

The microbiological quality of potable water on board ships docking in the UK and the Channel Islands: an association of Port Health Authorities and Health Protection Agency Study

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ABSTRACT

Providing safe potable water onboard vessels presents particular challenges and contamination can occur directly from source waters as well as during loading, storage and distribution. Between May and October 2005, 950 potable water samples were collected from 342 ships docking at ports. Comparison with Guidelines found 9% of samples contained coliforms, *Escherichia coli* or enterococci and 2.8% had faecal indicators (*E. coli* or enterococci). Action levels of aerobic colony count (ACC) bacteria were detected in 20% (22°C) and 21.5% (37°C) of samples. ACC results from one-off sampling are not informative as this does not enable port health authorities to monitor ACC trends. They should be removed as a routine criterion for remedial action and vessels should adopt the WHO Water Safety Plan approach, whilst continuing to monitor water quality with public health-based indicators (e.g. chlorine residual, coliforms, *E. coli* and enterococci). Logistic regression analyses identified practices associated with water quality. Practices protective against coliforms, *E. coli* or enterococci in potable supplies were: good hose hygiene, processing water onboard, maintaining free chlorine residual at ≥ 0.2 mg/L. This emphasizes the importance of good hygiene during potable water loading and maintaining adequate disinfection of supplies onboard.

Key words | bacterial indicators, potable water, public health, ships, water quality

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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. 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 holidays have increased in popularity.

Outbreaks of human illness associated with ships' water supplies are well described (Davies *et al.* 1972; Merson *et al.* 1975; Hooper & Husted 1979; O'Mahony *et al.* 1986; Khan *et al.*

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1994; Mintz *et al.* 1998; Daniels *et al.* 2000; Cramer 2002) 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 (BBC News 2006a,b). A recent WHO (2001) review implicated waterborne transmission in approximately one-fifth of outbreaks occurring aboard vessels between 1970 and 2000. 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.

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” (WHO 2001), from source to consumption. The WHO *Sanitation on Ships* guide provides practical advice on protecting potable water supplies onboard ships and is in the process of being up-dated to reflect contemporary ship design and current infectious disease risks (WHO 2006). The development and implementation of a Water Safety Plan, based on the Hazard Analysis and Critical Control Point (HACCP) approach used in the food industry, is recommended as an effective means of ensuring a safe water supply through its design, construction, operation and routine inspection and maintenance (WHO 2004).

In the UK the master of a ship is legally obliged to provide an adequate water supply fit for human consumption, in line with the Merchant Shipping (Provisions and Water) Regulations 1989 (with the exception of ships under 24 metres in length, pleasure craft, submersible craft, offshore installations whilst on or within 500 metres of their working stations) (Anon 1989). However, the Water Supply (Water Quality) Regulations 2000 (Anon 2000) which apply to mains potable water supplies 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) (HPA 2003). 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 per 1 ml.

The use of indicator organisms to monitor the potential presence of waterborne pathogens is well established on the basis that these “indicator bacteria” indicate the risk of contamination with human or animal faeces and/or deterioration of water quality. Unlike methods used to detect specific pathogens, monitoring for indicator organisms provides a sensitive and rapid result and has served well to protect public health from drinking water related illness (EA 2002). 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 derive from vegetative sources, soil or may grow attached to surfaces within the water distribution system. The presence of coliforms may therefore not be directly related to faecal contamination or present a direct risk to public health, but indicates post process contamination, re-growth or local contamination within the distribution system (EA 2002). *E. coli* and enterococci in drinking water are direct indicators of contamination with human or animal faeces and may also indicate the presence of enteric pathogens (EA 2002). Examination of water samples for ACC (heterotrophic) bacterial growth which is carried out at 37°C and 22°C, with the same action level for both tests, does not give any indication of faecal contamination and is of limited public health value unless levels are monitored regularly, whereby an increase above expected levels can indicate insufficient disinfection efficacy of potable water supplies (EA 2002).

The frequency with which authorised UK Port Health Officers inspect ships docking in the UK is based on a risk rating system outlined in the statutory Food Law Code of Practice (Food 2006) (although initially consideration is given to any available documentation from the ship's master identifying all food and water related activities undertaken on the vessel). Together with regular inspection of ships' water supplies and risk assessment, water quality monitoring is an important element 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 potable 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* (HPA 2003). 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

Between 1 May and 31 October 2005, staff from 19 Port Health Authorities and nine Local Authorities collected 500-ml potable water samples from ships docking in UK and Channel Islands ports. Samples were transported to laboratories in accordance with the *Guidelines for Water Quality on board Merchant Ships Including Passenger Vessels* (HPA 2003). Free chlorine concentration was analysed at the time of sampling by the sampling officer, using a comparator or commercially available test kit.

Information on samples and ships was obtained by observation and enquiry and recorded on a standard questionnaire. This included information on the vessel such as age and type of ship, passenger and crew capacity, and if international routes were undertaken. Additional information collected on potable water samples included the supply, treatment and storage of water, and whether routine water quality checks were carried out.

Sample examination

Potable water samples were examined for ACC, enterococci, *E. coli* and coliforms in 20 Official Control Laboratories. ACC, enterococci, *E. coli* and coliforms were enumerated in accordance with HPA Standard Microbiological Methods (HPA 2005a, b, c, d). Microbiological results of potable water samples were compared with published criteria (Table 1) (HPA 2003).

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 different potable water indicator organisms (presence/absence) was assessed using simple logistic regression,

Table 1 | Microbiological criteria for potable water on board ships (HPA 2003)

Parameter	Acceptable level	Borderline level	Action level
Coliforms	0 in 100 ml	–	≥ 1 in 100 ml
<i>E. coli</i>	0 in 100 ml	–	≥ 1 in 100 ml
Enterococci	0 in 100 ml	–	≥ 1 in 100 ml
ACC	< 100/1 ml	100–1000/ml	≥ 1000/1 ml

tests for trend and Fisher's exact tests. The correlation between ACC counts 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 presence of coliforms, *E. coli* and/or enterococci in potable water samples was assessed using logistic regression. Variables were considered statistically significant at $p < 0.05$. Factors significant at $p < 0.1$ in the univariate analyses were included in a stepwise multiple logistic regression model. Tests for confounding of variables were performed using chi-squared tests and stratified logistic regression. As multiple samples were taken from ships, all logistic regression models were performed with random effects to control for clustering by individual ships.

RESULTS

Nine-hundred and fifty potable water samples were collected from 342 ships at 43 ports across the UK and The Channel Islands. Over half (57%; 571) of the samples were taken from cargo vessels, 162 (16%) from cruise ships and 83 (8%) from passenger ferries. Other vessels surveyed included container ships, naval ships, tug boats, research vessels and rescue boats.

Ships were aged between less than one and 65 years (median = 13 years; 95% CI 12–14 years) with the capacity for 0 to 2500 passengers and 1 to 1000 crew members (median_{passengers} = 20; median_{crew} = 19). Eighty-eight percent (301/342) of ships surveyed undertook international routes; in the majority of cases (193/348) vessels had most recently visited a port in Northern Europe, 11% (38/348) had arrived from Southern Europe and 12%

(41/348) from international destinations. Less than 1% (27/348) had returned from a location within the UK. Ships were sampled a median of 3 days after departing their most recent destination.

Most potable water samples were taken from galley taps (42%; 403/949) and cabins (or the furthest point in the distribution system) (32%; 304/949). The remainder were collected from water storage tanks (16%; 146/949) and drinking water dispensers (10%; 96/949). Outlet water temperature ranged from 0 to 40°C (mean = 21.3°C, SD = 5.2°C) and storage tank water from 6 to 37°C (mean = 20.4°C, SD = 4.9°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). Potable water free chlorine concentration ranged from 0 to 22 mg/L, with a median of 0.06 mg/L (95% CI 0.05–0.07 mg/L). Twenty percent (190/950) of samples contained a free chlorine residual within the recommended range (0.2–5.0 mg/L) (HPA 2003; CDC 2005), 49% (467/950) fell below the minimum recommended concentration, and 0.4% (4/950) exceeded the recommended maximum.

Microbiological quality of potable water

The proportions of samples containing action levels of coliforms, *E. coli* and enterococci (≥ 1 CFU in 100 ml) are shown in Table 2. Approximately nine percent (79/918) tested positive for at least one of the 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 in 100 ml, respectively (median count = 0 for all indicators).

Table 3 shows the proportions of ships yielding at least one action level sample, stratified by ship type. Coliforms, *E. coli* or enterococci were detected in potable supplies onboard 54 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%) 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 3).

The proportion of samples containing action levels of ACC bacteria (≥ 1000 CFU/ml) was slightly higher at 37°C than at 22°C (Table 4). Bacteria recovered in colony counts at 22°C generally represent those bacteria naturally present in water and are not of sanitary significance, and thus, have limited public health significance, whereas colony counts at 37°C are thought to indicate a deterioration in quality (EA 2002). ACC levels ranged from 0 to 300,000 CFU/ml at 37°C (median = 55 CFU/ml) and 0 to 110,000 CFU/ml at 22°C (median = 38 CFU/ml). ACC levels at the two temperatures were correlated (correlation coefficient = 0.627; $p < 0.0001$). 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 (at 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).

Correlation between indicator organisms

Of 203 samples containing action levels of ACC, 25 (12.3%) contained coliforms, three (1.5%) contained *E. coli*, and eight (3.9%) contained enterococci. Thirty-three (16.3%) potable

Table 2 | Potable water samples containing coliforms, *E. coli* and/or enterococci

	Coliforms	<i>E. coli</i>	Enterococci	Faecal indicators (<i>E. coli</i> /enterococci)	Coliforms, <i>E. coli</i> or enterococci
Action level samples (≥ 1 CFU in 100 ml)	64/947	7/947	19/918	26/918	79/918
% total	6.76%	0.74%	2.07%	2.83%	8.61%

Table 3 | Ships containing coliforms, *E. coli* or enterococci in at least one potable water sample

Ship type	No. ships yielding ≥ 1 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%

water samples with an ACC action level contained at least one of these organisms. The proportion of samples containing coliforms increased with ACC 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, $p < 0.001$).

Action levels, i.e. the presence, of coliforms in potable water samples were significantly associated with those of faecal indicators (*E. coli* and/or enterococci) (OR = 11.61, $p < 0.0001$). Seventeen percent (11/64) of samples containing coliforms also contained faecal indicators and 42.3% (11/26) of samples containing faecal indicators contained coliforms. The presence of coliforms, *E. coli* and/or enterococci was therefore used as the outcome in all logistic regression analyses.

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

CFU/ml	No. samples (% total) ACC at 22°C, 68 \pm 4 hrs	ACC at 37°C, 44 \pm 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

Univariate analysis: presence of coliforms, *E. coli* or enterococci

Ship characteristics and routes travelled

The risk of potable water samples containing coliforms, *E. coli* and/or enterococci increased with ship age (OR_{log-age} = 2.32, $p = 0.016$) and declined with increasing crew capacity (OR_{<10} = 1.00, OR₁₁₋₅₀ = 0.15, OR_{>50} = 0.11; $p = 0.016$). There is some evidence to suggest that samples were less likely to contain these indicators if vessels undertook international routes, compared with those travelling in the UK only (OR = 0.14, $p = 0.061$) (Table 5). Vessel type, passenger capacity, last region visited and time since departure from that destination showed no association with the presence of indicator organisms in potable water samples ($p = 0.157, 0.605, 0.628$ & 0.240 , respectively).

Potable water loading

Microbiological water quality was associated with the region in which potable water was most recently loaded: action level samples were less likely to occur on ships loading in Northern Europe (OR = 0.15, 95% CI 0.03–0.66) compared with the UK (destinations outside of Europe did not differ significantly from the UK) (overall $p = 0.047$; Table 5). Analysis of variables relating to loading practices revealed a reduced risk of action levels of coliforms, *E. coli* and/or enterococci on board vessels using their own hoses (OR = 0.22, $p = 0.006$), disinfecting hoses and couplings before use (OR_{hoses} = 0.04, $p < 0.0001$; OR_{couplings} = 0.007, $p = 0.008$), and storing hoses in dedicated lockers (OR = 0.15, $p = 0.014$). Potable water quality was not associated with the time period since storage tanks were last filled ($p = 0.722$) and the method used (hose and hydrant *versus* water barge; unadjusted Fisher's exact $p = 0.610$).

Potable water storage

Microbiological potable water quality was associated with storage tank capacity: ships with tanks of medium volume (1000–10,000 litres) yielded a higher proportion of action level samples than other tank capacities onboard vessels (OR = 16.06, $p = 0.005$; Table 5). The number, insulation,

Table 5 | Univariate and multivariable analyses: microbiological quality of potable water on board ships (presence of coliforms, *E. coli* and/or enterococci)

Variable	Univariate analysis Odds Ratio (95% CI)	p-value	Multivariate analysis Odds Ratio (95% CI)*	p-value
Age of ship (<i>natural log</i>)	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 ≥ 0.2 mg/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	0.014
1	0.07 (0.009–0.57)		0.08 (0.01–0.59)	0.102
2	0.20 (0.03–1.46)		0.22 (0.37–1.34)	–
3	–		–	0.002
4	0.007 (0.0004–0.11)		0.03 (0.002–0.27)	
Hoses & couplings labelled <i>Potable Water Only</i>	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).

[†]This odds ratio represents the average increase in risk with each log-unit increase in age (age was log-normalised to meet the assumptions of the regression model).

[‡]The hose hygiene score relates to how many of the 4 potable water loading practices were in place (ships owning hoses, storing hoses in dedicated lockers, disinfecting hoses and of couplings before use).

water temperature and time since last cleaning of storage tanks were not associated with the presence of coliforms, *E. coli* and/or enterococci ($p = 0.142, 0.493, 0.412$ & 0.153 respectively). Colour-coding of potable water pipes also showed no effect on microbiological water quality ($p = 0.161$).

Storage and usage sites of potable water

Potable water samples taken from storage tanks and galley taps were more likely to be of poorer microbiological quality (contain action levels of coliforms, *E. coli* and/or enterococci) than those from cabins or the furthest point in the distribution system ($OR_{\text{storagetanks}} = 3.71$;

$OR_{\text{galleytaps}} = 3.44$; $p = 0.038$; Table 5). A potable water free chlorine concentration at or above the recommended minimum (0.2 mg/L) was significantly protective against the presence of indicators ($OR = 0.13, p = 0.008$). Outlet water temperature showed no association with microbiological water quality ($p = 0.630$).

Potable water processing and quality monitoring

Processing potable water on board was protective against the presence of indicator organisms ($OR_{\text{processing}} = 0.13, p = 0.002$; Table 5). However, no individual processing or treatment method – distillation, evaporation, reverse

osmosis, ultraviolet irradiation, chlorination or filtration – was identified as being significantly more protective than the others. Using more than one method did not confer additional benefit to processing with a single technique ($p = 0.191$).

There is some evidence to suggest that performing regular water quality checks is protective against generating action level samples ($OR_{\text{regular checks}} = 0.29$, $p = 0.064$; Table 5).

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

Prior to multivariable analysis, tests for confounding revealed that four variables relating to potable water 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. These variables were therefore combined into a “hose hygiene score” (0–4), assigned according to how many of these four factors were in place.

Testing for confounders also showed that the association between sampling site (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 ($< \text{or} \geq 0.2 \text{ mg/L}$); 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 5). The risk of generating action level samples increased with age ($OR_{\text{log-age}} = 1.99$, $p = 0.029$) but was reduced in vessels processing potable water onboard ($OR = 0.16$, $p = 0.025$). Ships reporting all four hose hygiene practices – ownership of hoses, storage of hoses in dedicated lockers, disinfection of hoses and couplings before use – were at less risk of their potable supplies containing coliforms, *E. coli* and/or enterococci ($OR = 0.03$, $p = 0.002$) (performing at least one of these practices was protective to a lesser extent; Table 5). There is also some evidence that a free chlorine concentration at or above 0.2 mg/L also remained protective ($OR = 0.19$, $p = 0.071$).

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 100 ml sample, or unacceptable levels of ACC bacteria ($\geq 1000/\text{ml}$), remedial action should be taken to restore adequate water quality (HPA 2003). In this study, 8.6% of potable water samples contained coliforms, *E. coli* or enterococci. This is comparable to the failure rate of potable water samples collected from ships during PHA inspections in England in 2002, examined by Health Protection Agency (HPA) and HPA collaborating laboratories (8.3% of samples from 1609 ships contained coliforms or *E. coli*; C. Lane, HPA personal communication). Coliforms are very sensitive to the levels of chlorine used in water treatment, their presence in potable water may indicate inadequate disinfection or post process contamination not necessarily of faecal origin. However, the presence of *E. coli* and enterococci are indicative of faecal contamination of the supply, either arising directly from source waters or during loading, storage or distribution.

This study has highlighted practices which can protect against poor water quality in ships' water supplies. Potable water was less likely to contain coliforms, *E. coli* or enterococci if vessels owned their hoses, stored these hoses in dedicated lockers and disinfected loading equipment 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 (HPA 2003; MCA 2004; CDC 2005; APHA 2006). 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 (0.2 mg/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 (HPA 2003; MCA 2004; CDC 2005).

This study identified an association between processing potable water on board and improved microbiological water quality. Potable water supplies on 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 a limited number of ships, the findings reported here provide evidence of the potential benefits of processing potable water on board vessels. Whilst loading potable water from a good quality source is clearly preferential to treating contaminated water (Rooney *et al.* 2004), further investigation into the effects of different processing methods may reveal the most appropriate techniques for vessels with the capacity for on board potable water processing.

The presence of coliforms, *E. coli* or enterococci in potable water was also related to ships' age, samples from older ships being at greater risk of microbiological failure. Examination of ships' water supplies in England during 2002 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.* (2003) have described a similar trend, whereby the likelihood of failing sanitary inspection scores increased with ship age. This underlines 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, 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 (WHO 2003). 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' on board. The WHO Expert Consensus on Heterotrophic Plate Counts (equivalent to ACC) and Drinking Water Safety states that "Heterotrophic Plate Count 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" (WHO 2003). This questions the public health value of PHAs or local authorities testing ships' potable water supplies for ACCs, 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, and (3) management plans for normal and incident conditions (WHO 2006). Rooney *et al.* (2004) 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 on board cruise ships arriving from overseas, as a means of highlighting and managing risks in the water supply chain. Vessels must then 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 (Rooney *et al.* 2004).

CONCLUSIONS

The Water Safety Plan approach enables 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 appropriate training of crew and port health officers, this strategy would provide an effective means of protecting ships' potable water supplies.

This study has highlighted practices which may facilitate the provision of safe potable water supplies on ships and based on these, the following conclusions and recommendations are made:

- (1) The Water Safety Plan approach should be adopted by vessels to assess, maintain and manage the safety of potable water supplies onboard, according to *WHO Guidelines for Drinking Water Quality 3rd Edition* (WHO 2004), with appropriate training of crew and inspecting port health officers.
- (2) The aerobic colony count (ACC) should be removed as a criterion for remedial action, since one-off sampling by port health authorities does not enable monitoring of ACC trends in potable supplies on ships. However, vessels with the capacity to test onboard, or those PHAs who 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) Monitoring of the microbiological quality of potable water on board ships should continue, using public health based indicators as per the current guidelines (coliforms, *E. coli* and enterococci), and appropriate remedial action be taken where necessary.
- (4) Hygienic practices should be in place throughout the potable water loading process, storing hoses in dedicated lockers and disinfecting hoses and couplings before use.
- (5) Maintaining free chlorine concentrations of at least 0.2 mg/L (and below 5.0 mg/L), as per the current guidelines, is essential to protect the quality of potable water supplies onboard ships.

These recommendations will be used to inform a revision of the current *Guidelines for Water Quality on Board Merchant Ships Including Passenger Vessels*, to ensure the safety of potable water supplies on vessels and protect the health of their passengers and crew.

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