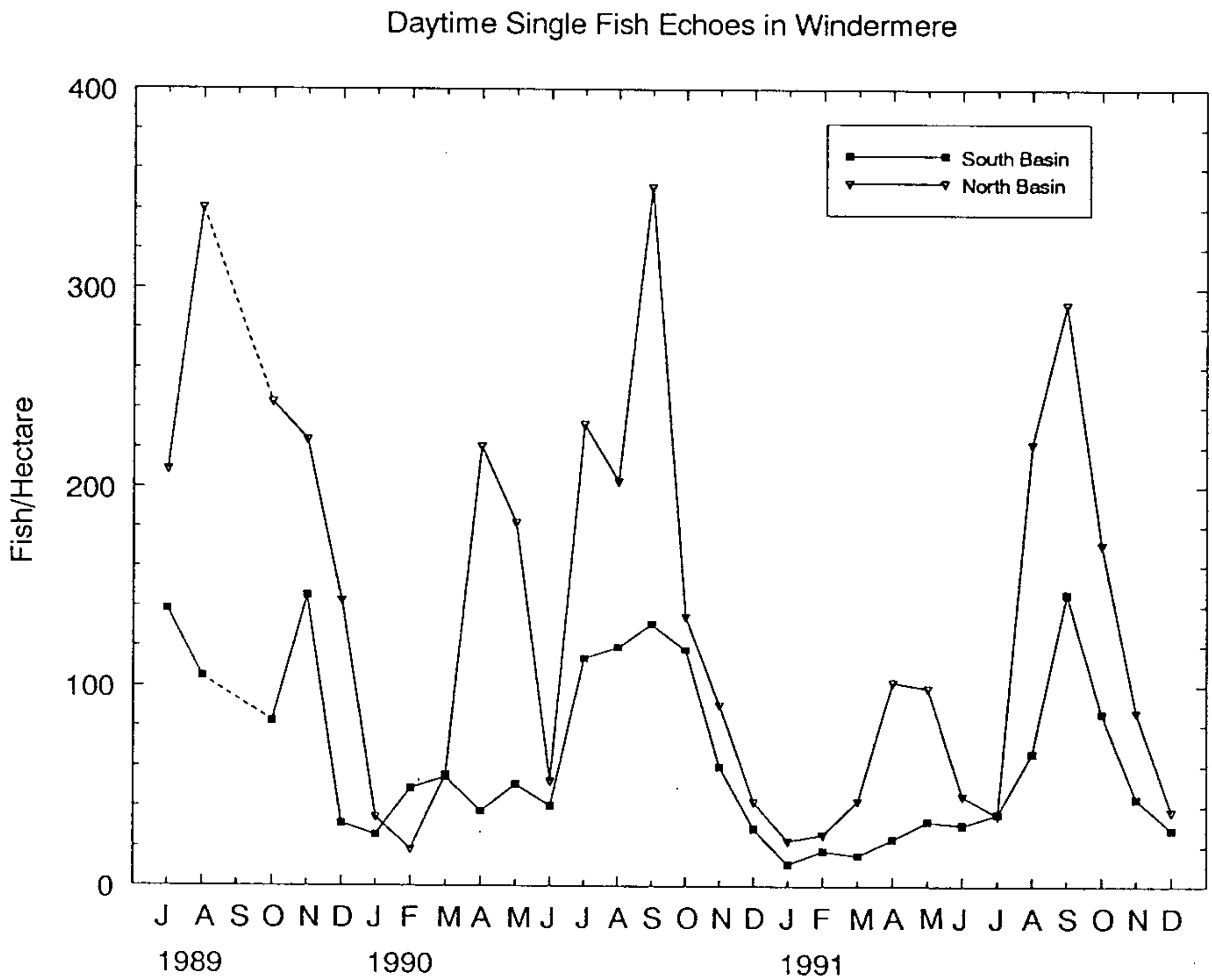

Fig. 11. Monthly estimates of fish density from echo-sounding in the North and South Basins of Windermere: during the day.

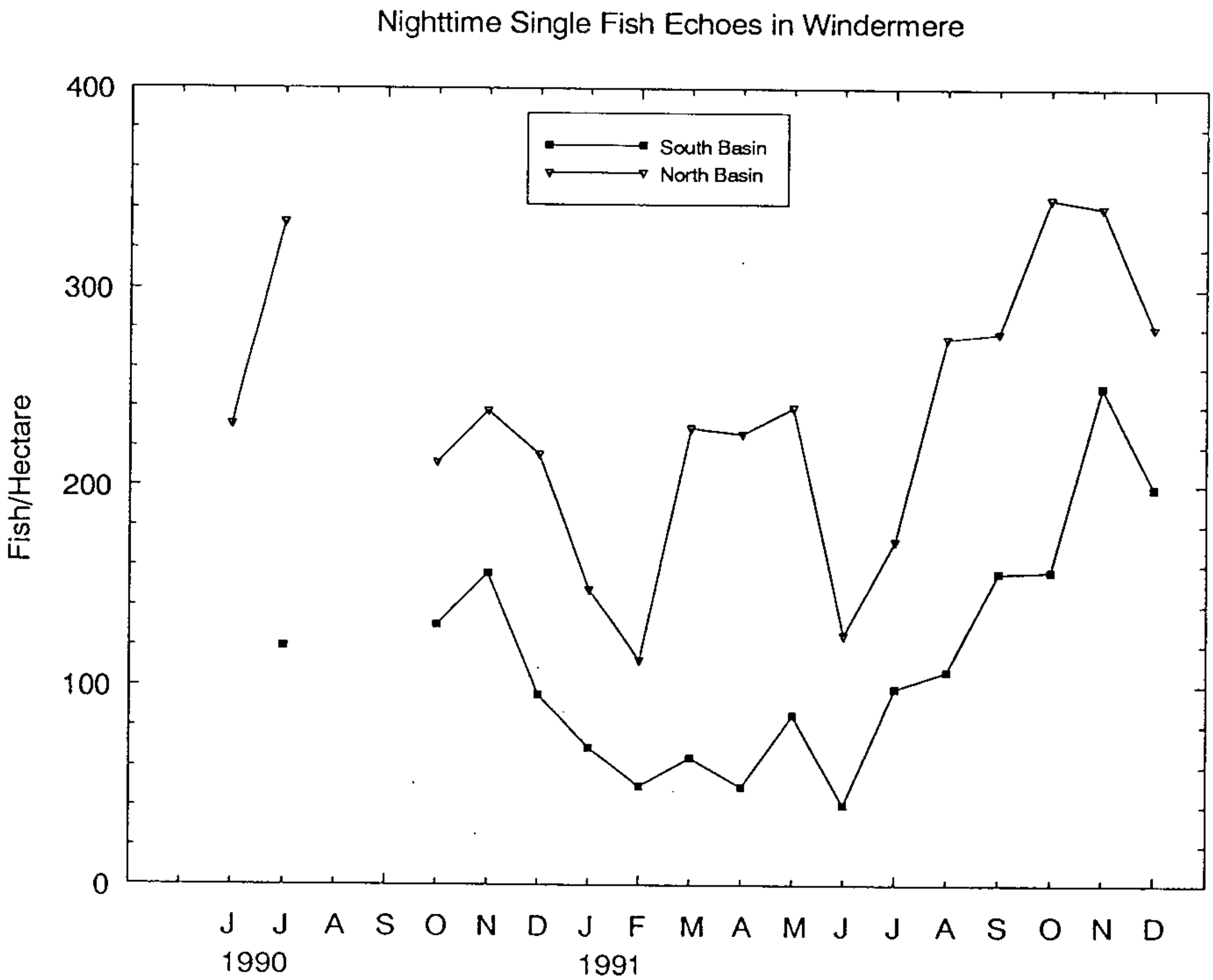

Fig. 12. Monthly estimates of fish density from echo-sounding in the North and South Basins of Windermere: during the night.

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