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Changes in water quality within angler's keepnets during the confinement of fish

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Changes in water quality within anglers keepnets during the confinement of fish

Abstract The influence of mesh size and loading density on conditions within keepnets during the confinement of fish was examined. The performance of a mixed-mesh net was also evaluated. Confinement of fish within nets of a standard diameter and length and of three different mesh sizes for 5 hours resulted in no deleterious changes in levels of dissolved oxygen, unionized ammonia, carbon dioxide, or pH at any of three sample points within each net. Transfer of fish to similar nets at a similar, and a higher, loading for 5 hours resulted in a depletion of oxygen, and accumulation of ammonia, in the high-load nets. No changes in carbon dioxide levels or pH were observed in nets containing either moderate or high loads. Confinement of fish in mixed-mesh nets for 5 hours resulted in a depletion of dissolved oxygen in the lower section of the net and an accumulation of unionized ammonia. There were no changes in carbon dioxide, or pH. These results are discussed with reference to the water quality requirements of freshwater fish. It is concluded that changes in water quality within anglers keepnets during the confinement of fish are not of sufficient magnitude to adversely affect the confined fish.

Introduction

It is common practice among freshwater anglers in the United Kingdom to retain their catch within keepnets during an angling session. The fish are normally weighed and/or photographed at the termination of the session, prior to being returned, alive, to the water. The use of keepnets is particularly important in competitive angling in which total catches within a predetermined time period are ranked by weight. Although regional legislation exists within the UK to dictate minimum permissible net dimensions and mesh sizes, a systematic study of the effect of confinement within keepnets on fish has yet to be undertaken. Four main areas of concern related to keepnet confinement can be identified :

- effects on the fish of changes in water quality during confinement within the net;
- effects on the fish arising from the physiological stress of capture and/or confinement within the keepnet;
- physical damage to the fish, incurred during handling associated with capture, transfer to the net, weighing/photographing, and release;
- the possibility of long-term behavioural and physiological effects following release;

Despite increasing concern regarding the welfare of fish in catch-and-return fisheries, and the impact of angling on fish populations, there have been no studies carried out specifically to address any of these points. The aim of the present study was to establish whether the confinement of fish within keepnets results in alterations in water quality, and if so, whether such changes in water quality are potentially harmful to the fish.

Water quality within keepnets is an important factor in the well-being of the confined fish. Fish require dissolved oxygen to sustain life and, as a consequence of metabolism, produce a number of waste products. As oxygen is removed from the water by respiration, carbon dioxide is released. In addition, as a result of the continual turnover of protein within the fish, nitrogen is excreted both in the form of urea, and predominantly, ammonia. Ammonia is excreted to a limited extent via the urine but predominantly across the gill epithelium. The replacement of water in the immediate vicinity of the fish is therefore important in maintaining adequate levels of oxygen and facilitating the removal of ammonia and carbon dioxide which can exert toxic effects at high concentrations. It is clear that if fish are confined in numbers within a net which impedes the flow of water, or the net is sited in static water, a potentially damaging combination of low oxygen levels and high concentrations of metabolic waste may occur. This study examines the interaction of two factors likely to affect water quality during the confinement of fish; mesh size and loading density of fish. In addition, the influence of a mixed-mesh net on water quality was examined.

Materials and methods

The experiments were carried out at the National Rivers Authority (North West Region) Leyland fish farm in Lancashire. The fish used were predominantly fully-scaled mirror carp, *Cyprinus carpio* (L.) with some tench, *Tinca tinca* (L.), chub *Leuciscus cephalus* (L.), and roach *Rutilus rutilus* (L.). The size range of fish employed in these experiments was 7 - 600 g with a mean weight of 120 ± 15 g (Mean ± SEM, n= 67). The fish were fed once daily on commercial feed. The nets employed during the investigation were provided by Keenets Ltd. (Woodcock Estate, Warminster, Wilts.). Further details are provided in the relevant sections below.

Water samples were removed from fixed points within the keepnets using two polypropylene syringes (60 ml capacity) mounted in clips attached to the end of a 3 m hollow plastic pole. A length of wire, attached at each end to stakes placed on the bank and in the lagoon, was passed through the centre of the keepnet to provide a guide for the sampling apparatus, which was hooked onto the guide-wire to ensure removal of the water sample from a central position within the net. The syringe plungers were operated by means of a wire passing down the centre of the pole. Water samples were retrieved rapidly and with the minimum of disturbance, and either placed in plastic bottles for subsequent analysis (ammonia, carbon dioxide) or analysed immediately (pH, oxygen). The experiments were carried out in August 1990. Water temperature was recorded at hourly intervals during the experiments, at the surface, and at a depth corresponding to the mid-net sampling point. Temperature data were logged automatically on a Grant Squirrel 1200 series data logger.

Chemical analyses

Dissolved oxygen. A portable oxygen meter (Jenway model 9070) was used to measure dissolved oxygen (DO_2) in water samples. The probe was calibrated at regular intervals throughout the sampling period. Immediately following retrieval of the water sample, the sample was transferred, with minimal agitation, to a 60 ml polypropylene bottle within which the probe was immersed and a reading made. Under laboratory conditions, employing the same method of sample collection and transfer, pre- and post-transfer DO_2 measurements were found to be indistinguishable down to levels of 40% saturation. Below this point post-transfer measurements were elevated compared to pre-transfer values.

pH. Aportable pH meter (Jenway model 3050) was used to measure pH in the water samples. The probe was calibrated on each day of use according to the manufacturer's instructions. The pH of each sample was established immediately following determination of DO_2.

Ammonia levels. The levels of ammoniacal nitrogen ($NH_3 + NH_4^+$ - N) in water samples were determined using the indophenol blue method (Mackereth, Heron & Talling 1989) employing a Pye Unicam AC1 automatic chemistry unit. From these values total ammonia levels were calculated. The proportion of unionized ammonia in each sample was calculated according to Alabaster and Lloyd (1980) where

$$\textit{percent unionized ammonia} = \frac{100}{1 + \text{antilog}\ (pk_a - pH)}$$

pk_a = negative log of the ionization constant, taken in this case to be 9.56.

Carbon dioxide. The levels of total dissolved carbon dioxide (CO_2) were determined indirectly from the pH of the sample and its measured alkalinity (Mackereth *et al*. 1989). Alkalinity was determined employing Gran titration methodology (Mackereth *et al*. 1989).

Statistical analysis. Data were analysed using a multifactorial analysis of variance (ANOVA, Genstat) with sample time, sample point within the net, and net type as factors (Experiment 1); sample time, sample point within the net, and load as factors (Experiment 2); sample time and sample point as factors (Experiment 3). For each analysis, residuals were plotted against fitted values to ascertain whether transformation of the data was necessary.

Experiment 1. The effect of mesh size on water quality within keepnets during the confinement of fish.

Three net types provided mesh sizes typical of those in widespread use by anglers: Keenets K9 gudgeon mesh (10 mm), K34 Round Fre-Flo mesh (6 mm), K39 Round Micro-Flo mesh (3 mm). All nets were 40 cm in diameter and 2.5 m in length, with a submerged volume of approximately 220 l. Each net type was deployed in duplicate and erected at 2.5 m intervals along a single bank of the lagoon. Fish were seine-netted from an adjacent lagoon and transferred to the keepnets, ensuring that each net received a similar range of fish sizes, to a total weight of 13.6 kg net^{-1} (loading density 62 g $l^{-1)}$. Water samples were removed from the keepnets prior to the addition of the fish, and at hourly intervals after the addition of the fish, for five hours. At each sample time, water samples were removed from 3 points within each net and from a single site within the lagoon. Following completion of the experiment, the fish were returned to the holding lagoon.

Experiment 2. The effect of loading density on water quality within keepnets.

A single net type was employed (Keenet K39 Round Micro-Flo mesh, 3 mm) with two loading densities (moderate: 13.6 kg, 62 g l^{-1}; high: 35 kg, 160 g l^{-1}). The nets were deployed and fish transferred as described above.

Experiment 3. Changes in water quality during the confinement of fish within a mixed mesh net.

Two Keenet SW26 nets, rectangular in section (40 x 28 cm) and 2.5 m in length, were deployed as above and loaded with 20.5 kg of fish (loading density 105 g l^{-1}). Water samples were removed prior to the addition of the fish, and at hourly intervals subsequently, for five hours. Samples were removed for analysis from within the section enclosed by Keeper mesh (1mm at intervals) and from within the section enclosed by Micro-Flo mesh (3 mm).

Results

Experiment 1. The effect of mesh size on water quality within keepnets during the confinement of fish.

Dissolved oxygen. There were no significant differences between nets of different mesh sizes and therefore results for the three mesh types were combined. No differences in oxygen concentration between the three sample sites within the nets were apparent (Table 1). A significant overall change in dissolved oxygen concentration occurred with time, from 95.4 % satn. At 1-h to 100.0 % satn. After 5-h confinement (n = 18; P<0.01; Fig. 1a). The mean dissolved oxygen concentration (% satn.) for each net type over the 5 h experimental period was; 10-mm mesh: 98.4; 6-mm mesh: 97.9; 3-mm mesh: 97.9 (n = 36.).

Dissolved carbon dioxide. There were no significant differences between net types and the data for the three mesh types were combined. No significant differences in total carbon dioxide concentration at the three intra-net sample sites were apparent (Table 1). There was a significant decline in total carbon dioxide within the nets between 0-h (2158 $\mu E\ l^{-1}$) and 5-h (2088 $\mu E\ l^{-1}$; P<0.01, Fig. 1b, n = 18). The mean total carbon dioxide concentration ($\mu E\ l^{-1}$) for each net type over the five-hour sampling period was; 10-mm mesh: 2126; 6-mm mesh: 2111; 3-mm mesh: 2112 (n = 36).

Ammonia. There were no significant differences in total ammonia (NH_3 + NH_4^+) or unionized ammonia (NH_3) concentration related to mesh size so these data were combined. No differences in unionized ammonia concentration at the three intra-net sample points were observed (Table 1). There was a significant decline in total ammonia concentration within the nets, from 67.6 $\mu g\ l^{-1}$ at 0-h to 44.2 $\mu g\ l^{-1}$ at 5-h (P<0.05, n = 18) but no significant change with time (P>0.05) in the level of unionized ammonia within the nets, although values displayed an upward trend ranging from 2.5 $\mu g\ l^{-1}$ at 0-h to 2.9 $\mu g\ l^{-1}$ after 5-h (Fig. 1c, n = 18).

pH. There was a significant effect of mesh type on pH, a small but significant difference in pH between the three intra-net sampling points, and a significant change in pH with time. The latter was resolved as a significant increase in pH during the experimental period, rising from between pH 8.09 - 8.20 at 0-h to between pH 8.35 - 8.46 at 5-h (*P*<0.001, Fig. 1d, n = 18). Overall, the mean pH values for the three net types were; 10-mm mesh: 8.24; 6-mm mesh: 8.32; 3-mm mesh: 8.38 (*P*<0.001, n = 36). Mean values for the intra-net sample points are presented in Table 1. The pH at both middle and bottom sites was significantly greater than that at the top site (*P*<0.01, *P*<0.001, respectively, n = 36).

Experiment 2. The effect of loading density on water quality within keepnets.

Dissolved oxygen. Overall, mean dissolved oxygen levels (% satn.) in high-load nets were significantly lower than those in the low-load nets (97.9 *c.f.* 87.3, *P*<0.001, n = 36). This effect was apparent from 0-h onwards (Fig. 2). During the 5-hour confinement period, there was a small but significant increase in dissolved oxygen concentration in the low-load nets (*P*<0.01, Fig. 2a) but a marked decline in oxygen saturation in the high-load nets (90.5 to 79.8, *P*<0.001, Fig. 2a, n = 6). There was no difference in dissolved oxygen concentration at the three intra-net sample points in the low-loaded nets (Table 2) but in the high-load nets there was a significant decline (*P*<0.05) in oxygen concentration towards the bottom of the net (Table 2).

Dissolved carbon dioxide. There were no significant differences in total carbon dioxide levels either with time (Fig. 2b), due to loading, or related to intra-net sampling point (Table 2).

Ammonia. Overall, total ammonia levels were significantly higher in the high-load nets than low-load nets (137.6 *c.f.* 45.9 μg l^{-1}, *P*<0.001, n = 36). During the 5 hour confinement period total ammonia levels in the high-load nets rose from a mean of 46.7 μg l^{-1} to a maximum of 316.9 μg l^{-1} after 5 hours (*P*<0.01, n = 6). Total ammonia levels in the low-load nets remained relatively constant, declining from 49.8 μg l^{-1} at 0-h to 41.7 μg l^{-1} at 5-h. There were no significant differences in total ammonia levels between sample sites in the low-load net (*P*>0.05), although in the high-load net total ammonia concentration at the bottom sampling point (175.8 μg l^{-1}) was significantly greater than the concentration at the top sampling point overall (114.1 μg l^{-1} , *P*<0.05, n = 36). The concentration of unionized ammonia in the high load nets was significantly greater than that in the low-load nets at 5-h

(7.6 *c.f.* 3.1 μg $^{-1}$, p<0.01, Fig. 2c, n = 6). There was no difference overall in unionized ammonia concentration between sample points in either low- or high-load nets (Table 2). Overall the mean unionized ammonia levels were greater in the high-load nets (3.9 μg l^{-1}) than in the low-load nets (2.8 μg l^{-1}, p <0.01, n = 36).

pH. Overall, pH was significantly lower throughout the experimental period in the high-load nets (8.03 *c.f.* 8.38, *P*<0.001, n = 36), this difference was apparent at all sampling times (Fig. 2). There was a significant change with time in pH within the low-load nets (*P*<0.001, Fig. 2d, n = 6), pH rising from 8.2 at 0-h to 8.46 at 5-h. pH in the high-load nets declined significantly from 8.02 at 0-h to 7.97 at 5-h (*P*<0.05, Fig. 2d). There were no differences in pH between the three within-net sample points in either loading (Table 2).

Experiment 3. Changes in water quality during confinement of fish within a mixed-mesh net.

Dissolved oxygen. Dissolved oxygen levels were significantly lower within the keeper section than in the main body of the net (88.7 *c.f.* 90.8; *P*<0.05, n = 12). Too few data were available to make a statistically valid comparison of dissolved oxygen levels at each sample point at each time (Fig. 3a, n = 2).

Dissolved carbon dioxide. There was no significant difference in carbon dioxide concentration between the two intra-net sample points (2131 *c.f.* 2119, n = 12) so data for the two sites were combined for the time course in which values ranged between 2099 and 2149 μE l^{-1} (Fig. 3b).

Ammonia. No significant differences in ammonia concentration at the two intra-net sample sites were noted so the data for the two sites were combined. Overall, there was a significant increase in total ammonia concentration within the nets during the experimental period, values rising from 44.0 μg l^{-1} at 0-h to 174.2 μg l^{-1} at 5-h (*P*<0.05, n = 4). There was no significant difference in the concentration of unionized ammonia between the two within-net sample sites but there was a significant overall increase in the concentration of unionized ammonia within the nets, from 1.0 μg l^{-1} at 0 h to 4.6 μg l^{-1} (*P*<0.05, Fig. 3c, n = 4) after 5 h confinement.

pH. There were no significant differences in pH between the two within-net sample points (7.92 c.f. 7.98, n = 12). After combining the data from the two sites, there were no significant changes in pH with time during the period of confinement. Overall, pH values ranged between 7.86 and 8.04 (Fig. 3d, n = 4).

Discussion

The primary aim of this project was to establish whether the confinement of fish within keepnets resulted in their exposure to a potentially damaging micro-environment within the net. No other factors associated with keepnet confinement were considered.

Changes in water chemistry.

Experiment 1 was designed to establish whether mesh size of a keepnet is a factor in determining water quality within the net. Three mesh sizes, typical of the range in common use by anglers, were employed and the number and weight of fish chosen to load the nets was selected to represent an above-average catch. The keepnets were deliberately sited in what might be considered adverse conditions; within a shallow, still-water lagoon during the summer, and all the fish were added to the nets in one batch, rather than, as would occur during an angling session, intermittently. Despite this, during the five-hour period of confinement for which conditions within the nets were monitored, no deleterious alterations in water chemistry were observed. The increase in dissolved O_2 levels, and decline in total CO_2 levels, observed within the nets probably reflects the photosynthetic activity of algae present in the lagoon. Both these trends were noted in the water samples removed from the lagoon directly. Total NH_3 levels also declined during the confinement period, probably as a consequence of the activity of microorganisms utilising NH_3 as a nitrogen source. There was no alteration in levels of unionized NH_3. The rise in pH within the nets during the experiment, which was also observed within the lagoon, was probably linked to the removal of CO_2. The significant difference in pH within the three net-types in Experiment 1 is not readily explicable. If water flow across the net were impeded by a reduction in mesh size, then the production of CO_2 by the confined fish may have opposed the algal-driven removal of CO_2 and hence resulted in a reduced pH. However, the lowest pH occurred in the net with the largest mesh size. It is possible that the discrepancy is related to the relative siting of the nets since the pH differences were apparent at 0 h, before the addition of fish. Nevertheless, these results suggest that mesh size, within the range examined, is not an important factor in determining water quality within moderately loaded keepnets, even in static water.

Experiment 2 addressed the significance of loading density as a factor determining water quality within keepnets. Nets comprising Micro-Flo mesh (3 mm) were used, with two loading densities, moderate and high, in duplicate. The higher load was chosen to be typical of an above-average match catch. Environmental conditions were identical to those during the first experiment but again, fish were added to the net in a single batch, not sequentially as would be the case during an angling session. Therefore, the five hours of confinement at these loading densities represents an extreme not likely to be encountered under normal circumstances. During the course of the experiment there were several marked changes in water quality within the nets. DO_2 levels in the high-load nets declined during the five hours of confinement, counter to trends within the lagoon as a whole, and DO_2 concentration in the high-load nets was markedly reduced at the lower intra-net sample point compared to the upper sample point. Total NH_3 levels were markedly elevated after five hours in the high-load nets and were nearly threefold higher in the high-load compared to the low-load nets overall. This difference was reflected in higher unionized NH_3 levels in the high load nets. There was also a statistically significant difference in pH between the two loadings, pH rose significantly in the low-load nets, similar to changes within the lagoon as a whole, but remained significantly lower in the high-load nets throughout the confinement period. Overall, water quality changes within the nets appeared to be substantially affected by loading density, the high-load nets displaying significant changes in several parameters, which were not apparent in nets containing a lower loading density. The physiological significance of these results will be considered below.

The third experiment was designed to establish whether there is any advantage, in terms of water quality, in the use of mixed-mesh nets to retain captured fish. Two nets of this type were moderately loaded with fish and monitored for five hours. Overall, DO_2 levels in the bag-like endpiece were reduced compared to those in the upper section, but no differences in total CO_2 were found. Total and unionized NH_3 levels were elevated in both sections of the net and again no statistically significant differences were apparent. Similarly, pH did not differ between the two sections of the net. Other than the modest decline in dissolved oxygen levels noted in the keeper section, the use of a mixed-mesh net appears not to have significant effects on water quality under moderate loading conditions.

Physiological significance of the results

The four chemical parameters chosen as indicators of water quality in this investigation are either essential to sustain life (oxygen), or are known to be potentially damaging to fish when present in the environment in either excessive amounts (ammonia, carbon dioxide) or at extremes of a range (pH). The information available on tolerable limits for these factors for fish is variable, and that concerning each of the four factors will be considered in turn.

Dissolved oxygen. The data in this study have been reported as percent saturation, i.e. the amount of oxygen present expressed as a percentage of the maximum oxygen-carrying capacity of the water, at a given temperature. At the water temperature experienced during the field investigations (16.3°c) the maximum solubility of oxygen in water is 9.9 mg l^{-1} (Mackereth *et al*, 1989). In Experiment 1, dissolved oxygen concentrations were maintained above ~ 9.4 mg l^{-1} (95% satn.) throughout. In Experiment 2, even in the high-load nets, oxygen levels did not drop below ~ 7.9 mg l^{-1} (80% satn.) and in Experiment 3 the lowest oxygen level recorded in the mixed-mesh net was ~ 8.4 mg l^{-1} (85% satn.).

There have been two major reviews of the dissolved oxygen requirements of freshwater fish (Doudoroff & Shumway 1970; Alabaster & Lloyd 1980). Most investigations have established the minimum oxygen level tolerated by the species under study over a prolonged period of time, rather than the effect of an acute reduction in oxygen levels. Therefore estimates within the literature of tolerable minimum levels of dissolved oxygen are likely to be conservative when considered in the context of the effects of keepnet confinement. Doudoroff and Shumway (1970) summarised the data available between 1937 and 1970 on the tolerance of freshwater fish to low oxygen levels. Among the extensive list of species tested were a number of non-salmonid fish native to the UK. Although the reviewers noted that the methodologies in some instances were suspect it was apparent that among non-salmonid fish mortality did not occur until prolonged exposure to dissolved oxygen levels < 5.0 mg l^{-1}. Alabaster and Lloyd (1980) provided a series of tentative minimum dissolved oxygen levels for maintaining fish under otherwise favourable conditions. The criterion of most relevance to the present study is the oxygen level permitting survival of juveniles and adults for 1 day or longer, for which the authors suggested a minimum value of 3.0 mg l^{-1} dissolved oxygen. Based on this criterion the results from Experiments 1 - 3 suggest that the moderate depletion of dissolved oxygen observed within even the heavily loaded keepnet is unlikely to be of physiological significance.

Carbon dioxide. The data for carbon dioxide levels within the nets during the experimental procedures are given as total carbon dioxide; including both dissolved and gaseous carbon dioxide, and dissolved and ionized, carbon dioxide. The only notable change in total carbon dioxide level during these experiments was observed in Experiment 1 in the form of a significant decline in total carbon dioxide levels during the five hour confinement period. If the gaseous portion of the total dissolved carbon dioxide is calculated, carbon dioxide levels in Experiment 1 declined from 1.6 mg l^{-1} to 0.8 mg l^{-1} during the 5-hour experimental period. In Experiment 2 the start and finish values, although not significantly different, were 2.06 and 2.31 mg l^{-1}, and for Experiment 3 were 2.5 and 2.2 mg l^{-1}. Interest in the effects of high carbon dioxide levels on fish has generally arisen from consideration of the effects of pollution by organic matter, the oxidation of which reduces oxygen levels and elevates carbon dioxide concentration. In physiological terms, dissolved carbon dioxide has a direct effect on the oxygen carrying capacity of fish blood; high concentrations of carbon dioxide reduce the affinity of haemoglobin for oxygen (Randall 1970). This is of adaptive physiological significance when the internal environment of the fish is considered, but also means that high environmental carbon dioxide levels may elevate the minimum survivable dissolved oxygen level. Alabaster, Herbert & Hemens (1957) examined the survival of rainbow trout, *Oncorhynchus mykiss* (Walbaum), and perch, *Perca fluviatilis* (L.), at various concentrations of dissolved oxygen and carbon dioxide and found that as carbon dioxide tension increased, survival time at a given dissolved oxygen concentration was reduced. However, fish survived 24 hours exposure to 67 mg l^{-1} dissolved carbon dioxide, even at 40% of the air saturation value for oxygen. Perch were found to be more resistant to elevated carbon dioxide when ambient oxygen levels were low than rainbow trout. Basu (1959) also examined the combinations of dissolved oxygen and carbon dioxide required to bring about asphyxiation, in carp, *Cyprinus carpio* (L.). He estimated that a level of dissolved carbon dioxide >300 mg l^{-1} was required to bring about asphyxiation in carp maintained in water with a dissolved oxygen content of ~ 9.0 mg l^{-1}. In the light of these results, the dissolved carbon dioxide levels of 0.8 - 2.5 mg l^{-1} observed during the present investigation obviously pose no direct threat to the well-being of keepnet-confined fish.

Ammonia. The subject of ammonia toxicity in fish has received considerable attention, largely with respect to intensive fish cultivation systems. Unfortunately, few data are available concerning the effects of ammonia on species other than those of aquacultural importance. Ammonia in solution dissociates reversibly ($NH_3 + H_2O$ _ NH_4^+ + OH) and it is well established that only the unionized component (NH_3) is toxic to fish (Alabaster & Lloyd 1980). Ball (1967) studied the relative toxicity of ammonia to several non-salmonid fish, the bream, *Abramis brama* (L.), perch, roach, and rudd, *Scardinius erythrophthalmus* (L.) and found that the LC50 values (the concentration of ammonia required to kill half of the test fish in a given time period) were between 290 and 410 μg l^{-1} unionized ammonia. These values were derived from exposure times of up to 7 days. When shorter periods of exposure were considered the LC50 values rose considerably. For 7 hours exposure the figure is ~ 1200 μg l^{-1} undissociated ammonia. During a 10 day test period, Flis (1968) observed 16% mortality among carp exposed to unionized ammonia at concentrations of 1300 μg l^{-1}. Alabaster and Lloyd (1980) provide a summary of ammonia toxicity, concluding that levels of unionized ammonia which are toxic for short-term exposure periods lie between 600 μg l^{-1} for perch and 2000 μg l^{-1} for carp and tench with chub, *Leuciscus cephalus* (L.), and minnows, *Phoxinus phoxinus* (L.) being of intermediate sensitivity. Taking into account the possibility of deleterious physiological effects of some sub-lethal concentrations of unionized ammonia they suggested a safe level for prolonged exposure to be ~ 25 μg l^{-1}. Haywood (1983) also reviewed ammonia toxicity in fish and concluded that the maximum acceptable unionized ammonia levels for non-salmonid freshwater fish were in the region of 10 μg l^{-1}. During the present study, the maximum levels of unionized ammonia recorded occurred in Experiment 2, after 5 hours confinement (7.6 μg l^{-1}). During the 5 hour confinement period the overall mean unionized ammonia concentration within the high-load net was 3.9 μg l^{-1}. These figures, although high, are nonetheless lower than the recommended safe levels of unionized ammonia for prolonged exposure cited above (10-25 μg l^{-1}). It therefore seems likely that the accumulation of ammonia within keepnets, under conditions similar to those employed here, need not be considered harmful to the confined fish.

pH. In itself, change in pH within the keepnets during confinement of fish was not expected to be of physiological significance. Under these conditions, the importance of pH lies as a determinant of ammonia dissociation and an influence on the proportion of gaseous, as opposed to ionized, dissolved carbon dioxide. Additionally, the solution of carbon dioxide, as noted above, will lead to a reduction in pH through the formation of carbonic acid. In the present investigation, the only statistically significant changes in pH were in an upward direction and were probably due to the removal of carbon dioxide from the water by photosynthetic algal cells. The pH values observed in this investigation fall well within the safe range described in the EIFAC report on extremes of pH in inland waters (European Inland Fisheries Advisory Commission 1969). The EIFAC report summarised findings on the factors affecting pH and its toxicity to fish and concludes that a pH range of 6.5 - 9.0 is "harmless to fish, although the toxicity of other poisons may be affected by changes within this range". These conclusions are supported by Fromm (1980) who noted that most fish appear to be indifferent to pH within the range of approximately 10.5 - 5.5 in the absence of complicating factors. Thus, it may safely be concluded that, under the conditions employed in this investigation, pH is not a factor affecting fish during keepnet confinement.

Conclusion

In conclusion, this study has demonstrated that the changes in water quality observed during the confinement of freshwater fish in keepnets are of no physiological significance in the short-term, and are unlikely to affect the survival of captive fish, provided the nets are of adequate dimensions and are not overloaded with fish. Even the most pronounced changes in water quality observed in this investigation were well within the published safety limits for long-term, as opposed to acute, exposure of fish, and the loadings employed in this study are unlikely to be exceeded by the majority of anglers. Under circumstances where high catches are expected, for example during matches, the use of multiple keepnets may be advisable. Further work is needed to assess the impact of other factors (physical damage, physiological stress) on the well-being of freshwater fish subjected to capture by angling, and confinement.

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References

Alabaster J. S. & Lloyd R. (1980) *Water Quality Criteria for Freshwater Fish*. Butterworth and Co. London. 297 pp.

Alabaster J. S., Herbert D. W. M. & Hemens J. (1957) The survival of rainbow trout (*Salmo gairdneri* Richardson) and perch (*Perca fluviatilis* L.) at various concentrations of dissolved oxygen and carbon dioxide. *Annals of Applied Biology* **45**, 177-188.

Ball I. R. (1967) The relative susceptibilities of some species of freshwater fish to poisons - I. Ammonia. *Water Research* **1**, 767-775.

Basu S. P. (1959) Active respiration of fish in relation to ambient concentrations of oxygen and carbon dioxide. *Journal of the Fisheries Research Board of Canada* **16**, 175-212.

Black E. C., Fry, F. E. J. & Black, V. S. (1954) The influence of carbon dioxide on the utilization of oxygen by some freshwater fish. *Canadian Journal of Zoology* **32**, 408-420.

Blazka P. (1958) The anaerobic metabolism of fish. *Physiological Zoology* **31**, 117-128.

Doudoroff P. & Shumway D. L. (1970) Dissolved oxygen requirements of freshwater fishes. *FAO Fisheries Technical Paper* 86. 291 pp.

Downing K. M. & Merkens J. C. (1957) The influence of temperature on the survival of several species of fish in low tensions of dissolved oxygen. *Annals of Applied Biology* **45**, 261-267.

European Inland Fisheries Advisory Commission (EIFAC) (1969) Water quality criteria for European freshwater fish - extreme pH values and inland fisheries. *Water Res*earch

3, 593-611.

Flis J. (1968) Anatomicohistopathological changes induced in carp (*Cyprinus carpio*) by ammonia water. *Acta Hydrobiologia* **10**, 205-238.

Fromm P. O. (1980) A review of some physiological and toxicological responses of freshwater fish to acid stress. *Environmental Biology of Fish*es **5**, 79-93.

Haywood G. P. (1983) Ammonia toxicity in teleost fishes: a review. *Canadian Technical Reports in Fisheries and Aquatic Sciences* 1177.

Lozinov A. B. (1952) The reaction of young sturgeons to oxygen deficiency in relation to temperature. *Zoologicheski_ zhurnal* **32**, 686-695. (Russian, cited in Doudoroff and Shumway 1970)

Mackereth F. J. H., Heron J. & Talling J. F. (1989) Water analysis: some revised methods for limnologists. Second Impression. *Freshwater Biological Association Scientific Publication* no. 36. 120 pp.

Moore W. G. (1942) Field studies on the oxygen requirements of certain freshwater fishes. *Ecology* **23**, 319-329.

Privolnev T. I. & Koroleva N.V. (1953) Critical oxygen content of water for fish at different temperatures by season. *Doklady Akademii nauk. SSSR* **89**, 175-176. (Russian, cited in Doudoroff and Shumway 1970)

Randall D. J. (1970) Gas exchange in fish. In: W. S. Hoar & D. J. Randall (eds.) *Fish Physiology. Vol IV,* Academic Press. New York. pp 253-292

Shkorbatov G. L. (1965) Intraspecific variation of oxygen requirements of freshwater fishes. *Gidrobiologicheski_ zhurnal* **1**, 3-8. (Russian, cited by Doudoroff and Shumway 1970).

Tables

Table 1. Experiment 1. Effect of mesh size on within-net water quality. Values for each net type were combined. Significant differences between sites within nets are indicated by asterisks: different from top; ** *P*<0.01, *** *P*<0.001. Each value is the mean ± SEM, n = 36.

Position within net	DO_2 (% satn.)	CO_2 (μE l^{-1})	Unionized NH_3 (μg l^{-1})	pH
Top	98.1 ± 0.4	2124 ± 8	2.5 ± 0.1	8.28 ± 0.02
Middle	98.0 ± 0.4	2109 ± 8	2.8 ± 0.1	8.32 ± 0.02**
Bottom	98.0 ± 0.3	2116 ± 6	2.8 ± 0.2	8.33 ± 0.02***

Table 2. Experiment 2. Effect of loading on within-net water quality. No significant differences between loads were detected for CO_2 therefore values for high and low load nets were combined. Each value is the mean ± SEM, n = 24 for combined data, n = 12 for uncombined data. * denotes significantly different from Top measurement, $P<0.05$.

Determinand	Loading	Position within net		
		Top	Middle	Bottom
DO_2 (% satn.)	High	89.0 ± 0.9	87.3 ± 1.09	85.5 ± 1.75*
	Low	97.8 ± 0.6	98.2 ± 0.9	97.8 ± 0.7
CO_2 (µE l^{-1})	Combined	2115 ± 7.7	2108 ± 7.3	2098 ± 7.3
Un-ionized NH_3 (µg l^{-1})	High	3.4 ±0.7	3.5 ± 0.6	4.7 ± 1.0
	Low	2.8 ± 0.2	2.9 ± 0.3	2.8 ± 0.1
pH	High	8.05 ± 0.01	8.03 ± 0.02	8.02 ± 0.03
	Low	8.37 ± 0.03	8.38 ± 0.03	8.38 ± 0.03

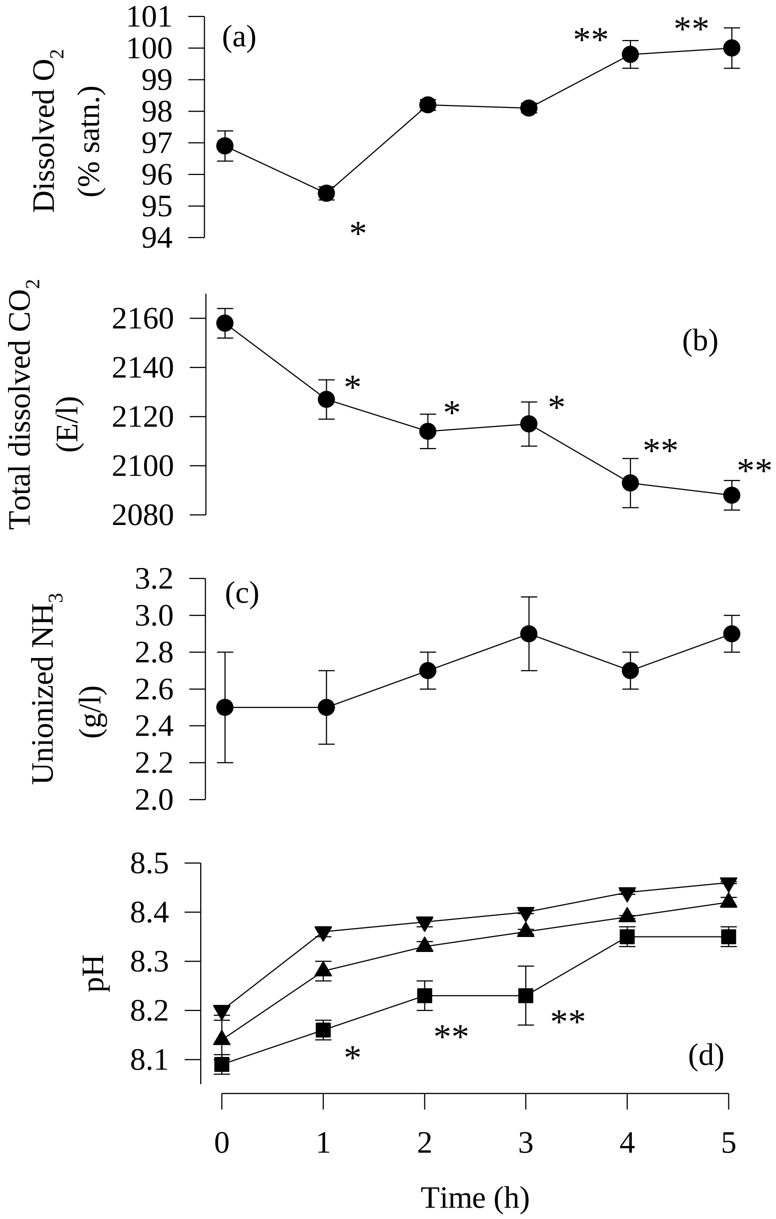

Figure 1. Experiment 1. Effect of mesh size on within-net water quality. Changes in (a) dissolved oxygen, (b) total dissolved carbon dioxide, (c) unionized ammonia, and (d) pH in keepnets with three different sizes of mesh. Because no significant differences were observed between net types for DO_2, total CO_2, or unionized NH_3, the values for the three net types have been combined and plotted as a single mean ± SEM, n = 18. A significant overall difference between mesh types was detected for pH and these data have been plotted separately; ▼ 3-mm mesh; Δ 6-mm mesh; ■ 10-mm mesh, n = 6. All points for each mesh type for pH are significantly different from the corresponding value at time 0 ($P<0.001$ except: * $P<0.05$, ** $P<0.01$.

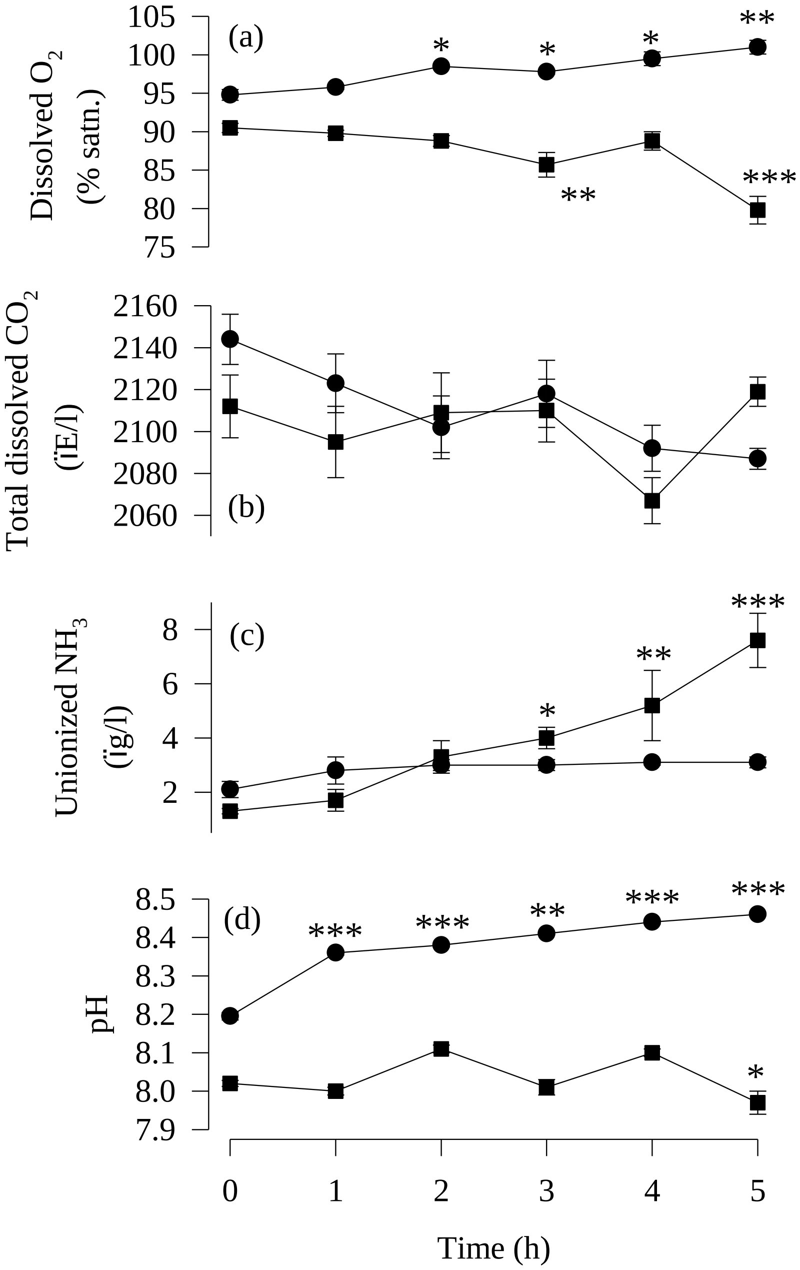

Figure 2. Experiment 2. Effect of loading on within-net water quality. Changes in (a) dissolved oxygen, (b) total dissolved carbon dioxide, (c) unionized ammonia, and (d) pH in 3-mm mesh keepnets containing either a 'moderate' load of fish (●; 13.6 kg, 62 g l^{-1}) or a high load of fish (■; 35 kg, 160g l^{-1}). Significant differences from 0-h *within* loads are indicated by asterisks: * $P<0.05$, ** $P<0.01$, *** $P<0.001$. There were significant differences *between* loads for DO_2 (all time points, $P<0.05$ - $P<0.001$), pH (all time points, $P<0.001$) and unionized NH_3 (5-h, $P<0.01$). These differences are not indicated on the graphs. Each point is the mean ± SEM, n = 6.

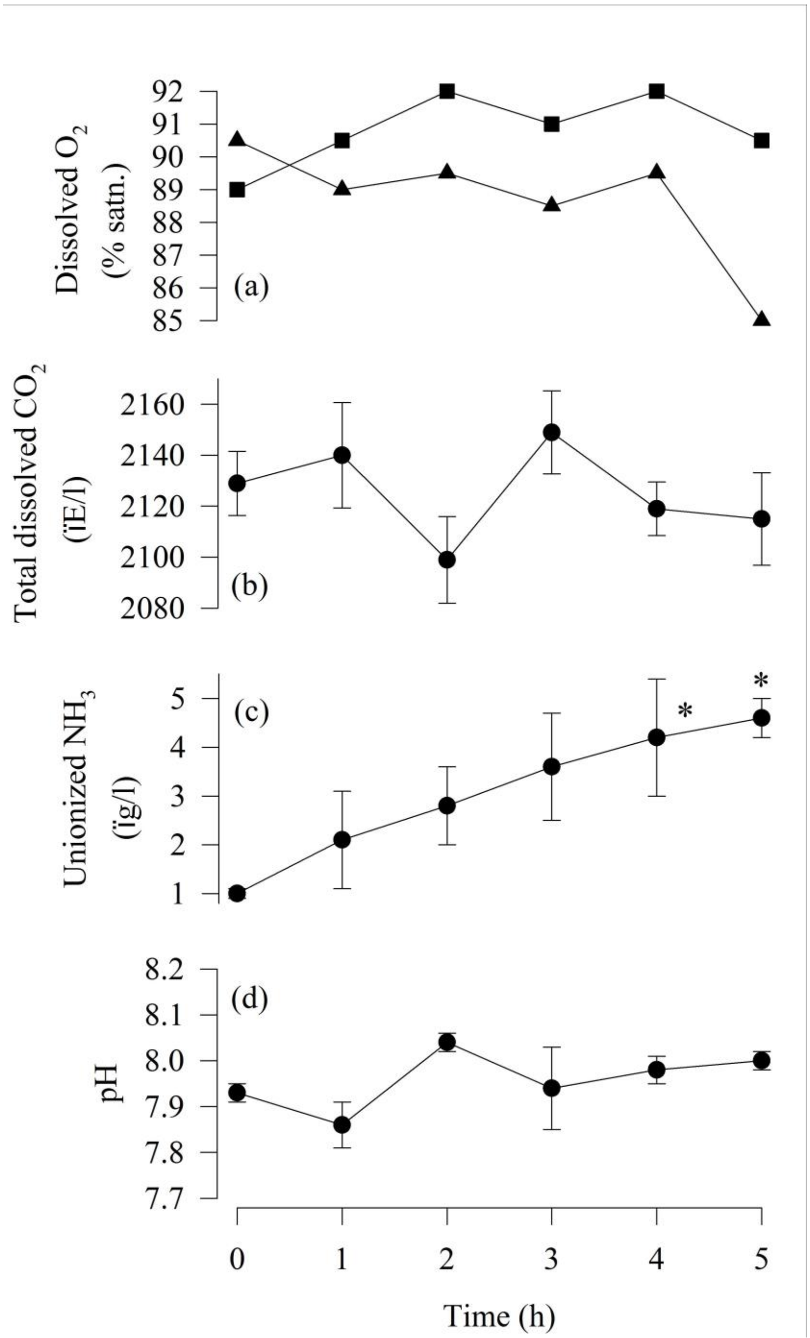

Figure 3. Experiment 3. Effect of mixed-mesh nets on water quality. Changes in (a) dissolved oxygen, (b) total dissolved carbon dioxide, (c) unionized ammonia, and (d) pH in a mixed mesh net. A significant difference overall between the bottom (1-mm mesh) section and middle (3-mm mesh) section was observed only for DO_2 and these data are presented separately (n = 2). Values for the remaining parameters represent the mean of both sections (mean ± SEM, n = 4).