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A commercial trial evaluating three open water sources for farmed ducks: effects on water usage and water quality

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Abstract 1. Providing open water to farmed ducks is beneficial for their health and behaviour but, at commercial densities, may also have negative consequences for the health of the ducks, the productivity of the farms and environmental contamination.

2. The current experiment investigated the suitability of three types of open water resources in a commercial setting, assessing their effects on water usage and water quality. The three resources were: narrow troughs (15 cm wide and 8 cm deep), intermediate troughs (20 cm wide and 12 cm deep) and wide troughs (50 cm wide and 8 cm deep). A total of 23 flocks of ducks with a mean size of 4,540 ± 680 individuals and a final stocking density less than 17 kg/m^2 were studied.

3. Intermediate troughs used twice as much water as narrow troughs and wide troughs. Intermediate troughs had the best microbiological water quality, wide troughs had the worst physical and microbiological quality and narrow troughs tended to be intermediate.

4. Open water provision resulted in high water usage, but this might be reduced by further investigating cleaning regimes, ballcock systems and the volumetric capacity of the troughs. It was difficult to maintain good water quality, and more research is needed to investigate the long term effects on productivity and public health.

INTRODUCTION

From a global perspective, duck meat production is on a relatively large scale. According to FAO statistics (FAOSTATS, 2012; data last updated from 2010) the world's duck meat production has increased from 1946 million birds processed in 2000 to 2708 million in 2010. In the UK, production has dropped from more than 18 million ducks in 2000 to less than 14 million in 2010. However, UK retail sales of duck meat have increased by 6·4% in the last year (Crane *et al.*, 2011) and the price per kilogram of duck meat has increased by more than 85% over the last 10 years. The duck meat retail market is increasing and consumers are willing to pay for this quality product.

Domestic ducks (*Anas platyrhynchos*) are the main species raised for meat production and most of them are Pekin ducks reared in indoor intensive systems. An increasing number of ducks are being reared indoors, due primarily to concerns about water pollution (Lee *et al.*, 1992). The Council of Europe's recommendations (2002) state that farmed ducks should have access to water that is deep enough to at least dip their heads in, and easily accessible open water has proved to be beneficial for the birds' health (Heyn *et al.*, 2006; Jones and Dawkins, 2010; O'Driscoll and Broom, 2011). However, provision of open water for birds housed indoors at commercial densities could also have negative consequences for the ducks' health, the farm's productivity and the environment (Rodenburg

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et al., 2005), as the water sources can become highly contaminated. A wide range of substances can contaminate water (microorganisms, organic minerals, etc.) and changes such as an increased level of suspended solids or an aversive taste, odour or colour can cause animals to modify their water intake.

In recent years, research has been conducted on the effects of open water on the welfare of farmed ducks (Knierim *et al.*, 2004; Jones *et al.*, 2008; Erisir *et al.*, 2009), but few of these studies have focused on the quality of the water being offered. Kuhnt *et al.* (2004) analysed the hygienic consequences of providing open water resources (showers, shallow pools and deep pools) for Muscovy ducks. High bacterial counts were found in both types of pools, but these did not affect the health or performance of the birds. They concluded that showers were more hygienic, but they were scarcely used. Pools, in contrast, were frequently visited, but the authors argued that allowing the birds access to open water resulted in increased labour demands and increased risks to food safety. However, the study was conducted with small groups of ducks which is a significant limitation on the results. It is important to ensure that research is also carried out on a commercial scale, since this provides a very different environment from that of small controlled groups in research facilities (Dawkins *et al.*, 2004).

The aim of this study was to compare the effects of three types of open water resources when introduced into a commercial setting. The effects of the different resources on water usage and water quality were investigated. The three open water resources tested had different dimensions: narrow troughs (15 cm wide and 8 cm deep); intermediate troughs (20 cm wide and 12 cm deep) and wide troughs (50 cm wide and 8 cm deep).

MATERIALS AND METHODS

Animals and treatments

A total of 23 commercial flocks, each containing 3500–5000 ducks, were assessed during this trial: 7 barns contained 3500 birds and the rest contained 5000 ducks. The total number of ducks studied was approximately 105 000. Ducklings (Cherry Valley Pekin type) were brooded and reared under commercial conditions. They were fed a standard commercial duck feed appropriate for their age. Three replications were conducted, with 7 or 8 flocks being sampled each time, during November 2010, March 2011 and June 2011 (total $N = 23$ flocks).

The ducklings were brooded in barns constructed on a concrete floor with forced ventilation, having access to gas heaters until 12 d post-hatch, and were managed on straw litter that was topped up daily. From d 1 post-hatch, ducklings were restricted to a section of the barn where they had access to narrow lip bell drinkers (diameter: 23 cm, height: 12 cm, trough width: 4·5 cm, water depth to lip: 4 cm) and hopper feeders (width: 89 cm, length: 145 cm). At 14 d, the ducklings were provided with access to the entire barn where the same hopper feeders were present and the drinking water was provided in narrow troughs (length: 150 cm, height: 14 cm, width: 15 cm, water depth to lip: 8 cm). At 21 d, the different water resources to be tested were introduced to the barns. The three water resources tested were: a narrow trough, identical to the ones provided from d 14 (water volume: 18 l); an intermediate trough (length: 150 cm, height: 15 cm, width: 20 cm, water depth to lip: 12 cm; water volume: 36 l); or a wide trough (length: 100 cm, height: 15 cm, width: 50 cm, water depth to lip: 8 cm; water volume: 40 l). Treatments were randomly distributed among the flocks and the replications.

The barns had a central straw-bedded area on a solid concrete floor ($42\ \mathrm{m} \times 18\ \mathrm{m} = 756\ \mathrm{m}^2$), as well as grooved concrete ramps down the length of both sides ($42\ \mathrm{m} \times 0{\cdot}40\ \mathrm{m} \times 2$ ramps $= 33{\cdot}6\ \mathrm{m}^2$) leading to raised drainage areas with perforated plastic floors ($42\ \mathrm{m} \times 3{\cdot}00\ \mathrm{m} \times 2$ drainage areas $= 252\ \mathrm{m}^2$). The total floor area per barn was approximately $1040\ \mathrm{m}^2$ and the final stocking density was $15{\cdot}64\ \mathrm{kg/m}^2$ on average during the trial (average slaughter age: 43 ± 3 d, with a target final weight of 3·5 kg). This density was in accordance with the RSPCA Freedom Food standards followed at the commercial facilities tested. The water resources were located on the raised drainage areas of the barns and they were the only water sources available to the birds. They were individually connected to the mains water supply and were self-filling, with the water level controlled by ballcocks. The total space allowance around the perimeter of the water resources was 7 mm per bird for all treatments. The water resources were emptied, cleaned and refilled twice a day, in the morning and the afternoon, during the routine checks made on the flocks.

Water usage

Water meters (Beta30 meter, Obart Pumps Ltd, Kent, UK) were fitted into the pipes entering the barns to quantify water usage. Readings were taken on d 21, 28 and 35 post-hatch after the morning cleaning of the troughs (corresponding to 0, 1 and 2 weeks after the introduction of the test troughs). Readings were also recorded on the day of slaughter, after depopulation.

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Average daily water expenditure was calculated per duck per d for the period between introduction of the treatments (d 21) and slaughter.

Water quality

The water contained in the different open water resources was tested on d 21, 28 and 35 post-hatch. One trough was randomly selected per barn and water samples were collected at intervals to assess water quality and its rate of change. The first sample was collected before the morning cleaning of the troughs at 0800 (16 h after the last cleaning at 1600 on the previous day) and then 1 h, 3 h and 6 h after the morning cleaning. Three samples were taken at each collection time: in a 1 l glass jar to assess the physical water quality and in two 10 ml plastic tubes to perform various chemical and microbiological analyses.

Physical quality

A multi-probe (Aquaprobe AP-600, Aquaread Ltd., Kent, UK) fitted to a meter (Aquameter AM-200, Aquaread Ltd., Kent, UK) was immersed in the water collected in the glass jar to assess the physical quality of the water. The measurements taken with the multi-probe were: pH (indicator of water corrosivity, implications for facilities maintenance), temperature (°C); direct implications for duck behaviour (Liste *et al*., 2012*a*) and bacterial growth, dissolved oxygen (%; indicator of water suitability for the growth of different microorganisms), turbidity (NTU; mostly linked to faecal matter in the current context, implications for facilities disinfection), electrical conductivity (μS/cm; indicator of dissolved substances in the water), total dissolved solids (mg/l; mostly linked to faecal matter in the current context, implications for facilities maintenance), barometric pressure (mb; little fluctuation in the current context, affects the oxygen carrying capacity of the water) and salinity (PSU; indicator of salt and mineral contents, implications for duck health and production). The probe was calibrated every morning before the first readings were taken. It was then immersed in the sample and readings were recorded when steady measures had been reached. The probe was cleaned and rinsed with deionised water between readings.

Chemical quality

A 10 ml test tube was filled with sample water to assess chemical quality. Three tests were performed using reagents from Wagtech (Wagtech WTD, Tyne and Wear, UK). A portable Photometer 7100 from the same company was used to calculate the concentration of nitrates, nitrites and ammonia (mg of nitrogen per litre).

Microbiological quality

A sterile 10 ml test tube was filled with sample water and 0·1 g of sodium thiosulphate was added to avoid any effects of the water's chlorine on bacterial growth. Samples were kept refrigerated with ice packs inside a sealed Styrofoam box until arrival at the laboratory on the same day as they were collected. Once at the laboratory, samples were kept in a refrigerator at a constant temperature of 4°C overnight. The next morning they were processed with a Quanti-Tray® system (Quanti-Tray/2000, Idexx Laboratories Ltd., Chalfont St. Peter, UK) with Colilert reagent, to detect and quantify total coliforms and *E. coli* as indicators of faecal contamination, and with Enterolert reagent to detect and quantify enterococci levels. Samples were incubated at 36°C for 24 h and results were read by changes in colour or fluorescence.

Statistical analysis

Data were analysed using PASWStatistics18 software and the effects of treatment (3 levels), age (3 levels), testing time (4 levels) and replicate (3 levels) were calculated. Prior to analysis, all data were checked for normality by examination of histograms and normal distribution plots. Kolmogorov-Smirnov and Levene's test were also performed to assess normality and homogeneity of variance assumptions.

For the water usage analysis, a one way ANOVA was performed with treatment as the only fixed effect. The measurements of physical quality were analysed with a mixed multivariate ANOVA model which included age and testing time as repeated measures and treatment and replication as between-subjects effects. The same model was applied to the chemical quality measures, but a log transformation was needed to meet the assumptions of parametric statistics. For ease of interpretation, the results are presented as raw data. Microbiological measures did not fit parametric assumptions and non-parametric tests were used. Data were analysed for the effects of treatment and replication with Kruskal-Wallis tests and for the effects of age and treatment with Friedman's test. When significant effects were found, planned pairwise comparisons were performed using Mann-Whitney tests.

RESULTS

Water usage

Results are presented in Table 1 and show that intermediate troughs used significantly more

Table 1. *Mean ± SD of the volume of water used per duck per day for different open water resources. (Means with different superscripts are different at* $P < 0\cdot001$*).*

Trough width	*N*	Water usage/duck/day (l)
Narrow	8	$1\cdot7 \pm 0\cdot3^{a}$
Intermediate	7	$3\cdot3 \pm 0\cdot9^{b}$
Wide	8	$1\cdot5 \pm 0\cdot7^{a}$
All	23	$2\cdot1 \pm 1\cdot0$

water than narrow troughs and wide troughs. The water usage per duck was calculated based on the number of ducks slaughtered per barn. The usage per day was calculated from 21 d post-hatch (introduction of treatments) to slaughter, with a range of 18 to 28 d overall. These results translate into a water usage ranging from 27 to 92 l per duck, depending on the length of the production cycle and the type of trough being used, with consumption increasing as ducks aged.

Water quality: physical

The physical measures assessed in this study were strongly related to the presence of solid matter in the water, which consisted primarily of faecal matter. This relationship was assessed by bivariate correlations (Pearson's) between the level of total dissolved solids present in the samples and the other physical measurements. There were positive correlations for turbidity, conductivity and salinity (higher values of total dissolved solids meant higher values of turbidity $r = 0\cdot61$, conductivity $r = 0\cdot95$ and salinity $r = 0\cdot99$, all $P \leq 0\cdot001$) and negative correlations for pH, temperature and dissolved oxygen (higher values of total dissolved solids meant lower values of pH $r = -0\cdot24$, temperature $r = 0\cdot48$ and dissolved oxygen $r = -0\cdot64$, all $P \leq 0\cdot001$). Also, water temperature was strongly affected by ambient air temperature and the volume of water in the different resources tested (Liste *et al.*, 2012*a*).

Treatment had a significant effect on the levels of electrical conductivity ($F(2,8) = 13\cdot06$, $P < 0\cdot01$), dissolved oxygen, turbidity, dissolved solids, pressure and salinity (dissolved oxygen $F(2,8) = 28\cdot55$, turbidity $F(2,8) = 16\cdot25$, dissolved solids $F(2,8) = 19\cdot43$, pressure $F(2,8) = 20\cdot62$, salinity $F(2,8) = 21\cdot37$, all $P \leq 0\cdot001$), but it did not affect pH or temperature (Table 2). Overall, wide troughs presented the worst values for most of the variables, including the percentage of dissolved solids, dissolved oxygen, conductivity, and salinity, although narrow troughs showed equally poor values for turbidity. The narrow and intermediate troughs were similar for all measures except turbidity.

Table 2. *Mean ± SD for the effect of treatment on the physical quality of the water. (Means with different superscripts are different: ab,* $P < 0\cdot001$*; cd,* $P < 0\cdot01$*).*

Physical quality	Trough width		
	Narrow	Intermediate	Wide trough
pH	$7\cdot7 \pm 0\cdot1$	$7\cdot7 \pm 0\cdot1$	$7\cdot8 \pm 0\cdot1$
Temperature (°C)	$14\cdot6 \pm 2\cdot9$	$13\cdot7 \pm 2\cdot4$	$13\cdot3 \pm 3\cdot5$
Dissolved oxygen (%)	$44\cdot0 \pm 8\cdot6^{a}$	$51\cdot3 \pm 8\cdot7^{a}$	$36\cdot2 \pm 17\cdot8^{b}$
Turbidity (NTU)	539 ± 252^{a}	372 ± 232^{b}	598 ± 296^{a}
Electrical conductivity (μS/cm)	871 ± 120^{c}	847 ± 119^{c}	970 ± 176^{d}
Total dissolved solids (mg/l)	570 ± 66^{a}	553 ± 75^{a}	630 ± 115^{b}
Pressure (mb)	1010 ± 15^{a}	1007 ± 15^{a}	1012 ± 9^{b}
Salinity (PSU)	$0\cdot44 \pm 0\cdot05^{a}$	$0\cdot42 \pm 0\cdot06^{a}$	$0\cdot48 \pm 0\cdot09^{b}$

Testing time significantly affected all physical measures with the exception of conductivity and pressure (Figure 1) with the values of dissolved solids, dissolved oxygen, turbidity and pH worsening as time from last cleaning increased. Age affected pH ($F(2,16) = 20\cdot61$, $P < 0\cdot001$), turbidity ($F(2,16) = 5\cdot01$, $P < 0\cdot05$), total dissolved solids ($F(2,16) = 5\cdot85$, $P < 0\cdot05$) and salinity ($F(2,16) = 6\cdot03$, $P < 0\cdot04$), as shown in Table 3. Replication had a significant effect on all physical water quality measures with the exception of conductivity (Table 3).

To account for seasonal differences between replications, correlations were calculated between the water temperature and the rest of the physical measures, and these were significant in all cases ($P \leq 0\cdot001$). The levels of dissolved oxygen and pH were significantly lower when temperature was higher, while turbidity, conductivity, dissolved solids, pressure and salinity levels increased as the water temperature increased.

Water quality: chemical

Treatment had a significant effect on the concentration of nitrates ($F(2,8) = 5\cdot86$, $P < 0\cdot05$) and ammonia ($F(2,8) = 17\cdot86$, $P < 0\cdot001$), but did not affect the concentration of nitrites (Table 4). Intermediate troughs had better water quality than wide troughs with regard to the concentration of nitrates present, whereas intermediate and wide troughs presented similar levels of ammonia and both were better in this respect than narrow troughs. The testing time also significantly affected the concentration of nitrates ($F(3,24) = 12\cdot13$, $P < 0\cdot01$) and ammonia ($F(3,24) = 10\cdot73$, $P < 0\cdot001$) as shown in Table 4. The concentration of nitrates and ammonia gradually increased with time from last cleaning up to 6 h, but at 16 h the water returned to levels close to the initial values. Age did not affect any of the measures analysed with the exception of

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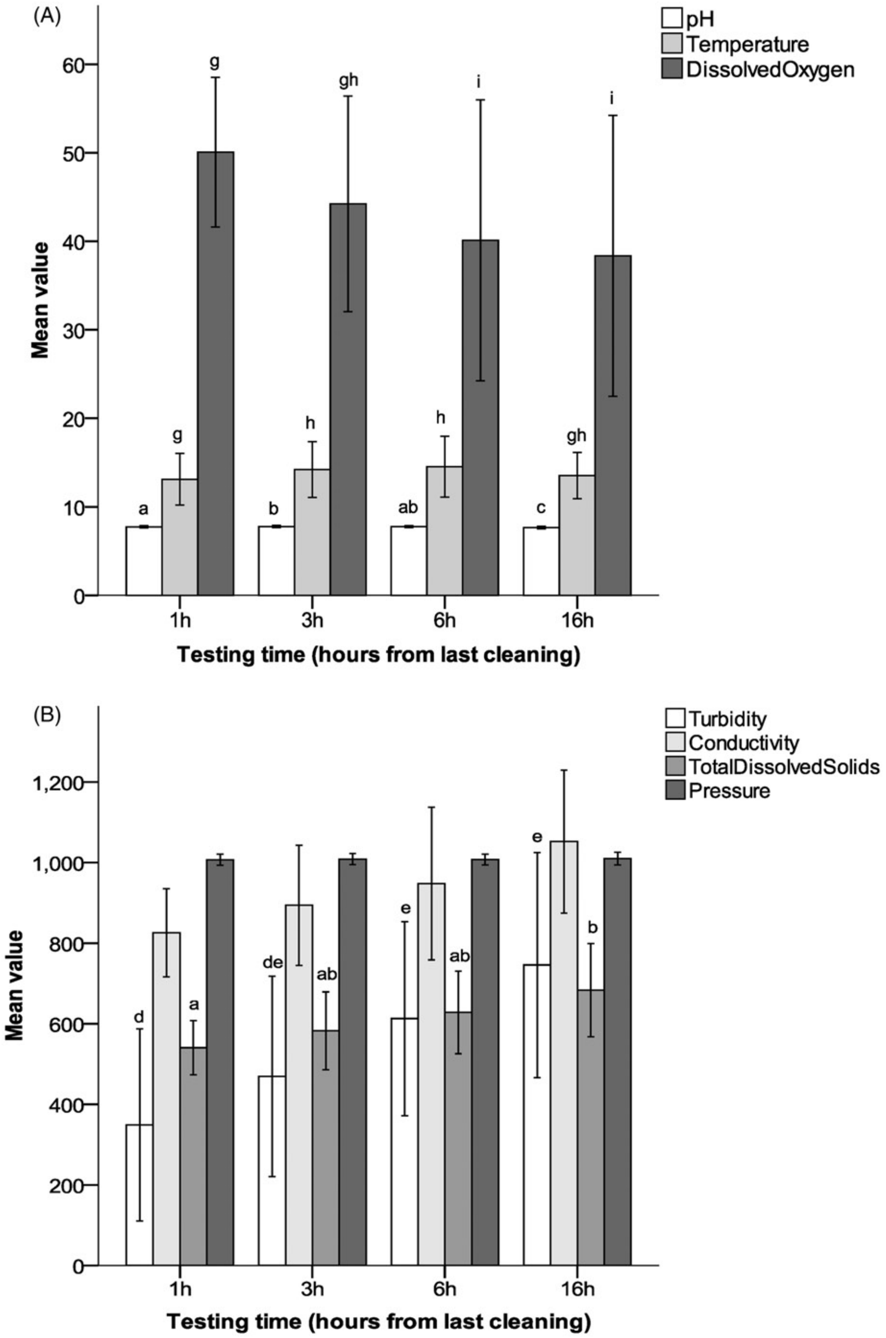

Figure 1. *Effect of testing time on the physical quality of the water. A: pH, temperature and dissolved oxygen. B: turbidity, conductivity, total dissolved solids and pressure. Data are shown as mean ± SD (bars not having the same letter are different: abc,* $P < 0{\cdot}001$*; de,* $P < 0{\cdot}01$*; ghi,* $P < 0{\cdot}05$*).*

Table 3. *Mean ± SD for the effect of replication and age on the physical quality of the water. (Means with different superscripts are different: ab,* $P < 0{\cdot}001$*; cd,* $P < 0{\cdot}01$*; ef,* $P < 0{\cdot}05$*).*

	Replication			Age		
Physical quality	1st (Nov.)	2nd (March)	3rd (June)	21 days	28 days	35 days
pH	$7{\cdot}8 \pm 0{\cdot}1^{e}$	$7{\cdot}8 \pm 0{\cdot}1^{e}$	$7{\cdot}6 \pm 0{\cdot}1^{f}$	$7{\cdot}6 \pm 0{\cdot}1^{a}$	$7{\cdot}8 \pm 0{\cdot}1^{b}$	$7{\cdot}8 \pm 0{\cdot}1^{b}$
Temperature (°C)	$10{\cdot}3 \pm 2{\cdot}0^{e}$	$14{\cdot}2 \pm 2{\cdot}0^{f}$	$16{\cdot}3 \pm 1{\cdot}7^{f}$	$13{\cdot}6 \pm 1{\cdot}9$	$14{\cdot}1 \pm 3{\cdot}0$	$13{\cdot}8 \pm 4{\cdot}0$
Dissolved oxygen (%)	$51{\cdot}2 \pm 9{\cdot}7^{c}$	$40{\cdot}9 \pm 13{\cdot}6^{d}$	$39{\cdot}6 \pm 14{\cdot}8^{d}$	$43{\cdot}1 \pm 8{\cdot}9$	$43{\cdot}2 \pm 15{\cdot}5$	$44{\cdot}0 \pm 16{\cdot}9$
Turbidity (NTU)	440 ± 237^{a}	400 ± 281^{a}	686 ± 223^{b}	438 ± 282^{e}	513 ± 298^{ef}	569 ± 259^{f}
Electrical conductivity (μS/cm)	830 ± 102	876 ± 170	973 ± 131	894 ± 129	872 ± 152	931 ± 167
Total dissolved solids (mg/l)	542 ± 67^{c}	573 ± 104^{c}	634 ± 82^{d}	582 ± 82^{e}	567 ± 99^{e}	612 ± 97^{f}
Pressure (mb)	999 ± 13^{a}	1015 ± 10^{b}	1013 ± 11^{b}	1010 ± 18	1011 ± 11	$1008 \pm 8{\cdot}6$
Salinity (PSU)	$0{\cdot}41 \pm 0{\cdot}05^{c}$	$0{\cdot}44 \pm 0{\cdot}08^{cd}$	$0{\cdot}48 \pm 0{\cdot}06^{d}$	$0{\cdot}44 \pm 0{\cdot}06^{e}$	$0{\cdot}43 \pm 0{\cdot}08^{e}$	$0{\cdot}47 \pm 0{\cdot}07^{f}$

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Table 4. *Mean ± SD for the effect of treatment, replication, age and testing time on the chemical quality of the water. (Means with different superscripts are different: ab,* $P < 0{\cdot}001$*; cd,* $P < 0{\cdot}05$*; ef,* $P < 0{\cdot}01$*).*

Effect	Treatment	Nitrates (mg N/l)	Nitrites (mg N/l)	Ammonia (mg N/l)
Trough	Narrow	9·3 ± 5·0^{cd}	0·40 ± 0·46	53 ± 66^{a}
	Intermediate	7·9 ± 4·6^{c}	0·30 ± 0·36	38 ± 55^{b}
	Wide	10·4 ± 5·4 ^{d}	0·52 ± 0·43	36 ± 53^{b}
Replication	1st (Nov.)	8·9 ± 5·3	0·47 ± 0·34^{c}	17 ± 19^{c}
	2nd (March)	11·2 ± 5·0	0·42 ± 0·54^{cd}	34 ± 49^{d}
	3rd (June)	7·5 ± 4·4	0·37 ± 0·36^{d}	70 ± 75^{d}
Age (days)	21	10·0 ± 4·9	0·31 ± 0·27	24 ± 39^{c}
	28	9·1 ± 5·4	0·49 ± 0·45	57 ± 68^{d}
	35	8·6 ± 5·0	0·45 ± 0·52	45 ± 61^{cd}
Testing time	1 h	8·3 ± 4·5^{e}	0·24 ± 0·24	36 ± 52^{a}
	3 h	9·1 ± 5·0^{ef}	0·46 ± 0·52	47 ± 65^{ab}
	6 h	11·4 ± 5·1^{f}	0·47 ± 0·32	62 ± 70^{b}
	16 h	8·0 ± 5·1^{e}	0·49 ± 0·53	19 ± 29^{a}

Table 5. *Effect of treatment, replication, age and testing time on the microbiological quality of the water. Data, in millions of colonies per 100 ml of water sample, are shown as median and inter-quartile ranges (values with different superscripts are different: abc,* $P < 0{\cdot}001$*; de,* $P < 0{\cdot}01$*).*

Effect	Treatment	Enterococci	Total coliforms	*E. coli*
Trough	Narrow	5·2 (7·8)^{a}	3·3 (5·7)^{a}	0·78 (1·44)^{a}
	Intermediate	2·5 (3·3)^{b}	1·9 (3·3)^{b}	0·58 (8·38)^{b}
	Wide	5·2 (8·9)^{a}	4·5 (8·1)^{a}	1·03 (2·61)^{c}
Replication	1st (Nov.)	2·9 (3·9)^{a}	4·1 (3·7)^{a}	0·48 (0·68)^{a}
	2nd (March)	4·3 (6·2)^{b}	2·5 (4·2)^{b}	0·85 (1·69)^{b}
	3rd (June)	6·2 (1·1)^{b}	3·3 (6·4)^{b}	1·05 (1·94)^{b}
Age (days)	21	5·7 (1·2)^{d}	2·6 (3·6)^{a}	0·92 (1·56)^{a}
	28	4·7 (9·2)^{d}	7·2 (3·2)^{b}	1·13 (2·27)^{a}
	35	3·2 (3·2)^{e}	1·9 (2·8)^{a}	0·46 (0·55)^{b}
Testing time	1 h	2·8 (4·5)^{a}	1·9 (4·0)^{a}	0·41 (0·73)^{a}
	3 h	4·4 (4·5)^{b}	3·3 (6·5)^{a}	0·78 (1·79)^{b}
	6 h	4·6 (8·8)^{b}	3·1 (4·8)^{a}	0·77 (1·48)^{b}
	16 h	6·7 (2·1)^{c}	4·7 (1·7)^{b}	1·03 (2·72)^{c}

concentration of ammonia, with concentrations being significantly lower at 21 d post-hatch than on d 28, and levels at 35 d being intermediate. Replication affected the concentration of nitrites ($F(2, 8) = 4{\cdot}50$, $P < 0{\cdot}05$) and ammonia ($F(2, 8) = 7{\cdot}70$, $P < 0{\cdot}05$), with nitrite values being higher in the 1st replication than in the 3rd, and ammonia levels being lowest in the 1st replication (Table 4). No correlation between concentration of nitrites and temperature could be found. However, temperature was positively correlated with the concentration of ammonia ($P \leq 0{\cdot}001$).

Water quality: microbiological

All independent variables assessed had a significant effect on the microbiological data collected, as shown in Table 5. Narrow troughs and wide troughs contained significantly higher levels of enterococci and total coliforms than intermediate troughs, while wide troughs showed the highest levels for *E. coli*. Intermediate troughs had the least contaminated samples for all measurements assessed. Both enterococci and *E. coli* levels were positively correlated with water temperature ($P \leq 0{\cdot}001$). However, total coliform levels were not correlated with temperature differences.

Age significantly affected all microbiological measures assessed. Levels of enterococci decreased with age, but total coliforms and *E. coli* fluctuated during the course of the production cycle, with the lowest levels occurring at 35 d of age. The testing time affected all the microbiological measures with a significant increase in all the bacterial counts when 16 h had passed since the last cleaning of the water resources.

DISCUSSION

Intermediate troughs used significantly more water than narrow and wide troughs, while narrow troughs and wide troughs had a similar level of water usage. Several aspects of the design

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of the water resources are likely to have been relevant. One factor is the volume of water available in the different open water sources at any given time. DEFRA (2007) states that there must be a space of at least 5 mm per duck at the perimeter of the water resource. During the current study, space allowance at the perimeter was the same for all resources, at 7 mm per duck. However, the different dimensions and depths of the water resources tested resulted in very different volumetric water availabilities in each treatment. The average amount of water allocated at any given time to each duck reared with narrow troughs was 42·4 ml, whilst ducks with intermediate troughs had 80·3 ml and those with wide troughs had 112·9 ml. This must have affected the water usage at the different resources, but does not fully explain why twice as much water was used with intermediate troughs compared to narrow and wide troughs. Another factor to take into consideration is the ballcock system. The narrow troughs used in this study had an exposed ballcock, not protected by a servicing box, as is common in this type of resource, because of its small size. This caused repeated overflowing of the troughs because ducks frequently pecked at, or sometimes perched on, the ballcock and it could explain why the narrow troughs showed less efficient water management than expected from their volumetric size. The distance from the water surface to the lip of the trough should also be considered. In the current study, intermediate troughs had the smallest distance (3 cm) and wide troughs had the highest (7 cm) and this was clearly reflected in their water usage efficiency. All these factors, in conjunction with the ease of access for ducks into the different types of troughs (e.g. accessibility was easier in wide troughs, because of its width and the greater space for the ducks to manoeuvre, than in narrow troughs), also have implications for the quality of the water and affect the environmental impact of the open water resources.

The water usage when providing different water resources for ducks and the effect of restricting access time on water expenditure have previously been investigated. Heyn *et al.* (2006) studied small groups of Pekin ducks with access to bell drinkers, showers or troughs, in the presence of nipple drinkers. Access to the open water was either continual, or restricted to 8, 4 or 2 h per d. All the water resources tested used at least twice as much water as nipple drinkers, but this difference was significantly reduced when access was restricted to 4 h per d or less. Although restriction of open water access might seem desirable to save on water costs, the benefits to the health and behaviour of the ducks might be compromised with restrictive regimes. The ducks persisted in their use of the open water resources when access was restricted, with the nipple drinkers accounting for only 35% of total daily water usage when they had access to the open water for 4 h per d, suggesting that open water sources were of some value to the ducks. Heyn *et al.* (2006) concluded that open water has positive effects on the health and behaviour of farmed ducks but that economic assessments and water quality assessments are necessary to study its viability at the commercial level. De Buisonje and Kiezebrink (1999) also found that expenditure on water was doubled when comparing open water resources to nipple drinkers. Waste production was increased by 100%, due to spoilage of clean water and an increased volume of manure production, and this led to poor litter quality. However, the location and management of the open water resources in this study were not clearly reported. Damme *et al.* (2010) tested a novel open water resource, modified-round drinkers, provided directly over straw bedding in comparison with nipple drinkers. Access was restricted to 6 h per d but they still concluded that this novel option was uneconomical because of higher water consumption, higher demand for straw, increased slurry production and a greater workload (twice as much bedding was required, as well as daily cleaning of modified-round drinkers). In view of the problems that have been reported with wet litter (De Buisonje and Kiezebring, 1999; O'Driscoll and Broom, 2011) and the need to provide more litter (Damme *et al.*, 2010), the current authors strongly advise against placing open water sources directly over straw bedding. Knierim *et al.* (2004) described equipment that allowed the continuous cleaning of bathing troughs and reported a satisfactory hygienic quality of the water. However, water loss during the cleaning process was considerable, and labour costs were significantly increased (Rodenburg *et al.*, 2005).

In the present study, water quality was assessed from three perspectives (physical, chemical and microbiological) in a commercial environment. It is difficult to decide on a set of maximal values beyond which the water should be considered too dirty and where duck health and production could be compromised. Most of the values reported in the present study are much higher than those recommended for duck drinking water, although no legal requirements for water quality have been specified to date.

The physical quality of the water measured in the current study showed that wide troughs had the worst quality, with intermediate troughs being the best with respect to turbidity and similar to narrow troughs in other respects. This was probably due to the resources' design, dimensions and volumetric usage. The turbidity

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and amount of dissolved solids also worsened with the age of the birds, which means that older ducks were using poorer quality water. This quality decline may be explained by the fact that as ducks grew they produced more faeces, while the volume of water available was constant throughout the production cycle. Poor physical water quality may not necessarily have direct negative effects on duck health, but pH could affect taste (Oram *et al.*, n.d.). High levels of turbidity can interfere with disinfection, affecting maintenance efficiency and costs, and solid particles provide a medium for microbial growth (Oram *et al.*, n.d.). In the current study, ambient temperature had a significant effect on physical measures of water quality. Temperature is likely to have influenced the level of trough use, which would be expected to be greater in warmer conditions, resulting in increased soiling of the water. Temperature also regulates the maximum % of dissolved oxygen in water and influences the rate of chemical and biological reactions that could have a direct impact on microbiological quality (Oram *et al.*, n.d.).

Nitrogen in the form of nitrate is not especially toxic, except for ruminants, and less than 100 mg/l of nitrates is not expected to harm poultry (Pfost and Fulhage, 2001). Nevertheless, more than 300 mg/l should be avoided because this contributes significantly to the salt content of the water. On the other hand, water should never contain more than 50 mg/l of nitrites because of their greater toxicity (Pfost and Fulhage, 2001). Ammonia occurs as a breakdown product of nitrogenous material in water, and it is harmful to fish and other forms of aquatic life, so ammonia concentrations are a good indicator of environmental impact. In the current study the concentrations of nitrogen derivatives in all types of troughs were within the general recommended limits.

The levels of enterococci, total coliforms and *E. coli* were lowest in the intermediate troughs. The narrow and wide troughs had similar levels of enterococci and total coliforms, while *E. coli* levels were higher in the wide troughs. These findings might be explained in terms of the water volumes available and the ease of full body access to the different type of troughs (easier in wider troughs than in narrower ones). Overall, these levels of bacteria were higher than any reference data found in the literature, but they did not affect the ducks' health (Liste *et al.*, 2012*b*). Nevertheless, consideration should be given to the potential negative effects of high bacterial counts in the drinking water if a disease were to break out and the animals were immuno-compromised. There could also be potential risks for human health, because these high bacterial counts could result in higher carcass contamination levels during processing. The US Environmental Protection Agency (1979) recommends that livestock water should contain less than 5000 coliforms per 100 ml, and that faecal coliforms should be near zero. Coliforms are usually not pathogenic organisms, and only mildly infectious, but if large numbers are found in water there is an increased probability that other pathogenic organisms, such as *Giardia* and *Cryptosporidium* may be present. This is less likely in indoor production systems, where external contamination is controlled, but most institutions recommend a low level of total coliforms per 100 ml of water sample (Oram *et al.*, n.d.).

Knierim *et al.* (2004) compared the microbiological contamination of water from nipple drinkers, showers, narrow and wide bell drinkers, shallow pools and deep pools. They found low levels of total bacteria and enterobacteria in nipple drinkers and showers, but very high contamination in all other water resources with similar values to the ones found in the current study. They recommended recycling or depurative systems to help minimise the environmental impact and reduce hygiene risks, and stressed the importance of drinker location to avoid excessive contamination of the water or poor bedding conditions. The economic viability of these systems at a commercial level was also questioned. From the results of the current study, it could be suggested that a 16 h interval between cleaning open water resources is too long with regard to the microbiological quality of the water, and that a significant improvement could be achieved if troughs were cleaned more often than this (somewhere between 6 and 16 h).

Jones and Dawkins (2010) analysed environmental conditions on duck farms in the UK and concluded that controlling temperature, humidity, litter moisture and ammonia is crucial to duck welfare and productivity, but water quality was not considered. Effective ventilation systems, high quality straw and access to some form of open water are considered key points for duck welfare, but more research is needed to address the poor water quality found in open water resources provided in commercial conditions. Hygienic and health risks due to high microbiological contamination need to be addressed, and the possible negative effects of poor physical quality (such as high turbidity or salinity) on the ducks' drinking habits should be considered.

In conclusion, the provision of open water resources on a commercial scale resulted in high water usage in all cases, especially when using intermediate troughs, and attention should be paid to the dimensions of the resource, the ballcock system and the cleaning regime to minimise this. It seems difficult to maintain good water quality when using open water resources at commercial densities, and more research should be conducted to investigate the long term effects on productivity and public health.

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