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ABSTRACT
This study aims to establish the spatial distribution of stream water faecal coliform (FC) concentrations in specific winter recreation areas in the Northern Corries of the Cairngorm Mountains, Scotland. A total of 207 water samples were collected from 10 sites during two winter seasons (2007–2008 and 2008–2009) and analysed by Colilert® 24 for the presence of FC, specifically *Escherichia coli* (*E. coli*). *E. coli* was not detected at Sites 1–7, above 635 m. Sites 8, 9 and 10 (below 635 m) had positive detection rates for *E. coli*, these being 32%, 35% and 31%, respectively. Results provide important data on the level of faecal bacteria in selected Scottish mountain streams, whilst also providing comparative benchmark data for similar studies proposed in other UK upland recreational hotspots.

KEY WORDS: faecal coliforms, *E. coli*, winter recreation, human waste, cairngorms, Scotland

1. Introduction

In 2003 the Cairngorms National Park (CNP) became the second national park in Scotland, following the Trossachs and Loch Lomond National Park, which was established in 2002. CNP is the largest national park in the UK, having an area of approximately 3800 km2. The Cairngorms National Park Authority (2007) reported that approximately 10% of the land is owned by the government; 75% is privately owned, with non-governmental organisations owning approximately 13%. CNP is listed as a Natura site, and is a Category V protected area under the International Union for Conservation of Nature’s categorisation (Dudley 2008), focusing on the protection and conservation of landscapes created by traditional management practices. It is visited by approximately 1.4 million people each year (Cairngorms National Park Authority 2007). Given CNP’s national and international importance, the increasing trend in visitor numbers has the potential to increase environmental impacts. The Northern Corries are widely accepted as a major recreational resource for skiing, winter mountaineering and mountain walking. It is therefore important to develop our knowledge of faecal coliform (FC) levels in mountain streams flowing through the Northern Corries area.

Cole and Landres (1996) argued that the effects of recreation on aquatic systems is often more spatially extensive than the effects on soil and vegetation, concluding that most recreational research focused on terrestrial environments. They identified the need for more research into the effects of human activity on individual watercourses.

The oligotrophic watercourses of the CNP are a result of granite geology and are very sensitive to even low levels of eutrophication (Bryan 2002). Numerous organisations such as the Mountain Bothies Association (MBA) and the Mountaineering Council of Scotland (MCoS), advise recreation seekers to bury their organic waste. Liddle and Scorgie (1980) and Temple *et al*. (1982) identified the potential persistence and associated effects of the burial of human faeces. Bryan (2002) reported increased levels of coliform bacteria, up to 10 times that of the accepted background levels, around the Ryvoan Bothy (Mar Lodge Estate). However, Bryan (2002) did not quantify FC levels. Although not conclusive evidence of human-derived contamination, the findings highlight a tenuous link between areas of human activity and raised coliform levels in mountain streams.

Leung and Marion (2000) reported that the summit of Mount Rainier receives up to 10,000 climbers each year, raising the possibility of faecal contamination of watercourses. However, the investigations by Ells (1997, 1999) indicated that there was no significant evidence of faecal contamination derived from surface runoff. Caution is needed when making generalisations from the Muir Snowfield to other locations. The snowfields on Mount Rainer are permanent and do not see the extensive annual summer thaws observed in the sub-arctic climate of the CNP.

The disposal of human waste is a recurring concern amongst wilderness managers with visitation trends having a potential impact on FC levels (Cilimburg *et al*. 2000). The impact of wild camping has been a focus of attention for the various recreational governing bodies, such as the MCoS, MBA and British Mountaineering Council. During the winter months, concerns generally relate to the activity of snowholing and bothies, since tented camps are less popular in the harsh winter conditions. Anecdotal evidence (Cairngorm Ranger, pers. comm., 16 April 2009) suggested that during the 2008/2009 winter season, in the region of 400 snowholing parties had accessed Ciste Mhearad (site 1, Figure 1), one of the closest snowholing sites to the Coire Cas ski area (Figure 1). Considering the views of Cilimburg *et al*. (2000), this level of activity has the potential to cause numerous environmental impacts.

FCs are described synonymously with Escherichia coli (*E. coli*), which forms 60–90% of Total Coliform (TC) group (Leclerc *et al*. 2001) and are widely accepted as a suitable Faecal Indicator Organism. FCs are classified as thermotolerant coliforms, a point argued by Payment *et al*. (2003), which is based on the fact that not all thermotolerant coliforms are of faecal origin. Mediums such as industrial effluents or decaying plant materials and soils can be sources of origin for thermotolerant coliforms. Toranzos *et al*. (2002) classify FC (including *E. coli)* as thermotrophic or facultative thermophiles, which are tolerant to high temperature.

Mountains and upland areas provide 70% of the country's water supplies (Watson & Albon 2011). These upland 'water towers' supply the local population for consumption, but also provide water resources for industry and recreation. Aquatic habitats have many variables affecting bacterial growth, for example, temperature and pH (Foppen & Schijven 2006)

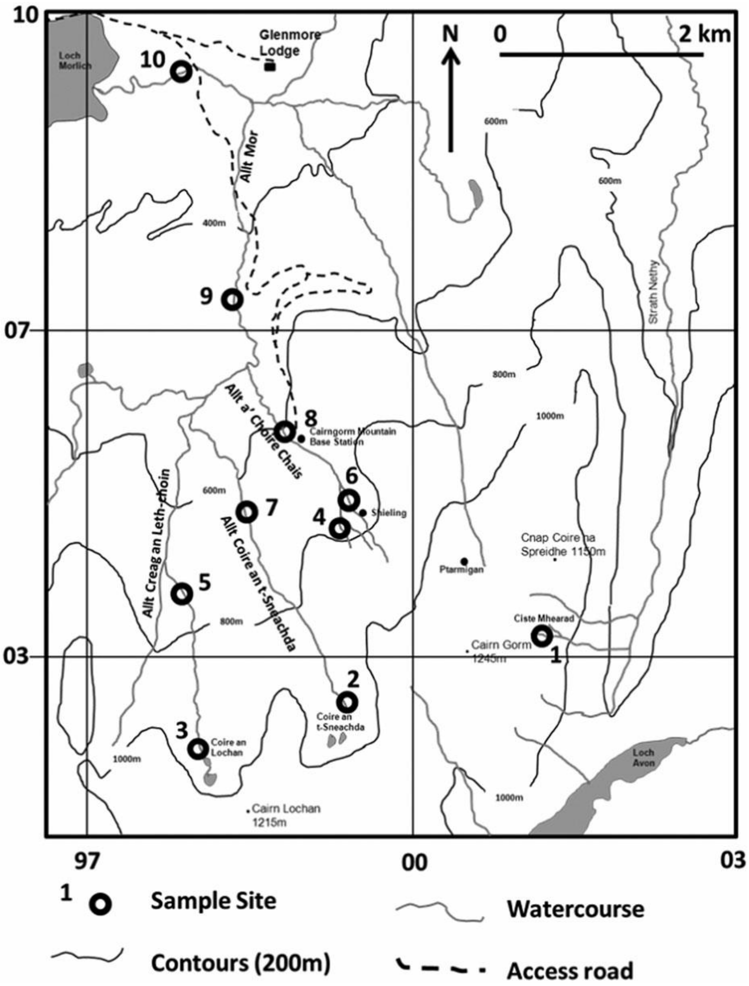

Figure 1 Location of stream water sampling points in the Northern Corries, Cairngorms.

and bacteriophage predation (Ashbolt *et al*. 2001). The thermotolerant nature of these bacteria means that they become dormant in colder conditions (Alonso *et al*. 1999; Leclerc *et al*. 2001; Toranzos *et al*. 2002) particularly in the sub-zero temperatures normally observed during winter on higher ground in CNP. All these factors have a major impact on the mortality and persistence, or as Schueler (2000) refers to it 'die off', of FCs, including *E. coli*.

Previous research has reported the microbial status of watercourses in remote areas for example: Schueler (2000); Foppen and Schijven (2006); Kay *et al*. (2008) and McDonald *et al*. (2008). Youn-Joo and Breindenbach (2005) monitored *E. coli* and TC in natural springs in areas associated with mountain recreation, concluding that there might be unacceptable risks to human health when drinking from 'raw' water. McDonald *et al*. (2008) conducted a bacterial survey of the waters within the CNP, taking 481 spot samples from 59 sites between March 2001 and October 2002. An estimated 75% of their samples tested positive for *E. coli* and 85% for TC. There is a plethora of studies of faecal bacteria in low-altitude catchments where microbial loading of watercourses originates from agricultural and stock grazing lands (e.g. Hunter *et al*. 1992; Wilkinson *et al*. 1995; Hunter *et al*. 1999; Rodgers *et al*. 2003; Cimenti *et al*. 2005), and for recreational areas used for watersports (e.g. Fewtrell *et al*. 1992). However, few data are available for specific upland recreational areas. This paper is a response to the work of Bryan (2002) and McDonald *et al*. (2008), but focuses on the FC status of watercourses in the main winter recreation areas of the Northern Corries. Consequently, the aim of the study reported here is to establish the spatial distribution of stream water bacterial concentrations under a variety of winter recreational user intensities in the Northern Corries of the Cairngorms National Park.

2. Materials and Methods

2.1. Field Procedures

Monthly field visits (December to May) to the Northern Corries, CNP, were undertaken over two winter seasons (2007–2008 and 2008–2009) following the methodologies employed by Schoonover and Lockaby (2006). In total, 207 water samples were retrieved from eight streams and two lochans (Figure 1; Table 2 – Supporting Information presents descriptive statistics for all sampling sites).

Samples were collected in sterilised 100 ml polypropylene bottles using the grab method (Lurry & Kolbe 2000). Individual samples were taken at a depth of approximately 0.6 of the total flow depth (Wilkinson *et al*. 1995) for the purpose of consistency and reliability (Swank & Crossley 1988; Swank & Waide 1988). Water samples were stored in a cold box during transportation and analysed within 24 h of collection in line with the methods of Olson *et al*. (1991), Tam (2000) and Kay *et al*. (2008). The streams were chosen to include the most prominent watercourses in the five main winter recreational areas of the CNP (Figure 1): (1) the popular snowholing area of Ciste Mhearad (site 1); (2) the popular climbing/mountaineering areas of Coire an t-Sneachda and Coire an Lochan (sites 2 and 3); (3) winter walking/ski touring areas (sites 5 and 7); (4) downhill skiing areas (sites 4 and 6) and (5) areas downstream of ski and tourist infrastructure (sites 8, 9 and 10).

The Northern Corries area is dominated by upland grasses and heather, which is grazed by mammals and birds such as Mountain Hare (Lepus timidus), Reindeer (Rangifer tarandus) and Ptarmigan (Lagopus mutus), all of which are potential sources of coliform bacteria.
Below the 500 m contour, this vegetation becomes replaced by Caledonian Pine forest.

2.2. Laboratory Procedures

Colilert 24® was used to detect the presence of *E. coli* colony-forming units (cfu). Colilert® products are manufactured by IDEXX Technologies and are widely used in the watertesting industry. They have been compared to International Standard Organisation reference methods (Niemela *et al*. 2003). All samples were processed under aseptic conditions and incubated as per manufacturer's instructions for 24 h at 35 ± 1°C. Technical training and specialist equipment were offered by IDEXX industries. Simpson *et al*. (2002) offer a critique of an alternative method of analysis, Microbial Source Tracking (MST), which allows for differentiation between sources of *E. coli* bacteria, that is, human or animal. Over the recent decades, this technique has gained favour when attempting to identify exact sources of microbial pollution (Simpson *et al*. 2002). Whilst this is an important point to note, the differentiation of sources was not an aim of this study. Furthermore, Quilliam *et al*. (2011) identify major limitations with MST, particularly the fact that it does not deal well with the complexity associated with the persistence and survival of indicator species within the environment. They also raised concerns over the spatial and temporal heterogeneity within these different environments, and suggest that spatial heterogeneity can confuse attempts to identifying the source, particularly when water bodies are not well mixed. Therefore, the authors deem the use of MST as being outside the scope of this study.

2.3. Enumeration of the Results

Colourless wells were deemed negative. Wells of a yellow colour, equal to or greater than the IDEXX Comparator Tray were viewed under a 6 watt 365 nm UV lamp. Fluorescent wells were recorded as positive for *E. coli*. The final calculations of cfu 100 ml?1 utilised the IDEXX MPN Generator Software and then exported into Microsoft Excel for statistical handling.

3. Results

E. coli was not present in any samples sourced from sites 1 to 7 during the study period (Table 1). *E. coli* was detected at sites 8 (Day Lodge Car Park), 9 (Sugar Bowl Car Park) and 10 (Glenmore Bridge) with the percentage of positive samples being 32%, 35% and 31%, respectively (Table 1). Figure 2 is a schematic representation of the *E. coli* data for the whole study area.

4. Discussion

The analysis shows that *E. coli* was not present during the sampling campaign at sites 1 to 7. Samples from Ciste Mhearad (site 1), the popular snowholing site, revealed no *E. coli*. This does not necessarily mean that *E. coli* were not present; it could be that any contaminated water bypassed the sampling location during flush events, which occurred between the monthly sampling times. In comparison, McDonald *et al.* (2008) presented *E. coli* detection rates for the Mar Lodge Estate, Cairngorms, where % detection for *E. coli* ranged from 59% to 93%. In that study, samples were collected between March and October, and McDonald *et al*. suggested that wild camping activity in the study area might have affected bacterial levels. Whilst it is tempting to compare our data with those reported by McDonald *et al*. (2008) from the south side of the CNP, it is problematic due to their samples being collected during the summer season. Also, McDonald *et al*. (2008) show in their Figure 1 that samples were taken from an altitude range from 350 m at Linn of Dee to 650 m in Luibeg Burn. In contrast, samples in our study were taken between 326 m at Glenmore Bridge and 1099 m in Ciste Mhearad, showing that our sampling extends the altitude range sampled by McDonald *et al*. (2008) upwards by around 450 m.

There could be several reasons for the detection of *E. coli* at sites 8–10. The presence of tourist and visitor infrastructure could be influential. As increases in visitor numbers are recorded so the pressure on the sanitation systems also increases. Another possibility is that animal or recreational visitor densities could be higher at these lower altitudes.

In 2013 the Water Environment (Controlled Activities) (Scotland) was amended and continues to regulate organisations in Scotland, which apply for a Scottish Environment Protection Agency (SEPA) licence for ‘consented release’. SEPA (2013) define ‘consented release’ as the release of any liquid produced in the course of any business. The authors therefore assume that

Table 1 Descriptive statistics for *E. coli* at 10 sampling locations for the 2008 and 2009 winter seasons (December to May) in the Northern Corries, Cairngorms

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site number	1	2	3	4	5	6	7	8	9	10
site name	Ciste Mhearad	Coire an t-Sneachda source	Coire an Lochan source	Cas Bridge	Coire an Lochan fords	White Lady	Coire an t-Sneachda fords	2008 Day Lodge Car Park	Allt Mor at Sugar Bowl Car Park	Glenmore Bridge
Altitude (m)	1099	929	913	821	752	738	645	624	467	326
Location	NJ 01122 04694	NH 99397 03609	NH 98102 03084	NH 99597 05069	NH 97972 04449	NH 99552 05409	NH 98512 05259	NH 98872 05964	NH 98422 07144	NH 98042 09449
Aspect	ENE	N	N	NW	NNW	NW	NNW	NNW	N	W
No samples	31	18	18	18	16	26	17	26	18	19
EC mean	0.0	0.0	0.0	0.0	0.0	0.0	0.0	7.3	3.3	3.3
EC min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	2.6	1.0	2.6
EC max	0.0	0.0	0.0	0.0	0.0	0.0	0.0	16.9	5.2	4.7
EC stdev	0.0	0.0	0.0	0.0	0.0	0.0	0.0	6.4	2.2	1.1
EC SE	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.8	0.7	0.4
EC % positive	0.0	0.0	0.0	0.0	0.0	0.0	0.0	32.4	32.5	30.7

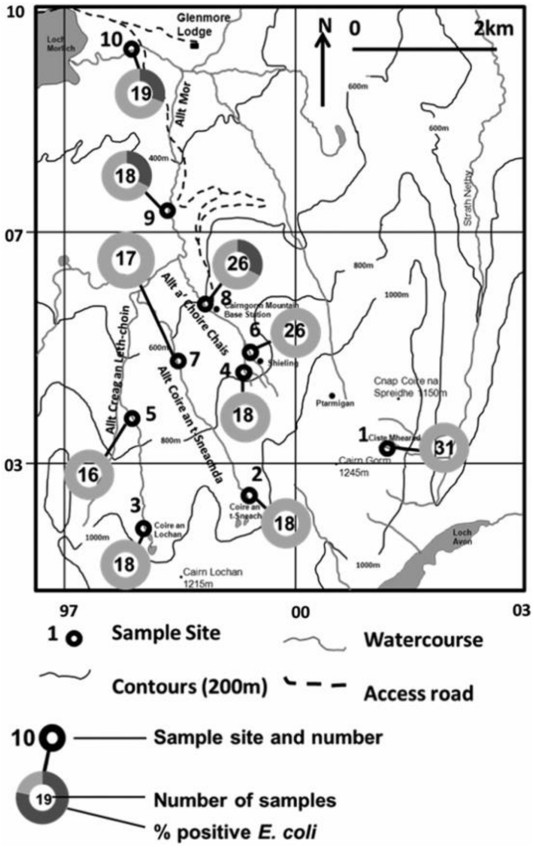

Figure 2 Percentage positive *E. coli* detected at Northern Corries sampling sites.

the company which manages the ski resort has permission to discharge waste just above site 8, where a septic tank sewage system is located. Another consideration relates to differential survival rates of FC (including *E. coli*) or differences in uplift related to stream turbulence or biofilm strength or development (Droppo *et al*. 2001; Rehmann & Soupir 2009; Balzer *et al*. 2010). However due to the consistent detection of *E. coli* at sites 8–10 (Table 1), the authors would advise against anyone drinking water from streams downstream of site 8 as these are highly likely to contain the *E. coli* bacteria.

The data indicate that Ciste Mhearad was a site of low risk throughout both winter seasons since no *E. coli* were detected in Ciste Mhearad, which questions anecdotal evidence that it is risky to drink from this stream during winter. The authors make no assumptions about summer norms and trends based on the data collected during this project. It should be borne in mind that the interpretation of these data is based on results recorded during 10 visits and no data exist outside those sampling days and locations. We accept that bacterial flushing, which may occur during rainstorms or snowmelt events, could have been missed.

In conjunction with the findings of McDonald *et al*. (2008), these data not only indicate where *E. coli* occur, but also offer an insight into the patterns that would be seen throughout a typical Cairngorm year. During both winter seasons, a pattern seems to have emerged, which shows that no *E. coli* were detected above 635 m. An important caveat, however, is that the data may be recording the 'disappearance' and not the 'die off' of bacteria (Foppen & Schijven 2006). Whilst biologically correct, the literature suggests that during these phases the potential for risk to human health is minimal (Coyne 1998).

Literature reporting illness after drinking from contaminated mountain streams in the British Isles is scarce. Illnesses from freshwater contamination are less frequently reported than those from food or agricultural sources and are more difficult to authenticate (Pond 2005). Another issue relates to human risk perception. Fewtrell (1991) reported that most of the studies relating to actual health risk centred on the measurement of disease perception rather than incidence.

Recreational governing and advisory bodies suggest that the best way of disposing of faecal waste is to dig a small hole and bury it. This can introduce pathogens into the soil with the potential to persist for over 12 months after burial (Temple *et al*. 1982; Ells 2000). Bridle and Kirkpatrick (2005) undertook trial burials of toilet paper in alpine environments, and their results showed very little decay of the paper after a two-year period. Similar problems have been found in the wilderness areas of North America, New Zealand and Australia (Temple *et al*. 1982; Cole *et al*. 1987; Cessford 2001; McPherson & Graham-Higgs 2005; McPherson *et al*. 2005). McDonald *et al*. (2008) suggested that the occurrence of TC and *E. coli* pollution in the CNP was exacerbated by the lack of disposal facilities. Bridle and Kirkpatrick (2005) found that water quality decreased after periods of heavy rainfall in the areas proximal to huts and toilet facilities. In their study, microbial analysis of faecal sterols showed that up to 30% of the contamination was of human origin.

McDonald *et al*. (2008) tentatively suggested that the installation of remote toilet facilities can detract from the wilderness condition and can impact on people's wilderness experience. This point raises questions about the level of impact that recreationalists have in areas where toilets are not provided. Fewtrell (1991) and Pond (2005) suggested that more projects have failed to show significant relationships between recreational activities and raised bacterial contamination, than have succeeded. A further consideration is that the treatment of raw water has become standard practice for many remote travellers. This complicates the issue of developing a coherent management policy since this kind of treatment prevents the traveller from becoming ill but does not provide any evidence of contamination. Pond (2005) suggested that it was almost impossible to apportion causality.

This discussion considers the *E. coli* cfu within the study area but also touches upon some wider social issues related to the management of human sanitation in these remote and protected areas. The data from this study add to those of McDonald *et al*. (2008), providing comparative altitudinal and seasonal benchmarks. It points to the need for further research into bacterial concentrations in upland areas which are used for recreation.

5. Conclusions

The results of this study indicate that during the winter season the presence of bacteria is suppressed, supporting previous findings. The data show that above 635 m there is no evidence of *E. coli*. Considered alongside the findings of McDonald *et al*. (2008), it is clear that more work needs to be done to quantify the health risks associated with sourcing 'raw' water in CNP. It would seem that the risk is higher in the summer months, but detailed causal linkages between drinking mountain stream water and health risks cannot yet be established with confidence, reflecting the views of Fewtrell (1991), Fewtrell *et al*. (1992) and Pond (2005).

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Conflicts of Interest

To the best of our knowledge, we the authors of this paper declare that there are no conflicts of interest.

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