Association of Port Health Authorities/Health Protection Agency Collaborative Study: The Microbiological Quality of Water on Board Ships

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Summary

Providing safe potable water onboard vessels presents particular challenges with the potential for contamination at various points in the water supply chain; directly from source waters which may be of varying quality, as well as during loading, storage and distribution. The aim of this collaborative study was to assess the microbiological quality of potable and pool water onboard ships docking in the UK and Channel Islands and to inform a review of the current *Guidelines for Water Quality On Board Merchant Ships Including Passenger Vessels.* Between May and October 2005, 950 potable water samples and 48 pool water samples were collected from 342 ships, and analysed according to recommended microbiological criteria. Standard questionnaires were completed to provide details of the water supply, treatment, loading, storage and monitoring practices. Logistic regression analyses were used to identify parameters associated with microbiological water quality.

Based on the current Guidelines, 9% (79/918) of potable water samples contained coliforms, *E. coli* or enterococci and did not meet the accepted water quality criteria with 2.8% (26/918) showing evidence of faecal contamination (*E. coli* or enterococci present). Action levels of Aerobic Colony Count (ACC) bacteria (≥1000/ml) were also detected in 20% (22°C for 68±4 hours) and 21.5% (37°C for 44±4 hours) of potable water samples. Good hygiene practices had a protective effect against microbial contamination in potable supplies: good hose hygiene (ships owning hoses, storing hoses in dedicated lockers, and disinfecting hoses & couplings before use), processing water onboard and maintaining the minimum recommended free chlorine residual (≥0.2mg/l). Conversely, microbiological water quality of potable water declined with ship's age. Three (of 46) pool water samples contained coliforms and three (of 47) contained action levels of *Pseudomonas aeruginosa*. Four (of 24) spa pool samples had action levels of ACC but no samples contained action levels of *Legionella* spp.

This study emphasizes the importance of maintaining good hygiene standards throughout the potable water loading process and ensuring sufficient residual disinfection of the supply. The findings have also identified a beneficial effect on microbiological water quality of processing potable water onboard ships; further research into the impact of individual methods on potable water generation and treatment on board ships would elucidate which techniques are most appropriate for use on ships.

This study yielded a high proportion of potable water 'failures' according to ACC levels. Whilst there is no evidence of any adverse health effects due to ACC exposure through drinking water, an ACC above expected levels can indicate inadequate potable water treatment or post treatment re-growth or contamination. However, since sampling is undertaken on a one-off basis when a vessel is in port, port health authorities are not able to monitor ACC trends on ships. A more appropriate approach is therefore needed.

It is recommended that vessels adopt the Water Safety Plan approach, in accordance with WHO guidelines, to identify potential contamination points in potable water supplies, to implement and manage appropriate control measures, whilst continuing to monitor water quality with public health-based indicators (i.e. coliforms, *E. coli* and enterococci).

Introduction

The nature of water supplies on board ships presents particular challenges to the provision of safe, potable water. Supplies intended for drinking, food preparation, washing and bathing can potentially become contaminated at a variety of stages, directly from source waters as well as during loading, storage and distribution. Complex distribution networks require specialised design to prevent contamination from proximate non-potable supplies or sea water. Safe water and sanitation are essential to the health of passengers and crew, a rapidly growing population as cruise ship holidays become increasingly popular.

Outbreaks of human illness associated with ships' water supplies are well described[1-8] and have affected naval, cargo and cruise vessels. In addition to posing a considerable public health threat, ship-associated outbreaks have incurred substantial financial and legal costs as well as attracting negative media coverage[9-11]. A recent World Health Organization (WHO) review implicated waterborne transmission in approximately one-fifth of outbreaks occurring aboard vessels between 1970 and 2000[12]. Twenty-one outbreaks linked to water ingestion affected almost 6500 passengers and crew members. A range of improper practices were implicated relating to loading, storage, repairs, cross-connection between potable and non-potable water and insufficient residual disinfection of potable water supplies. Fifty-five incidents (outbreaks or cases) of Legionnaires' disease have also been linked to ships between 1970 and 2004, involving almost 200 cases and resulting in 11 deaths[12-14]. Some of these incidents have been linked to ship's water systems, air-conditioning and recreational spa pools[12;14]. Acquired via inhalation of water aerosols containing *Legionella pneumophila* bacteria, Legionnaires' disease is a rare form of pneumonia with a fatality rate of approximately 8% in Europe, for which risk factors include older age, underlying disease, smoking and alcoholism[15].

Outbreaks on board ships can largely be avoided if appropriate measures are taken to ensure "hygienic handling of water at every stage in the supply chain"[12], from source to consumption. The WHO *Sanitation on Ships* guide provides practical advice on protecting potable water supplies onboard ships and is currently being up-dated to reflect contemporary ship design and current infectious disease risks[16]. The development and implementation of a Water Safety Plan, based on the HACCP approach used in food industry, is recommended as an effective means of ensuring a safe water supply through its design, construction, operation and routine inspection and maintenance[14,17].

In the UK the master of a ship is, with certain exceptions (i.e. ships under 24 metres in length, pleasure craft, submersible craft, offshore installations whilst on or within 500 metres of their working stations) legally obliged to provide an adequate water supply fit for human consumption, in line with the Merchant Shipping (Provisions and Water) Regulations 1989[18]. The Water Supply (Water Quality) Regulations 2000 which apply to mains potable water supplies, however, do not encompass off-shore water supplies. Guidelines providing advice on the microbiological quality of water on board ships were published in 2003 through collaboration between the Health Protection Agency (HPA), the Maritime & Coastguard Agency (MCA), the Chartered Institute of Environmental Health (CIEH) Port Health Centre and the Association of Port Health Authorities (APHA)[19]. This publication specifies microbiological criteria for indicator organism levels above which action should be taken to restore acceptable water quality. *Escherichia coli*, coliforms and Enterococci should be absent from a 100 ml potable water sample and Aerobic Colony Counts (ACC) should not exceed 1000 in 1 ml.

The use of indicator organisms to monitor for the potential presence of water-borne pathogens to protect public health is well established and are used on the basis that these "indicator bacteria " indicate the risk of contamination with human/animal faecal or sewage and/or deterioration of water quality. Unlike methods used to detect pathogens, the use of indicator organism tests provide a sensitive and rapid result and have served well to protect public health from drinking water related illness[20]. Coliform bacteria belong to the family Enterobacteriaceae which includes potential pathogens such as *Salmonella* and *Shigella* spp. However not all coliforms originate from animals but may originate from vegetative sources, soil or may grow attached to surfaces within the distribution system. Therefore, the presence of coliforms may not be directly related to faecal contamination or a direct risk to public health but they do indicate that there has been post process contamination; re-growth or local contamination within the distribution system[20]. The presence of *E. coli* and Enterococci, in drinking water indicates contamination with human or animal faeces (i.e. faecal indicators) and may indicate the presence of enteric pathogens[20]. Examination of water samples for ACC bacteria (heterotrophic bacteria) growing at 37°C and 22°C do not indicate faecal contamination and are of limited public health value unless monitored regularly so that a trend analysis can be performed, but are a useful indicator in the monitoring of disinfection efficacy of potable water supplies[20].

The guidelines also cover recreational water quality on board ships. The health risks associated with spa pools are well documented and are the focus of recently published guidelines on the management of spa pools[21]. As well as *Legionella*, other infectious agents commonly found in spa pools include *Pseudomonas aeruginosa*, which can cause skin, urinary and ear infections, and environmental mycobacteria some of which are respiratory pathogens. Swimming-pool associated outbreaks of gastroenteritis are also well documented and are commonly attributed to contamination with chlorine-resistant *Cryptosporidium* oocysts[22].

Authorised officers from Port Health Authorities would normally consider the frequency of inspection of ships based on a risk rating system outlined in the statutory Food Law Code of Practice[23]. Initially, however, consideration is given to any documentation that might be available from the ship's master and the identification of all food and water related activities undertaken on the vessel. Coupled with risk assessment and regular inspection of ships' water supplies, water quality monitoring is an important part of ensuring safe water provision and verifying the effectiveness of procedures in place to control infection risks. The aim of this collaborative study was to review the microbiological quality of water onboard ships docking in the UK and the Channel Islands between May and October 2005, as a basis for revision of the current *Guidelines for Water Quality on board Merchant Ships Including Passenger Vessels*[19]. This report will focus on the microbiological quality of water from potable supplies, swimming and spa pools. To our knowledge, this is the first published study to assess the microbiological quality of potable water supplies on board ships.

Materials and Methods

Sample Collection

A total of 950 and 48 potable water and pool water samples, respectively collected from 342 ships were examined in 20 laboratories (11 Health Protection Agency (HPA) & HPA Collaborating, 4 National Public Health Service (NPHS), 2 Public Analyst (PA) , 2 NHS/Public Health Laboratory (PHL) and 1 private) in the UK between 1 May and 31 October 2005 (Annex 1). Water samples (500ml, or 1000ml for *Legionella* testing of spa pool samples) were collected and transported to laboratories by staff from 19 Port Health Authorities and 9 Local Authorities (Annex 2), in accordance with the *Guidelines for Water Quality on board Merchant Ships Including Passenger Vessels*[19], the *British Standards Institute PAS 39: 2003 Code of Practice for the Management of public swimming pools*[24], and the Health and Safety Executive (HSE)/HPA *Guidance on the Management of Spa Pools*[25].

Potable water samples were analysed for free chlorine at the time of sampling by the sampling officer. Pool water samples were analysed for free and total chlorine or total bromine, and also for pH, at the time of sampling by the sampling officer. A comparator test kit or commercially available test kits were used for analysing chlorine or bromine levels. Commercially available test kits or properly calibrated electrical instruments were used to determine pH values.

Information on samples and ships was obtained by observation and enquiry and recorded on a standard questionnaire (Annex 3). This included information on the vessel with regard to age and type of ship, capacity number of passengers and crew, and if international routes were undertaken. Additional information collected on potable and pool water samples included, for example, the supply, treatment and storage of water, whether routine water quality checks were carried out, and details concerning the use of pools on board ships.

Sample Examination

Potable water samples were examined for Aerobic Colony Counts (ACC), enterococci, *E. coli* and coliforms. Swimming and spa pool water samples were also examined for these organisms, and in addition for *Pseudomonas aeruginosa.* One optional microbiological test for spa pool samples included *Legionella* spp. Aerobic Colony Counts (ACC), enterococci, *E. coli,* coliforms, *Ps. aeruginosa* and *Legionella* spp. were enumerated or detected in accordance with HPA Standard Microbiological Methods[26-33]. Microbiological results of potable and pool water samples were compared to criteria based on published guidelines (Tables 1-2)[19].

Table 1. Microbiological criteria for potable water on board ships[19]

Parameter	Acceptable Level	Borderline Level	Action Level
Coliforms	0 in 100ml	-	≥1 in 100ml
E. coli	0 in 100ml	-	≥ 1 in 100ml
Enterococci	0 in 100ml	-	≥ 1 in 100ml
ACC	<100 / ml	100-1000/ml	≥ 1000 / ml

Table 2. Microbiological criteria for swimming and spa pool water on board ships[19]

Parameter	Satisfactory Level	Acceptable Level	Action Level*
Coliforms	0 in 100ml	N/A	≥ 1 in 100ml
E. coli	0 in 100ml	N/A	≥ 1 in 100ml
ACC	≤10 in 1ml	N/A	≥ 10 in 1ml
Ps. aeruginosa			
Swimming pools	0 in 100ml	1-<10 in 100ml	≥ 10 in 100ml
Spa pools	0 in 100ml	0 in 100ml	≥ 1 in 100ml
***Legionella* spp** (*Spa pools only*)	Not Detected	Present <10^2 / litre	≥10^2 / litre

Statistical analysis

Descriptive and statistical analysis of the data was carried out using Microsoft Excel and Stata 8.2 statistical software (StatCorp, College Station, TX). The relationship between potable water indicator organisms (presence/absence) was assessed using simple logistic regression, tests for trend and Fisher's exact tests. The correlation between ACC counts in potable waters at 22°C and 37°C was determined using log-normalized simple linear regression.

The effect of ship, water storage, loading and use parameters on the microbiological quality of potable water was assessed using simple logistic regression. Variables were considered statistically significant at $p<0.05$. Odds ratios were calculated by comparing the likelihood of generating action levels in one group with that of a baseline group (e.g. odds of positive samples in cruise ships ÷ odds of positive samples in cargo vessels). Factors significant at $p<0.1$ in the univariate analyses were included in a stepwise multiple logistic regression model. Tests for confounding of variables (factors associated with the outcome and independently associated with each another) were performed using chi-squared tests and stratified simple logistic regression.

All logistic regression models were performed with random effects, to control for clustering by individual ship (due to multiple samples being taken from ships).

The small number of pool water samples prohibited statistical analysis; therefore only descriptive results are presented.

Results

A total of 950 potable water samples, 23 swimming pool and 25 spa pool water samples were collected from 342 ships at 43 ports across the UK and The Channel Islands (for a list of ports where sampling took place, see Annex 4).

Ship characteristics

Over half (57%; 571) of samples were taken from cargo vessels, 162 (16%) from cruise ships and 83 (8%) from passenger ferries. Other types of vessels surveyed include containers, carriers, naval ships, tug boats, research vessels and rescue boats (a complete list of ship types sampled is provided in Annex 5).

Ships were aged between less than one and 65 years, with a median of 13 years (95% CI 12-14yrs). The passenger and crew capacity of ships sampled ranged from 0 to 2500 and 1 to 1000, respectively ($median_{passengers}$ = 20; $median_{crew}$ = 19).

Eighty-eight percent (301/342) of vessels surveyed undertake international routes. In the majority of cases, ships had most recently visited a port in Northern Europe (193/348*), with 11% (38/348) having arrived from Southern Europe and 12% (41/348) from international destinations. Less than 1% (27/348) of vessels had returned from a location within the UK (all countries visited are listed in Annex 6). Ships were sampled a median of 3 days after departing their most recent destination.

Potable water on board ships

<u>Sample parameters</u>

Most potable water samples were taken from galley taps (42%; 403/949) and cabins (or the furthest point in the distribution system) (32%; 304). The remainder of the samples were taken from water storage tanks (16%; 146) and drinking water dispensers (10%; 96).

Outlet water temperatures ranged from 0 to 40°C, with a mean of 21.3°C (SD=5.2) and the temperature range of storage tank water was 6 to 37°C (mean=20.4°C, SD=4.9). Potable water samples taken from drinking water dispensers were cooler than those from other locations (11.7% drinking water dispenser samples below 10°C vs. 0.3-1.8% of other samples; mean temperature for drinking water dispensers=16.9°C, cabins=22.1°C, galley taps=22.0°C; storage tanks=21.0°C). Samples above 25°C were most common on board cargo ships (30.6%, 163/532; compared with cruise ships 17.9%, 20/112; passenger car ferries 9.6% 8/83; and others 14.4%, 23/160).

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* Exceeds total no. ships as some ships were sampled on multiple occasions, on return from different destinations.

The concentration of free chlorine in potable water samples ranged from 0 to 22mg/l, with a median of 0.06mg/l (95% CI 0.05-0.07mg/l). Only 20% (190/950) of samples contained a free chlorine residual within the recommended range (0.2 - 5.0 mg/l)[19;34], 49% (467) fell below the minimum recommended concentration and 0.4% of samples (4) exceeded the recommended maximum. Table 3 shows free chlorine concentrations according to sample site.

Table 3: Potable water free chlorine concentration by site sampled

Site Sampled	**<0.2mg/l** *No. samples* *(% by site)*	**≥0.2mg/l** *No. samples* *(% by site)*	**Total no. samples**
Cabin/furthest point in distribution system	138 (45.4)	54 (17.8)	304
Drinking water dispenser	53 (55.2)	15 (15.6)	96
Galley tap	209 (51.9)	77 (19.1)	403
Storage tank	67 (45.9)	43 (29.5)	146
All sites	**467** (49.2)	**190** (20.0)	**950**

Microbiological quality of potable water

The proportion of potable water samples containing action levels of coliforms, *E. coli* and enterococci (≥ 1 CFU/100ml) are shown in Table 4. Nine percent (79/918) of samples tested positive for at least one of these three indicator organisms and 2.8% (26/918) contained one or more faecal indicators (*E. coli* and/or enterococci). Coliform, *E. coli* and enterococci counts ranged from 0 to 300, 0 to 18 and 0 to 3000 CFU/100ml, respectively (median count = 0 for all indicators).

Table 4. Potable water samples containing coliforms, *E. coli* and/or enterococci.

	Coliforms	***E. coli***	**Enterococci**	**Faecal indicators** (*E. coli*/ enterococci)	**Coliforms, *E. coli* or enterococci**
Action level samples (≥ 1 CFU in 100ml) (% total)	64 (6.76%)	7 (0.74%)	19 (2.07%)	26 (2.83%)	79 (8.61%)
Total no. samples	947	947	918	918	918

Table 5 shows the proportion of ships yielding at least one action level sample, stratified by ship type. Coliforms, *E. coli* or enterococci were detected in potable supplies onboard fifty-three vessels (16.1%; n=335), in one to six samples per vessel (median of one failure per ship). Cruise ships experienced the lowest rate of failure (7.1%; 2/28) whereas 17 to 19% of cargo, passenger car ferries and other vessels' potable supplies contained coliforms, *E. coli* or enterococci in at least one sample (see Table 5).

Table 5. Ships containing coliforms, *E. coli* or enterococci in at least one potable water sample

Ship type	**No. ships yielding at least one action level sample**	**Total no. ships**	**Failure rate** (% ships failing at least once)
Cargo	32	199	16.1%
Cruise ships	2	28	7.1%
Passenger car ferries	4	23	17.4%
Other	16	85	18.9%
Total	**54**	**335**	**16.1%**

Aerobic colony count results of potable water samples at 22 and 37°C are provided in Table 6. The proportion of samples containing action levels of ACC bacteria (≥ 1000 CFU/ml) was slightly higher at 37°C than at 22°C (21.4% vs. 20.0%).

Table 6. Potable water quality according to the level of ACC bacteria obtained with incubation at 22°C (68±4 hrs) and 37°C (44±4 hrs)

CFU/ml	*No. samples (% total)*	
	ACC at 22°C & 68±4 hrs	**ACC at 37°C** & 44±4 hrs
Acceptable (< 100)	508 (53.9%)	491 (52.1%)
Borderline (100 - <1000)	246 (26.1%)	249 (26.4%)
Action (≥ 1000)	189 (20.0%)	203 (21.5%)
Total	943	943

The relationship between aerobic colony counts at 22°C and 37°C is shown in Table 7. ACC levels ranged from 0 to 300000 CFU/ml at 37°C (median=55 CFU/ml) and 0 to 110000 CFU/ml at 22°C (median=38 CFU/ml). ACC levels at the two temperatures were correlated, as illustrated in Figure 1 (correlation coefficient=0.627; $p<0.0001$). Presentation of potable water sample ACC results from this point forward is therefore based on incubation at 37°C as this is more of an indication of health related contamination than those at 22°C (environmental bacteria).

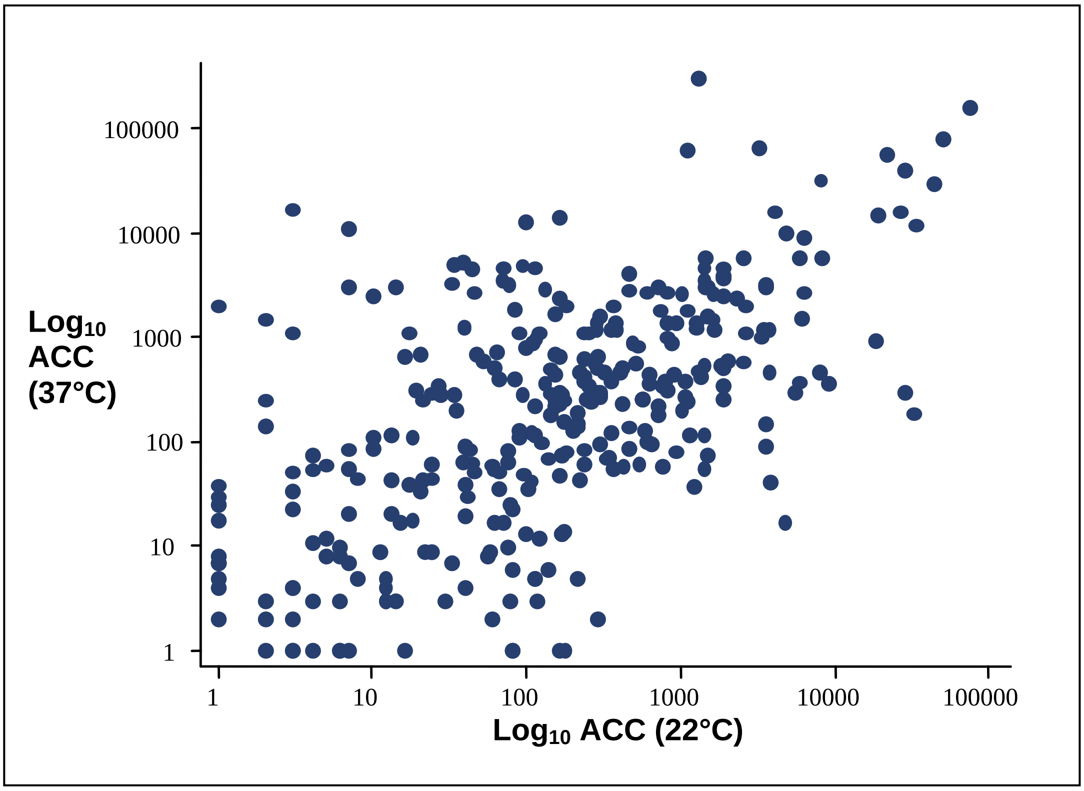
Table 7: Potable water samples and comparison of ACC results obtained with incubation at 22°C (68±4 hrs) and 37°C (44±4 hrs)

ACC at 37°C & 44±4 hrs (CFU/ml)	**ACC at 22°C & 68±4 hrs (CFU/ml)†**						
	0	1 – 99	100 - 999	1000 - 9999	≥ 10000	Void/ invalid	Total (%)
0	92	67	22	1	0	9	**191** (20.2)
1 - 99	75	160	45	10	0	9	**299** (31.6)
100 - 999	17	50	101	30	3	35	**226** (23.9)
1000 - 9999	8	22	34	51	1	3	**119** (12.6)
≥ 10000	2	3	4	10	15	1	**35** (3.7)
Void/invalid count*	3	8	10	1	2	53	**77** (8.1)
Total	**197** (20.8)	**310** (32.7)	**216** (22.8)	**103** (10.8)	**21** (2.2)	**100** (10.6)	**947** (100)

†Categories 0 and 1-99 CFU/ml represent acceptable levels, 100-999/ml borderline levels and 1000-9999 & ≥10 000 CFU/ml action levels

*This includes results recorded as a count range, not fitting into the above grouping (e.g. >1000)

Figure 1: Potable water samples and correlation between ACC results obtained with incubation at 22°C (68±4 hrs) and 37°C (44±4 hrs) (log_{10} scale)



The level of ACC bacteria (at 37°C) by sample site is shown in Table 8. Action levels of ACC bacteria were most commonly detected in samples taken from potable water storage tanks: a quarter (25.3%) of samples contained at least 1000 CFU/ml (37°C). Twenty-one percent of drinking water dispenser samples also contained action levels, compared with 13.8% of those taken from galley taps and cabins (or the furthest point in the distribution system).

Table 8: Potable water aerobic colony count level by site sampled

	No. samples (% by sample site)				
ACC at 37°C & 44±4 hrs (CFU/ml)	**Cabin/ furthest point**	**Drinking water dispenser**	**Galley tap**	**Storage tank**	**Total**
0	62 (20.4)	13 (13.5)	95 (23.8)	20 (13.7)	190 (20.1)
1 - 99	98 (32.3)	29 (30.2)	122 (30.5)	50 (34.3)	299 (31.6)
100 - 999	80 (26.3)	24 (25.0)	89 (22.3)	33 (22.6)	226 (23.9)
1000 - 9999	34 (11.2)	14 (14.6)	42 (10.5)	29 (19.9)	119 (12.6)
≥ 10000	8 (2.6)	6 (6.3)	13 (3.3)	8 (5.5)	35 (3.7)
Void/invalid count*	22 (7.2)	10 (10.4)	39 (9.8)	6 (4.1)	77 (8.1)
Total	**304** (100)	**96** (100)	**400** (100)	**146** (100)	**946** (100)

*This includes results recorded as a count range, not fitting into the above grouping (e.g. >1000)

Correlation between indicator organisms

Table 9 shows the relationship between ACC levels and the presence of other indicators organisms in potable water samples. Of 203 samples containing action levels of ACC (≥ 1000 CFU/ml), 25 (12.3%) also contained coliforms, 3 (1.5%) contained *E. coli,* and 8 (3.9%) contained enterococci. Thirty-three (16.3%) potable water samples with an ACC action level contained at least one of these organisms.

The proportion of samples containing coliforms increased with ACC count level (acceptable/borderline/action) (test-for-trend OR=1.88, p<0.001). A similar relationship was observed between the presence of at least one indicator - coliforms, *E. coli* or enterococci - and ACC level (test-for-trend OR=1.96, p<0.001).

The presence of coliforms and of faecal indicators (*E. coli* &/or enterococci) in potable water samples was significantly associated (OR=11.61, p<0.0001). Of 64 potable water samples containing coliforms, faecal indicators were present in 11 (17.2%) and absent from 53 (82.8%) samples. Twenty-six samples contained faecal indicators, and of these coliforms were present in 11 (42.3%) but not in 15 (57.6%). The presence of coliforms, *E. coli* and/or enterococci was therefore used as the outcome in all single variable and multivariate analyses, since this was a more sensitive outcome measure.

Table 9: Correlation between ACC levels and presence of other indicator organisms in potable water samples

	No. (%) samples containing:					
ACC at 37°C & 44±4 hrs (CFU/ml)	**Coliforms**	***E. coli***	**Enterococci**	***E. coli* &/or enterococci**	**Coliforms, *E. coli* &/or enterococci**	**Total**
< 100	17 (3.5)	2 (0.4)	5 (1.0)	7 (1.4)	21 (4.3)	491 (100)
100–999	22 (8.8)	2 (0.8)	6 (2.4)	8 (3.2)	25 (10.0)	249 (100)
≥ 1000	25 (12.3)	3 (1.5)	8 (3.9)	11 (5.4)	33 (16.3)	203 (100)

Single variable analysis: presence of coliforms, E. coli or enterococci

The results of the single variable analyses, using presence of coliforms, *E. coli* and/or enterococci as an outcome, are presented in Tables 10-14. Odds ratios and p-values were adjusted for clustering by individual ship, to account for the fact that the majority of ships (93.9%; 862/918) were sampled more than once.

Ship characteristics and routes travelled

The risk of potable water samples containing coliforms, *E. coli* and/or enterococci increased with ship age and decreased with crew capacity number (Table 10). There is some evidence to suggest that samples were less likely to contain these indicators on vessels undertaking international routes, compared with those travelling in the UK only (this association was of borderline statistical significance) (Table 10).

Vessel type, passenger capacity, last region visited and time since departing the last destination showed no association with the presence of indicator organisms in potable water sampled on board ship (Table 10).

Table 10. Single Variable Analysis: The effect of ship characteristics and routes on the microbiological quality of potable water on board ship

Variable	Samples with coliforms, *E. coli* &/or enterococci (total)	% Action Level Samples (95% CI)	Adjusted odds ratio* (univariate)	p-value
Ship type				0.157
Cargo	50 (549)	9.1 (6.8-11.8)	1.00	
Cruise ship	3 (113)	2.7 (0.6-7.6)	0.12 (0.01-1.37)	
Passenger car ferry	5 (79)	6.3 (2.1-14.2)	0.82 (0.15-4.53)	
Other	21 (177)	11.9 (7.5-17.6)	2.87 (0.64-12.93)	
Ship age† (*natural log*)	-	-	2.32† (1.17-4.59)	0.016
Passenger capacity number				0.605
0	66 (617)	10.7 (8.4-13.4)	1.00	
1-100	3 (98)	3.1 (0.6-8.7)	0.17 (0.02-1.70)	
101-500	6 (48)	12.5 (4.7-25.3)	0.93 (0.18-4.92)	
501-1000	3 (60)	5.0 (1.0-13.9)	0.44 (0.05-3.96)	
>1000	0 (63)	0 (0-5.7)	-	
Crew capacity number				0.016
<10	39 (291)	13.4 (9.7-17.9)	1.00	
11-50	29 (422)	6.9 (4.7-9.7)	0.15 (0.04-0.60)	
>50	8 (156)	5.1 (2.2-9.9)	0.11 (0.02-0.72)	
International routes				0.061
No	13 (85)	15.3 (8.4-24.7)	1.00	
Yes	65 (829)	7.8 (6.1-9.9)	0.14 (0.02-1.09)	
Last region visited				0.628
UK	5 (68)	7.4 (2.4-16.3)	1.00	
N Europe	43 (523)	8.2 (6.0-10.9)	1.14 (0.10-13.75)	
S Europe	2 (88)	2.3 (0.3-8.0)	0.20 (0.01-6.00)	
International	11 (131)	8.4 (4.3-14.5)	1.16 (0.08-17.56)	
Time since visited				0.240
≤ 1 week	27 (541)	5.0 (3.3-7.2)	1.00	
1week-1 month	17 (145)	11.7 (7.0-18.1)	2.73 (0.54-13.71)	
> 1 month	7 (58)	4.3 (5.0-23.3)	38.87 (0-580883)	

*Adjusted for clustering by individual ship (using simple logistic regression with random effects)
†Since age had to be log-normalised to meet the assumptions of the regression model, this odds ratio represents the average increase in risk with each log-unit increase in age

Potable Water loading

The most recent place of potable water loading was found to be associated with microbiological water quality. Action level samples were less likely to occur on ships loading potable water in Northern Europe and, to some extent, Southern Europe (borderline statistical significance) compared with the UK (destinations outside of Europe did not differ significantly from the UK) (Table 11). Analysis of variables related to loading practices revealed that disinfection of hoses and couplings before use, storage of hoses in dedicated lockers and ships owning their own hoses were each associated with a reduced risk of action levels (coliforms, *E. coli* and/or enterococci). Labelling of hoses and couplings as "Potable Water Only" showed a borderline protective effect only.

The time period since storage tanks had last been filled and the method used (hose & hydrant vs. water barge) were not associated with potable water quality (Table 11).

Table 11. Single Variable Analysis: Potable water loading in relation to microbiological quality of potable water on board ship

Variable	**Samples with coliforms, *E. coli* &/or enterococci (total)**	**% Action Level Samples (95% CI)**	**Adjusted odds ratio*** (univariate)	**p-value**
Region tank last filled				0.047
UK	46 (372)	12.4 (9.2-16.2)	1.00	
N Europe	19 (254)	7.5 (4.6-11.4)	0.15 (0.03-0.66)	
S Europe	1 (51)	2.0 (0.1-10.5)	0.01 (0-1.16)	
International	4 (58)	6.9 (1.9-16.7)	0.26 (0.05-1.53)	
Time since tank(s) last filled				0.722
≤ 1 week	42 (476)	8.8 (6.4-11.7)	1.00	
> 1 week – 1 month	22 (172)	12.8 (8.2-18.7)	1.03 (0.21-5.03)	
> 1 month	4 (78)	5.1 (1.4-12.6)	0.49 (0.07-3.49)	
Method used to fill tank				0.610†
Hose & hydrant	66 (673)	9.8 (7.7-12.3)	- †	
Water barge	0 (10)	0 (0-30.9)	- †	
Hoses disinfected before use				<0.001
No	63 (455)	13.9 (10.8-17.4)	1.00	
Yes	11 (264)	4.2 (2.1-7.3)	0.04 (0.01-0.27)	
Hoses stored in dedicated locker				0.014
No	30 (227)	13.2 (9.1-18.3)	1.00	
Yes	31 (492)	6.3 (4.3-8.8)	0.15 (0.03-0.68)	
Hoses owned by ship				0.006
No	44 (254)	17.3 (12.9-22.6)	1.00	
Yes	32 (514)	6.2 (4.3-8.7)	0.22 (0.07-0.64)	
Couplings disinfected before use				0.008
No	67 (461)	14.5 (11.4-18.1)	1.00	
Yes	7 (250)	2.8 (1.1-5.7)	0.007 (0-0.27)	
Hoses & couplings labelled *Potable Water Only*				0.093
No	34 (276)	12.32 (8.68-16.79)	1.00	
Yes	35 (442)	7.92 (5.58-10.84)	0.33 (0.09-1.20)	

*Adjusted for clustering by individual ship (using simple logistic regression with random effects);
†P-value derived from Fisher's exact test, not adjusted for individual ship

Potable water storage

The microbiological quality (presence of indicator organisms) of potable water samples was found to be associated with storage tank capacity, ships with tanks of medium volume (1000-10000 litres) yielding a higher proportion of action level samples than other vessels (Table 12).

The number of storage tanks on board a ship, insulation of tanks, tank water temperature, time since tanks were last cleaned and colour-coding of potable water pipes were not associated with microbiological water quality (Table 12).

Table 12. Single Variable Analysis: Potable water storage in relation to the microbiological quality of potable water on board ship

Variable	**Samples with coliforms, *E. coli* &/or enterococci (total)**	**% Action Level Samples (95% CI)**	**Adjusted odds ratio*** (univariate)	**p-value**
No. storage tanks				0.142
1-5	74 (765)	9.7 (7.7-12.0)	1.00	
6-10	2 (51)	3.9 (0.5-13.5)	0.06 (0.004-0.98)	
>10	0 (35)	0 (0-10.0)	-	
Storage tank capacity (litres)				0.005
≤1000	11 (181)	6.1 (3.1-10.6)	1.00	
>1000 – 10 000	12 (73)	16.4 (8.8-27.0)	16.06 (2.24-115)	
>10 000 – 100 000	39 (333)	11.7 (8.5-15.7)	3.43 (0.76-15.55)	
>100 000	13 (252)	5.2 (2.8-8.7)	0.64 (0.12-3.34)	
Storage tank(s) insulated				0.493
No	53 (535)	9.9 (7.5-12.8)	1.00	
Yes	22 (292)	7.53 (4.8-11.2)	0.65 (0.19-2.25)	
Time since tank(s) last				0.153
cleaned	22 (184)	12.0 (7.5-17.5)	1.00	
≤ 3 months	5 (115)	4.4 (1.4-9.9)	0.33 (0.17-1.69)	
> 3 months – 6 months	10 (133)	7.5 (3.7-13.4)	0.76 (0.16-3.64)	
> 6 months - 1 year	2 (97)	2.1 (0.3-7.3)	0.07 (0.006-0.84)	
> 1 year				
Tank water temperature	-		0.97 (0.91-1.04)	0.412
Potable water pipes appropriately colour coded				0.161
No	21 (191)	11.0 (6.9-16.3)	1.00	
Yes	48 (598)	8.0 (6.0-10.5)	0.34 (0.08-1.53)	

*Adjusted for clustering by individual ship (using simple logistic regression with random effects)

Storage and usage sites of potable water

On comparison of sampling sites, potable water samples taken from storage tanks and galley taps were more likely to be of poorer microbiological quality (i.e. contain coliforms, *E. coli* and/or enterococci) than those taken from cabins (or the furthest point in the distribution system) (Table 13). A potable water free chlorine concentration at or above the recommended minimum was significantly protective against the presence of indicators (when compared with <0.2mg/l).

Outlet water temperature showed no association with microbiological water quality (Table 12).

Table 13. Single Variable Analysis: Potable water sample parameters in relation to the microbiological quality† of potable water on board ship

Variable	**Samples with coliforms, *E. coli* &/or enterococci (total)**	**% Action Level Samples (95% CI)**	**Adjusted odds ratio*** (univariate)	**p-value**
Site sampled				0.038
Cabin/furthest point	16 (293)	5.5 (3.2-8.7)	1.00	
Drinking water dispenser	5 (94)	5.3 (1.8-12.0)	2.07 (0.42-10.30)	
Galley tap	45 (387)	11.6 (8.6-15.3)	3.44 (1.42-8.34)	
Storage tank	13 (143)	9.1 (4.9-15.0)	3.71 (1.15-11.98)	
Free chlorine level (mg/l)				0.008
<0.2	53 (447)	11.9 (9.0-15.2)	1.00	
≥0.2	5 (179)	2.8 (0.9-6.4)	0.13 (0.03-0.58)	
Outlet water temperature	-	-	0.98 (0.89-1.08)	0.630

*Adjusted for clustering by individual ship (using simple logistic regression with random effects)

Potable water processing and quality monitoring
Potable water samples taken from ships that processed potable water on-board were significantly less likely to contain indicator organisms than those from vessels loading potable water (Table 14). However, no individual processing method – distillation, evaporation, ultraviolet irradiation, or reverse osmosis – was identified as having a significant protective effect. Using more than one method did not confer any additional benefit to processing by a single technique.

There is some evidence to suggest that performing regular water quality checks, and testing onboard, were protective against generating action level samples (however these relationships were of borderline statistical significance only) (Table 14).

Table 14. Single Variable Analysis: Potable water processing and quality monitoring in relation to the microbiological quality† of potable water on board ship

Variable	**Samples with coliforms, *E. coli* &/or enterococci (total)**	**% Action Level Samples (95% CI)**	**Adjusted odds ratio*** (Univariate)	**p-value**
Potable water processed on-board				0.002
No	52 (394)	13.2 (10.0-16.9)	1.00	
Yes	22 (449)	4.9 (3.1-7.3)	0.13 (0.04-0.49)	
Method of water processing				- †
Production of potable water by:				
Evaporation	13 (184)	7.1 (3.8-11.8)	1.00	
Distillation	4 (23)	17.4 (5.0-38.8)	- †	
Reverse Osmosis	1 (29)	3.5 (0.9-17.8)	0.60 (0.02-19.30)	
Treatment by:				
UV irradiation	0 (41)	0 (0-8.6)	- †	
Other (Chlorination, filtration)	4 (172)	2.3 (0.6-5.9)	0.19 (0.03-1.15)	
No. processing methods used				0.191
One	18 (288)	6.3 (3.8-9.7)	1.00	
Multiple	3 (160)	1.9 (0.4-5.4)	0.31 (0.06-1.78)	
Routine water quality checks carried out				0.064
No	47 (407)	11.6 (8.6-15.1)	1.00	
Yes	28 (439)	6.4 (4.3-9.1)	0.29 (0.08-1.07)	
Checks performed onboard				0.092
No	14 (138)	10.1 (5.7-16.4)	1.00	
Yes	12 (261)	4.6 (2.4-7.9)	0.27 (0.06-1.24)	

*Adjusted for clustering by individual ship (using simple logistic regression with random effects)
†After adjusting for individual ship, small sample sizes prevented calculation of strata-specific odds ratios and overall p-value.

Multi-variable analysis: presence of coliforms, E. coli or enterococci

Prior to multivariable analysis, tests for confounding revealed that four variables relating to loading equipment – ships owning hoses, storage of hoses in dedicated lockers, disinfection of hoses and of couplings before use - were correlated with one another. However, none emerged as a clear confounder. It was therefore decided to combine these variables into a "hose hygiene score" (0-4), which was assigned according to how many of these factors were in place.

Testing for confounders also showed that the association between the site of sampling (cabin, drinking water dispenser, galley tap or storage tank) and the presence of indicator organisms in potable water samples could be fully explained by free chlorine concentration (< or ≥0.2mg/l); sample site was therefore excluded from the multivariable model.

On multivariable analysis, the following variables remained associated with presence of coliforms, *E. coli* and/or enterococci in potable water on board ship: age of ship, processing potable water onboard, hose hygiene and free chlorine residual (Table 14). The risk of generating action level samples increased with age, but was reduced in vessels processing their own water. Ships reporting all four hose hygiene practices – ownership of hoses, storage of hoses in dedicated lockers, disinfection of hoses & couplings before use – were at reduced risk of testing positive for coliforms, *E. coli* and/or enterococci (performing at least one of these practices was protective to a lesser extent). There is also some evidence that a free chlorine concentration at or above 0.2mg/l also remained protective (although this was of borderline statistical significance) (Table 15).

Table 15. Multivariable Analysis: Ship and water variables associated with the microbiological quality (presence of coliforms, *E. coli* and/or enterococci) of potable water on board ship

Variable	Univariate analysis Odds Ratio (95% CI)	p-value	Multivariate analysis Odds Ratio (95% CI) *	p-value
Age of ship (*natural log*)	2.32 (1.17-4.59)	0.016	1.99** (1.07-3.65)	0.029
Size of crew		0.016	-	-
<10	1.00			
11-50	0.15 (0.04-0.60)			
>50	0.11 (0.02-0.72)			
Ship undertakes international routes	0.14 (0.02-1.09)	0.061	-	-
Free chlorine ≥0.2mg/l	0.13 (0.03-0.58)	0.008	0.19 (0.03-1.15)	0.071
Storage tank capacity (l)		0.005	-	-
≤1000	1.00			
>1000-10 000	16.06 (2.24-115.31)			
>10 000-100 000	3.43 (0.76-15.55)			
>100 000	0.64 (0.12-3.34)			
Region tank last filled		0.047	-	-
UK	1.00			
N Europe	0.15 (0.03-0.66)			
S Europe	0.01 (0.0001-1.16)			
International	0.26 (0.045-1.53)			
Water processed on-board	0.13 (0.04-0.49)	0.002	0.16 (0.03-0.79)	0.025
Hose hygiene score†		0.014		
0	1.00		1.00	
1	0.07 (0.009-0.57)		0.08 (0.01-0.59)	0.014
2	0.20 (0.03-1.46)		0.22 (0.37-1.34)	0.102
3	-		-	-
4	0.007 (0.0004-0.11)		0.03 (0.002-0.27)	0.002
Hoses & couplings labelled ***Potable Water Only***	0.33 (0.09-1.20)	0.093	-	-
Regular water quality checks performed	0.29 (0.08-1.07)	0.064	-	-
Water quality checks performed onboard	0.27 (0.06-1.24)	0.092	-	-

* Adjusted for clustering by individual ship (using simple logistic regression with random effects)
**Since age had to be log-normalised to meet the assumptions of the regression model, this odds ratio represents the average increase in risk with each log-unit increase in age
†The hose hygiene score relates to how many of the 4 potable water loading practices were in place: ships owning hoses, storage of hoses in dedicated lockers, disinfection of hoses and of couplings before use (it was not possible to test the individual effect of these variables since they were all correlated)

Swimming and spa pool water

Twenty-three swimming pool and 25 spa pool water samples were collected from 18 cruise ships. Vessels surveyed contained up to five pools (median=2) and 81% (39/48) of those tested were located outdoors. Of 25 spa pool samples, 18 derived from pools at deck level with overflow and six from displacement type pools. Swimming pool water volume ranged from 20 to 200m^3 (median = 49m^3; insufficient data available for spa pools) (Table 16).

Swimming pools received a daily throughput of between five and 1700 bathers (median=30), and spa pools were visited by between 7 and 50 bathers daily (median=20). In four instances, bathers were present in the pool at the time of sampling (one bather present in a spa pool on one occasion; 2-4 present in swimming pools on 3 occasions).

Most swimming pools were filled with sea water (60.9%) whilst all spa pools were fresh water (Table 16). Swimming pools had last been filled up to 14 days prior to sampling and spa pools between 0 and 4 days (median=1 day for all pools). Ships reported that up to 100% of the water system volume was displaced (median=18.5% & 60% for swimming pools & spas, respectively). Pool surroundings were visually clean on 46 of 47 occasions and pool water was always visually clear (n=47).

Pool water was reported to be treated with chlorine, bromine, sand filtration or, in the majority of cases (66%; 31/47), through a combination of these methods (Table 16). Treatment was applied by an automatic dosing mechanism in 30 (65%) cases and manually in 26% cases. The majority of ships (79.5%; 35/44) reported backwashing filters on a daily basis, although in one swimming pool backwashing had never been performed.

Table 16. Characteristics of swimming and spa pools and their water treatment on board ship

	Swimming pools	Spa pools	Total
Location of pool			
Outdoor	19 (82.6%)	20 (80.0%)	39 (81.2%)
Indoor	4 (17.4%)	5 (20.0%)	9 (18.8%)
Type of pool water			
Sea Water	14 (60.9%)	0	14 (29.2%)
Fresh Water	9 (39.1%)	25 (100%)	34 (70.8%)
Volume of water in pool (m^3)			
Range (median)	20-200 (49)	- †	1-200 (36.8)
Pool treatment			
Sand filter	1 (4.35%)	0	1 (2.1%)
Chlorine	6 (26.1%)	1 (4.2%)	7 (14.9%)
Bromine	1 (4.35%)	7 (29.7%)	8 (17.0%)
Other (combination)	15 (65.2%)	16 (66.7%)	31 (66.0%)

†Insufficient data available for spa pools

Chemical parameters & targets

The pH of pool water at the time of sampling ranged from 6.8 to 8.3, with reported target values of pH 7 to 7.8 for swimming pools and pH 6 to 8.2 for spa pools (Table 17). For approximately half (20/41) of the samples, pH was reported to be routinely tested on board vessels every four hours, and the ships' records indicated that this schedule was adhered to in most (95%; 41/43) of cases.

The free chlorine and total chlorine/bromine concentrations of pool water samples ranged from 0.02 to 5.1mg/l (median=1.4) and 0.02 to 11.2mg/l (median=2.3), respectively (Table 16). Target chlorine/bromine concentrations were between 1 and 8mg/l for swimming pools and 1-10mg/l for spa pools. Ships reported routinely testing chlorine/bromine content before pool opening only (12/37), every two hours during opening hours (3/27), midway during opening hours (2/37) or at a combination of these intervals (30/37). In 95% of cases (43/47), examination of ships' records indicated that the reported testing routine was complied with.

Table 17. Pool waters and analytical testing details carried out on board ship

	Swimming pools	**Spa pools**	**Total**
pH at time of sampling *Range (mean)*	6.8-8.3 (7.7)	7.0-8.3 (7.6)	6.8-8.3
Free chlorine (mg/l) *Range (median)*	0.02-3.5 (0.9)	0.5-5.1 (1.6)	0.02-5.1 (1.4)
Total chlorine/bromine (mg/l) *Range (median)*	0.02-4.9 (1.3)	0.1-11.2 (3.5)	0.02-11.2 (2.3)

Microbiological testing

In the majority of instances (87.5%; 42/48), ships reported performing regular microbiological quality checks on pool waters (Table 18). Testing was typically carried out on a daily basis (59.5%; 25/42) and always onboard (n=42). Parameters routinely tested for included coliforms only (12/28) or coliforms & *E. coli* (14/28) (Table 18). One spa pool was also reported to be tested regularly for *Legionella*.

For 21 of 22 spa pools, there was a response plan for adverse monitoring results. In 73% (16/22) of cases, ships reported having in place a *Legionella* risk assessment for spa pools.

Table 18. Pool waters and microbiological testing details

	Swimming pools	Spa pools	Total
Are water quality checks routinely carried out?			
Yes	19 (82.6%)	23 (92.0%)	42 (87.5%)
No	4 (17.4%)	2 (8.0%)	6 (12.5%)
What parameters are tested?			
Coliforms only	7 (53.8%)	5 (33.3%)	12 (42.86%)
E. coli only	0	1 (6.7%)	1 (3.57%)
Coliforms & *E. coli*	6 (46.2%)	8 (53.3%)	14 (50.0%)
Coliforms & *Legionella*	0	1 (6.7%)	1 (3.57%)
Frequency of water quality checks			
Continuously	1 (5.3%)	2 (8.7%)	3 (7.2%)
Daily	11 (57.9%)	14 (60.9%)	25 (59.5%)
Weekly	5 (26.3%)	4 (17.4%)	9 (21.4%)
Fortnightly	2 (10.5%)	3 (13.0%)	5 (11.9%)

Microbiological quality of pool water

The proportions of swimming pool and spa pool water samples containing action levels of ACC, coliforms, *E. coli*, *Pseudomonas aeruginosa* and *Legionella* spp. are shown in Table 19. Swimming pool samples contained between 0 and 53 coliforms per 100ml and spa pools between 0 and 8/100ml (median=0 in both cases). Aerobic colony counts ranged from 0-8 per ml in swimming pools and 0-350 per ml in spa pools (median=0/ml for both swimming and spa pools). In total there were six adverse results that exceeded action levels for coliforms (3, ≥1/100ml) and *Ps. aeruginosa* (2 spa pools ≥1 in 100ml; 1 swimming pool ≥10 in 100ml) (Tables 2 and 19).

Table 19. Swimming and spa pool water quality: coliforms, *E. coli*, *Pseudomonas aeruginosa*, Aerobic Colony Count bacteria & *Legionella* species (spa pools only).

	No. action level samples (% of total)				
	Coliforms	***E. coli***	**Aerobic Colony Count**	***Pseudomonas aeruginosa***	***Legionella* spp.**
Swimming pools	2/22 (9.09)	0/22	0/23	1/23 (4.35)	-
Spa pools	1/24 (4.17)	0/24	4/24 (16.67)	2/24 (8.33)	0/6

Discussion

Potable water supplies onboard vessels docking in the UK are inspected and tested by port health authorities (PHA) or local authorities, based on specified microbiological criteria. According to current guidelines, if a supply contains coliforms, *E. coli* or enterococci in a 100ml sample, or unacceptable levels of ACC bacteria (≥1000/ml), remedial action must be taken to restore adequate water quality[19]. In this study, 8.6% of potable water samples contained coliforms, *E. coli* or enterococci, in close agreement with results observed in 1609 ships' potable water samples (8.3% samples contained coliforms or *E. coli*) collected during 2002 in England by PHAs during inspections and examined by HPA and HPA Collaborating laboratories (C Lane, HPA personal communication). The presence of coliforms in potable water is a marker of insufficient disinfection, whilst *E. coli* and enterococci indicate faecal contamination of the supply, either arising from source waters or during loading, storage or distribution. This study has highlighted various practices which can protect against unacceptable levels of these indicator organisms in ships' water supplies. Potable water supplies were less likely to contain coliforms, *E. coli* or enterococci if vessels owned their hoses, stored these hoses in dedicated lockers and disinfected loading equipment (hoses and couplings) before use. The *Guidelines for Water Quality On Board Merchant Ships Including Passenger Vessels*, the *APHA Handbook 2006*, the US CDC *Vessel Sanitation Program manual*, and the MCA Draft *Recommendations to Prevent Contamination of Freshwater Storage and Distribution Systems on Ships, Commercial Yachts and Fishing Vessels* all recommend that hoses are stored in lockers used solely for that purpose and flushed through before use[19;34-36]. The findings of this study emphasize the importance of good hygiene throughout the water loading process and indicate that additional protection may be conferred by disinfecting hoses and couplings before use.

Maintaining a free chlorine concentration at or above the recommended minimum for potable water supplies on board vessels (0.2mg/l) was also associated with improved microbiological water quality. However, only 20% of samples contained a free chlorine residual within the recommended range. It is essential that vessels monitor chlorine levels in their potable water supplies to ensure a sufficient concentration is maintained, in accordance with guidance provided by HPA/APHA, CDC and MCA[19;34;36].

This study identified an association between processing potable water onboard and improved microbiological water quality. Potable water supplies on board ships reporting one or more treatment method – distillation, evaporation, reverse osmosis, ultraviolet irradiation, chlorination or filtration – were at reduced risk of containing coliforms, *E. coli* or enterococci. Although the effects of individual techniques could not be deduced, since each method was reported by only a limited number of ships, the findings reported here provide evidence of the potential benefits of processing potable water onboard vessels. Whilst loading potable water from a good quality source is clearly preferential to treating contaminated water[37], further investigation into the effects of different processing methods may reveal the most appropriate techniques for protecting safe potable water supplies onboard.

The presence of coliforms, *E. coli* or enterococci in potable water was also related to ships' age, water on older ships being at greater risk of microbiological failure. Examination of ships' water supplies in England during 2002 also found that potable water quality was associated with ship age and that passenger vessels over 19 years old were more likely to contain *E. coli* or coliforms (C Lane, HPA personal communication). Cramer et al[38] have described a similar trend, whereby the likelihood of failing sanitary inspection scores increased with ship age. This highlights the importance of inspecting and maintaining ageing potable water systems, which may be particularly vulnerable to contamination.

In this study, the proportion of potable water samples containing action levels of aerobic colony count (ACC) bacteria far exceeded that of failures attributed to the presence of coliforms, *E. coli* or enterococci. The ACC is a useful indicator of disinfection efficacy in potable supplies if monitored regularly, whereby a significant increase above expected levels can indicate treatment failure or contamination. However, no adverse health effects have been associated with exposure to these bacteria through drinking water, on board ships or otherwise[39]. Furthermore, since testing ship water quality typically involves one-off sampling by port health officers when a vessel is at port, there is no means for port health authorities (PHA) to monitor ACCs or define 'expected levels' onboard. Indeed the WHO Expert Consensus on Heterotrophic Plate Counts (HPC) (equivalent to ACC) and Drinking Water Safety states that "HPC measurements alone are unsuitable for use in independent surveillance by health authorities where series results are unavailable; faecal indicator bacteria measurements are essential in this role"[39]. This questions the public health value of testing ships' potable water supplies for ACCs by PHAs or local authorities, and taking subsequent remedial action when a water sample 'fails' only on this parameter. A more appropriate approach is therefore needed.

WHO recommends the use of Water Safety Plans to assess and manage risks from source to tap, of which the key elements are: (1) system assessment to determine whether the water supply chain can provide potable water meeting health-based quality targets, (2) implementation and operational monitoring of appropriate control measures (3) management plans for normal and incident conditions[39]. Rooney et al[37] recommend that vessels adopt Water Safety Plans to minimize the risk of waterborne disease outbreaks occurring on ships. In the US, the CDC *Vessel Sanitation Program* (VSP) uses a rating system to identify critical points for potable water, swimming pools and spas on board cruise ships arriving from overseas, as a means of highlighting and managing risks in the water supply chain. Vessels must correct any deficiencies identified and implement a corresponding corrective-action plan. Since its inception in 1975, this program has seen a marked decline in the number of gastrointestinal disease outbreaks onboard vessels, despite an increase in passenger numbers[37].

The Water Safety Plan approach would enable vessels to identify potential contamination points in ships' water supplies - during loading, storage and distribution - and to apply appropriate control measures, whilst continuing to monitor water quality with public health-based indicators (i.e. coliforms, *E. coli* and enterococci). With adequate training of staff on board, this strategy would provide an effective means of protecting ships' potable water supplies.

Whilst the purpose of this study was not intended to estimate risk of legionella growth within the ships' distribution systems a number of water samples were within the temperature growth range of this organism (25-45°C) which poses an increased risk of legionellae growth[40], where this is combined with low chlorine levels the potential is obviously increased. Apart from the variability in quality and temperature of water uploaded to ships, safe management of water systems on ships poses additional problems from those that are land based. Water turnover is likely to be less with sometimes prolonged storage times on long journeys. Microbial growth may also result from long-term storage and stagnation of water in tanks or pipes, and this risk could be increased when vessels are laid up for several months. The ships' movement increases the risk of surge and back-siphonage and of sediments in tanks being re-suspended and dispersed. Ships' engine rooms are hot, and may affect water temperature in pipes passing nearby[14]. There have been many shipborne outbreaks of Legionnaires disease due to inadequate management and control of water systems including spa pools on board[14]. Vessels therefore should ensure that their water safety plan includes appropriate measures to identify and manage the risk of Legionnaires disease.

Recommendations

This report will be used to inform a revision of the current *Guidelines for Water Quality on Board Merchant Ships Including Passenger Vessels*, incorporating the following recommendations:

(1) Adoption of the Water Safety Plan approach to manage, monitor and control potable water supplies onboard ships, according to *WHO Guidelines for Drinking Water Quality 3rd Edition* (2004)[14,16].

(2) Removal of the aerobic colony count as a criterion for remedial action when sampling is carried out on a one-off basis. However, ships with the capacity to test onboard, or those PHAs that can obtain a series of samples from regularly visiting vessels, may wish to monitor ACC levels since an increase above expected levels may indicate problems with potable water treatment or contamination.

(3) Continued monitoring of the microbiological quality of potable water on board ships using public health based indicators, i.e. coliforms, *E. coli* and enterococci.

(4) Hygienic practice throughout the potable water loading process: hoses should be kept in dedicated lockers; hoses and couplings should be disinfected before use.

(5) Maintaining free chlorine concentrations of at least 0.2mg/l (and below 5.0mg/l) in potable water supplies onboard ships.

In 2003, the Public Health Laboratory Services (now the Health Protection Agency) and APHA produced a report on the microbiological quality of water on board aircraft, advising that water supplies should not contain coliforms, *E. coli* or enterococci in a 100ml sample (unpublished PHLS/APHA report). This is in agreement with the current guidelines for potable water quality on ships. In the absence of published guidelines referring specifically to aircraft, there is a need to formally align indicator levels above which action should be taken on both aircraft and ships.

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Annexes

Annex 1. Participating Laboratories and Number of Samples Processed

Table I. HPA and HPA Collaborating Laboratories

Laboratory Name	No. samples
Ashford	48
Bristol	30
Chelmsford	142
Chester	80
Hull	38
London	4
Newcastle	58
Norwich	53
Preston	19
Truro	53
Wessex Environmental Microbiology Services (Southampton)	246
Total	**771**

Table II. Other participating laboratories

Laboratory	No. samples
NPHS	
Bangor	13
Cardiff	12
Carmathen	9
Rhyl	2
Other	
Belfast City Hospital	60
Guernsey States Analyst's Laboratory	64
Kings Lynn & West Norfolk	51
Raigmore Hospital, Inverness	9
Marine Biological & Chemical Consultants	7
Total	**227**

Annex 2. Port Health Authorities/Local Authorities and Number of Samples Collected

Port Health Authority / Local Authority	No. samples
Belfast City Council Port Health Unit	41
Belfast PHA	19
Bristol PHA	18
Cardiff PHA	5
Dover PHA	10
Falmouth & Truro PHA	53
Fenland District Council	45
Great Yarmouth PHA	8
Highland Council Ross & Cromarty Area	9
Hull & Goole PHA	38
Ipswich PHA	9
Isle of Anglesey County Council	22
Kings Lynn & West Norfolk Borough Council	51
Lancaster PHA	19
London PHA	72
Manchester PHA	22
Medway Council	6
Mersey PHA	58
Portsmouth PHA	102
River Blyth PHA	36
Southampton PHA	144
States of Guernsey Environmental Health	64
Stroud District Council	12
Suffolk Coastal PHA	52
Swansea Bay PHA	9
Tendring District Council	45
Tyne PHA	22
Vale of Glamorgan Council	7
Total	**998**

Annex 3. Study proforma used to record potable and pool water practices and microbiological results

APHA/HPA Collaborative Study of Ships' Waters: PROFORMA

Port Heath/Local Authority Sampling details:

1. Name of Port………..
2. Port Health/Local Authority..........................……......……………………………………………………………...……...…..
3. Samples collected by...............…....………………...(PHO/EHO) 4. Sample collected at.……..……...(time) on (date) …..../….…./…..…
5. PHA/LA Sample Reference Number:…………………..…...………..

Ship details:

6. Ships' name ……..................……………......…………& Ships' former name(s)(if applicable)………………………..……………………
7. Ships' IMO / Official Number:……………………..………… 8. Shipline………………………………..……. or Not applicable ☐
9. Ships' home port / Flag State……………………………………..

10. Type of ship (please tick one):

Cargo	☐	Passenger Car Ferry	☐	Cruise Ship	☐
Fishing with cabin(s)	☐	RORO Passenger Ferry	☐	Other	☐(specify)……………..

11. What is the capacity number of: Passengers ……………..…... & Crew………..……..…….

12. What is the age of the ship?………………years or provide Year of Build: …………………..

13. Does the ship undertake international routes? YES ☐ NO ☐ If Yes please specify the last Port & Country visited & when: Port………..…..…… Country………………. Date ……/……/…..

Potable Water Sample:

14. Where was the sample collected from? Storage tank ☐ Galley tap ☐ Cabin (furthest point in distribution system) ☐ Drinking water dispenser (not bottled water) ☐

15. What is the free chlorine*: …………..mg/L *Please record chlorine levels using either a comparator test kit or commercial test kit*

16. Please record the temperature of the water at the outlet (take 1 minute after turning on the tap)……………°C

17. How many storage tanks are there on board (number):……..……… 18. What is the capacity of the tank(s)?...…..……...........L

19. Is the tank(s) insulated? YES ☐ NO ☐

20. When was the tank(s) last cleaned & disinfected (date): ……/……./…… Not known ☐

21. Please record the water temperature in the tank (via sampling point):……………..°C

22. When was the tank(s) last filled (date): ……/……./……. in which Port…………………… & which Country……..…………..…. & via Hose/Hydrant ☐ or Water barge ☐

23. Is water processed on board? YES ☐ NO ☐ If Yes is it by:

Reverse osmosis	☐	Distillation	☐
Evaporation techniques	☐	UV	☐
Other	☐ (specify)…………..……....……		

24. Are hoses disinfected before use? YES ☐ NO ☐ If Yes please specify…………………………………………………..……...

25. Are couplings disinfected before use? YES ☐ NO ☐ If Yes please specify……………………………………………………………...

26. Are hoses / couplings labelled "for potable water only"? YES ☐ NO ☐

27. Are hoses stored in a dedicated locker? YES ☐ NO ☐

28. Are the hoses owned by the ship? YES ☐ NO ☐

29. Is the piping of the potable water system appropriately colour coded? YES ☐ NO ☐
    (should be blue, or striped with blue bands, or a light blue stripe at fittings)

30. Are potable water quality checks routinely carried out? YES ☐ NO ☐
    30A) Are these on-board? YES ☐ NO ☐
    30B) How frequently are these carried out? Weekly ☐ Fortnightly ☐ Monthly ☐ Other ☐(Specify)………………….
    30C) What parameters are tested?……………………………………………………………….……………………………….
    30D) Who carried out the microbiological tests (specify Laboratory/Country)……………………………………………………………

Swimming Pool / Spa Pool Water Sample:

31. How many pools are there on board: Swimming pools (number)…………..…….. Spa pools (number) ……….….……….……..

32. Is the pool sampled a: Swimming pool ☐ or Spa pool ☐ & provide name/site of pool………………………………..…..

33. For Spa Pools, What is the spa pool design? Deck level with overflow ☐ or Displacement type (hot-tub design) ☐

34. Is the swimming/spa pool water: Sea water ☐ or Fresh water ☐

35. When was the pool last refilled (date): ….....…/….…/…..…

36. Is the pool? Outdoor ☐ or Indoor ☐

37. What is the normal pool treatment (tick all that apply)? Filtration ☐ Sand filter ☐ Diatomaceous earth ☐ Chlorine ☐ Bromine ☐ Ozone ☐ UV ☐ Other ☐ (Specify)………..…..

38. Is the disinfectant applied by: Hand ☐ Automatic dosing system ☐ Other ☐ (specify)………….……………………...…..

39. What disinfectant is used?……………………………………………….……………………………………………………………….

40. What is the target pH range of the water? ……………………..

41. What is the frequency of pH testing during normal operation? ≤2 hours ☐ > 2 hours ☐ (specify)………………………….

42. Do the ships' records indicate that this is consistently achieved? YES ☐ NO ☐

43. What is the pH of the water at the time of sampling? ……………..

44. What is the free chlorine: ……………. mg/L

45. What is the Total Chlorine/Bromine: ……………………mg/L

46. What is the target chlorine/bromine: ………………mg/L

47. What is the frequency of chlorine/bromine testing during normal operation (tick all that apply)? Before opening ☐ Every 2 hours when open ☐ Midway during opening hours ☐ After closing ☐

48. Do the ships' records indicate that this is consistently achieved? YES ☐ NO ☐

49. Are water quality checks routinely carried out? YES ☐ NO ☐
    49A) Are these on-board? YES ☐ NO ☐
    49B) How frequently are these carried out? Weekly ☐ Fortnightly ☐ Monthly ☐ Other ☐(Specify)……………………
    49C) What parameters were tested?……………………………………………………………………………………………………….
    49D) Who carried out the microbiological tests (specify Laboratory/Country)…………………………………….……………………

50. What is the size of the pool?………………… & what is the volume of water in the pool?……………………m^3

51. What is the turnover period (this is not the same as replacement) (days)?…………………………………………..…………..……

52. What is the frequency of backwashing?…………………

53. What is the throughput of bathers/day?………..… & what is the number of bathers at the time of sampling water…………………

54. Is the pool surround visually clean? YES ☐ NO ☐

55. How much water is displaced as a percentage of the system volume:………………………………

56. Is the pool water visually clear? YES ☐ NO ☐

For Spa pools only:

57. Is there a Legionella Risk Assessment? YES ☐ NO ☐

58. Is there a plan for response to adverse results from routine monitoring checks? YES ☐ NO ☐

59. Is the balance tank accessible for cleaning? YES ☐ NO ☐

PHA/LA Sample Reference Number……………………………………….

LABORATORY USE ONLY

Laboratory details:

Sample received in laboratory…….………. (time) on (date) .. …../. . …/… ….
Sample received by……………………………..……………………………..…..
Sample received from………………………….…………………..…………..…..
Temperature on receipt ……......°C
Sample examined ……………………….…. (time) on (date) ……/…..../..….
Laboratory Sample Number……………..……………………..

RESULTS:

Recording results *Record results using one of the appropriate tables below*

Please record the results of count per ml or 100ml as actual NUMBERS in the appropriate box within the table.

Please record the microbiological quality by placing ticks in the columns headed Satisfactory, Acceptable or Action Level as appropriate (please refer to Section 7 – 'Results' in the Sampling Protocol for the Summary of Microbiological Parameters)

Potable Water Sample

Parameter	CFU /ml or 100ml	Acceptable Level	Action Level
Coliforms / 100ml			
Escherichia coli / 100ml			
Enterococci / 100ml			
Aerobic Colony Count 37°C for 44h / ml			
Aerobic Colony Count 22°C for 68h / ml			

MICROBIOLOGISTS COMMENTS……..

………

Swimming Pool / Spa Pool Water Sample

Parameter	CFU /ml or 100ml	Satisfactory Level	Acceptable Level	Action Level
Coliforms / 100ml				
Escherichia coli / 100ml				
Pseudomonas aeruginosa / 100ml				
Aerobic Colony Count 37°C for 24h / ml				
Legionella spp.* (Spa pools only) / 1L	/ 1L			

***Optional Test**

MICROBIOLOGISTS COMMENTS………………………………………………………………………………………………………..
………

Signature ....……..........… Date reported ....…………..

Annex 4: Ports in which vessels were surveyed

Port Name	No. samples
Albert Dock, Hull	1
Alexandra Dock, Hull	1
Avonmouth Docks, Bristol	4
Barry	7
Belfast	60
Blyth	36
Cardiff	5
Chatham	6
Dover	10
Ellesmere Port	2
Falmouth	53
Felixstowe	52
Great Yarmouth	8
Guernsey	64
Harwich	45
Heysham	19
Holyhead	22
Hull	35
Invergordon	9
Ipswich	9
Kings Lynn	46
Liverpool	58
London	10
London Purfleet	4
London Thames Refinery	2
London Thamesport	3
London Tilbury	37
London Tilbury Power Station	1
London Vopac	2
Manchester	7
Cerestar, Manchester	2
Ince Oil Berth, Manchester	3
Stanlow, Manchester	8
Neath	2
North Killingholme	1
Port Talbot	2
Portsmouth	102
Ridham Sea Terminals	2
Royal Portbury Docks Bristol	14
Sharpness	12
Sheerness	11
Southampton	144
Sutton Bridge	47
Swansea	5
Tyne	22
Wisbech	3
Total	**998**

Annex 5. Ship types surveyed and Number of Samples Collected

Ship type	No. samples
Accommodation Vessel (stabilized mobile offshore unit)	3
Adapted fishing vessel (used as concert venue)	3
Bunkering Barge	3
Cable Layer	2
Cargo	571
Cargo & Passenger Car Ferry (Roro cargo ship)	17
Cruise Ship	162
Dredger	4
Drill Support	1
Drilling Rig (Semi-submersible)	3
Fishing vessel with cabin(s)	2
Lighthouse Tender	3
Naval Vessel	13
Offshore Supply Ship/Tug	3
Oil Platform	3
Passenger Car Ferry	83
Passenger Ferry	3
Rescue	6
Research Vessel	20
Sail Training Vessel	10
Salvage	1
Tall Ship	3
Tanker	48
Trip Boat	2
Tug	21
Well Stimulation Vessel	8
Total	**998**

Annex 6. Last country visited by ship and number of samples

Last Country Visited by Ship	No. samples
Antigua	4
Australia	6
Azores	12
Belgium	66
Brazil	3
Bulgaria	1
Channel Islands	7
Costa Rica	16
Denmark	17
Dominican Republic	12
Egypt	6
Estonia	7
Finland	5
France	109
Germany	56
Gibraltar	1
Greece	1
Guernsey	7
Iceland	2
Ireland	64
Italy	12
Jamaica	25
Kenya	2
Latvia	6
Malaysia	3
Mexico	3
Mozambique	2
Netherlands	149
Netherlands/ Colombia	4
New Zealand	3
Nigeria	2
Norway	26
Poland	10
Portugal	20
Russia	12
Senegal	21
South Africa	4
Spain	46
Sweden	22
Tunisia	3
Turkey	1
UK	84
USA	18
None yet*	2
Not recorded	116
Total	**998**

*Newly constructed