

Chapter 4

Water Quality

4.1. Introduction

Water quality monitoring in marine effluent discharge monitoring programmes serves three principal purposes. First, measurements can be used to track the dispersion of effluent in the receiving environment. Second, measurements can be used to determine if the outfall is meeting design specifications and permit conditions, which usually stipulate that water quality at the margin of the zone of initial dilution (in whatever manner this is defined) should be compliant with water quality guidelines or other standards protective of aquatic ecosystem and human health. Third, measurements can be used to estimate the risk posed to aquatic organisms and humans within and beyond the zone of initial dilution by comparing water quality indicator values/concentrations to water quality guidelines and other standards protective of aquatic ecosystem and human health.

This chapter discusses findings of the microbiological analysis and toxicity testing of seawater samples collected in the greater vicinity of the Green Point, Camps Bay and Hout Bay outfalls in 2016, and assesses the microbiological status of shoreline water in Table Bay and along the Cape Peninsula for the period 25 July 2007 to 29 June 2016.

4.2. Materials and Methods

4.2.1. Fieldwork

Seawater samples were collected at the surface of the water column at sites positioned in a more or less grid-like manner in the greater vicinity of the Green Point, Camps Bay and Hout Bay outfalls (Figures 4.1 - 4.3). The density of sampling sites was highest nearest the outfall diffuser sections, the sites generally aligned to the predominant dispersion direction of effluent as determined from satellite images provided in Google Earth that capture instances of effluent reaching the sea

surface. A set of sites were aligned more or less parallel to the shoreline and perpendicular to the outfall diffuser sections (note the latter was not always the case due to diffuser section orientation). The sites nearest the outfall diffuser sections were at a distance of about twice the depth at which the diffuser section is situated (about 56 m for Green Point outfall, 46 m for Camps Bay outfall, and about 80 m for the Hout Bay outfall; noting that the depth of the diffuser section varies along its length). These were informally taken as denoting the margin of the zone of initial dilution. Other sites in this array were about 300 and 1 200 m from the diffuser section. A series of sites was situated about 1 500 m from offshore of the latter sites, while another series of sites were situated nearer the shoreline, inshore of the outfall diffuser sections. In some cases the latter sites were situated in (e.g. Hout Bay harbour) or near (e.g. mouth of Disa River, near stormwater discharge points Granger Bay area) other possible sources of faecal indicator bacteria to the nearshore.

Seawater samples were collected by submerging autoclaved or hexane and deionised water rinsed sample containers below the sea surface. The samples were stored on ice in the field until transfer to the laboratory, where they were either analysed immediately (for faecal indicator bacteria) by the Scientific Services Branch of the City of Cape Town or transferred overnight on ice to the CSIR toxicology laboratory in Durban, where the samples were refrigerated until testing within four days of collection.

4.2.2. Laboratory Analyses

4.2.2.1. Faecal Indicator Bacteria

Seawater samples were analysed for *E. coli* and faecal streptococci using membrane filtration techniques (APHA, 1995). This involved passing an aliquot of the sample through a 47 mm diameter sterile membrane filter with a 0.45 µm pore size.

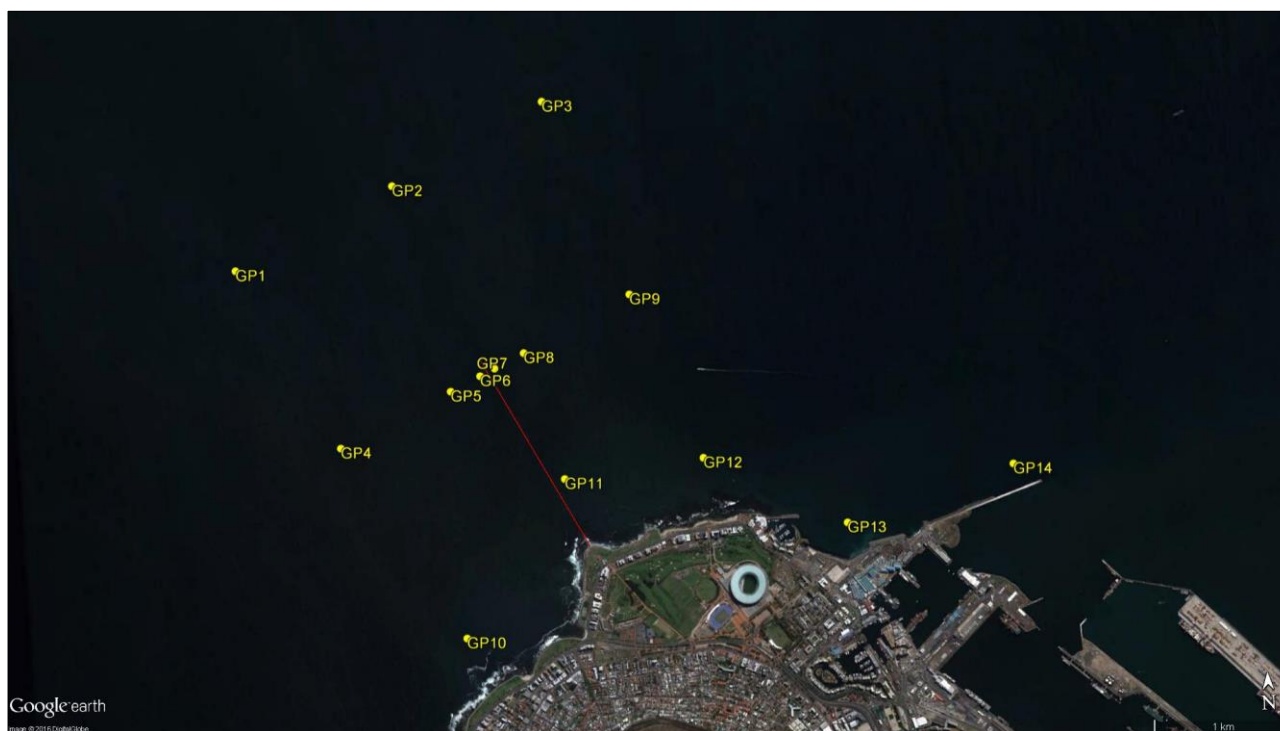


Figure 4.1. Aerial view of the Green Point area, showing the Green Point outfall (red line) and positions where surface seawater samples for microbiological analysis and toxicity testing were collected in 2016.



Figure 4.2. Aerial view of the Camps Bay area, showing the Camps Bay outfall (red line) and positions where surface seawater samples for microbiological analysis and toxicity testing were collected in 2016.

For *E. coli* the membranes were incubated on m-Tec agar for 2 hrs at 37°C and then at 44°C for 22 hrs. For faecal streptococci the membranes were incubated on m-Enterococcus agar for 2 hrs at 37°C and then at 44°C for 22 hrs. *E. coli* and faecal streptococci bacteria colony forming units were then enumerated.

4.2.2.2. Toxicity Testing

A subset of the seawater samples collected for each survey was tested for toxicity using the sea urchin fertilisation test. Details on the test method are provided in Chapter 2, noting that the seawater samples were not diluted prior to testing.



Figure 4.3. Aerial view of the Hout Bay area, showing the Hout Bay outfall (red line) and positions where surface seawater samples for microbiological analysis and toxicity testing were collected in 2016.

4.3. Results and Discussion

4.3.1. Faecal Indicator Bacteria - Offshore

The rationale for analysing faecal indicator bacteria in surface seawater samples collected in the greater vicinity of the Green Point, Camps Bay and Hout Bay outfalls for the 2015/2016 survey for the Cape Town outfalls monitoring programme was twofold. First, faecal indicator bacteria, such as *E. coli* and faecal streptococci, are amongst the most useful indicators for tracing the dispersion and dilution of effluent that has a significant domestic component in a marine receiving environment. This is because these bacteria are found only in the faeces of mammals and birds (Dufor, 1977) and are usually not present in unpolluted waters. They are present in large quantities in human faeces. It has, for example, been estimated that humans excrete about 100 billion coliform bacteria per day (von Sperling, 2007). There are no populations of marine mammals and birds that are permanently resident at the outfall diffuser sections. The presence of high colony forming unit counts of faecal indicator bacteria in seawater collected near the diffuser sections should thus reflect the presence of effluent, even though there could be a contribution from other animals (*e.g.* seals, birds) in or passing through these areas. However, the contribution

from these animals is likely to be dwarfed by the contribution from effluent on a volume to volume basis. Second, if faecal indicator bacteria (and other effluent constituents) are reaching the shoreline inshore of the outfalls there is a possibility this is through the transport of surface water onshore by wind and waves when effluent reaches the sea surface (sub-surface dispersion is quantitatively more important than surface dispersion based on the fact effluent does not continuously reach the sea surface). The routine incidence of high colony forming unit counts of faecal indicator bacteria at the sea surface between the points of effluent discharge (outfall diffuser sections) and shoreline may thus indicate that effluent constituents are being advected onshore and are possibly reaching the shoreline, notwithstanding the fact there are other vectors for the introduction of these bacteria to shoreline and nearshore marine waters in cities (*e.g.* stormwater - see below).

Faecal indicator bacteria colony forming unit counts in surface seawater samples collected at approximately monthly intervals in the greater vicinity of the Green Point, Camps Bay and Hout Bay outfalls in 2016 are provided as bubble plots in Figures 4.4 - 4.36. The bubbles represent ranges of colony forming unit counts.



Figure 4.5. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 29 February 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.6. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 4 April 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.7. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 12 April 2016. Cyan = <20 colony forming units.100 ml⁻¹, Green = ≥20 - <50 colony forming units.100 ml⁻¹, Yellow = ≥50 - <100 colony forming units.100 ml⁻¹, Orange = ≥100 - <500 colony forming units.100 ml⁻¹, Red = ≥500 colony forming units.100 ml⁻¹.

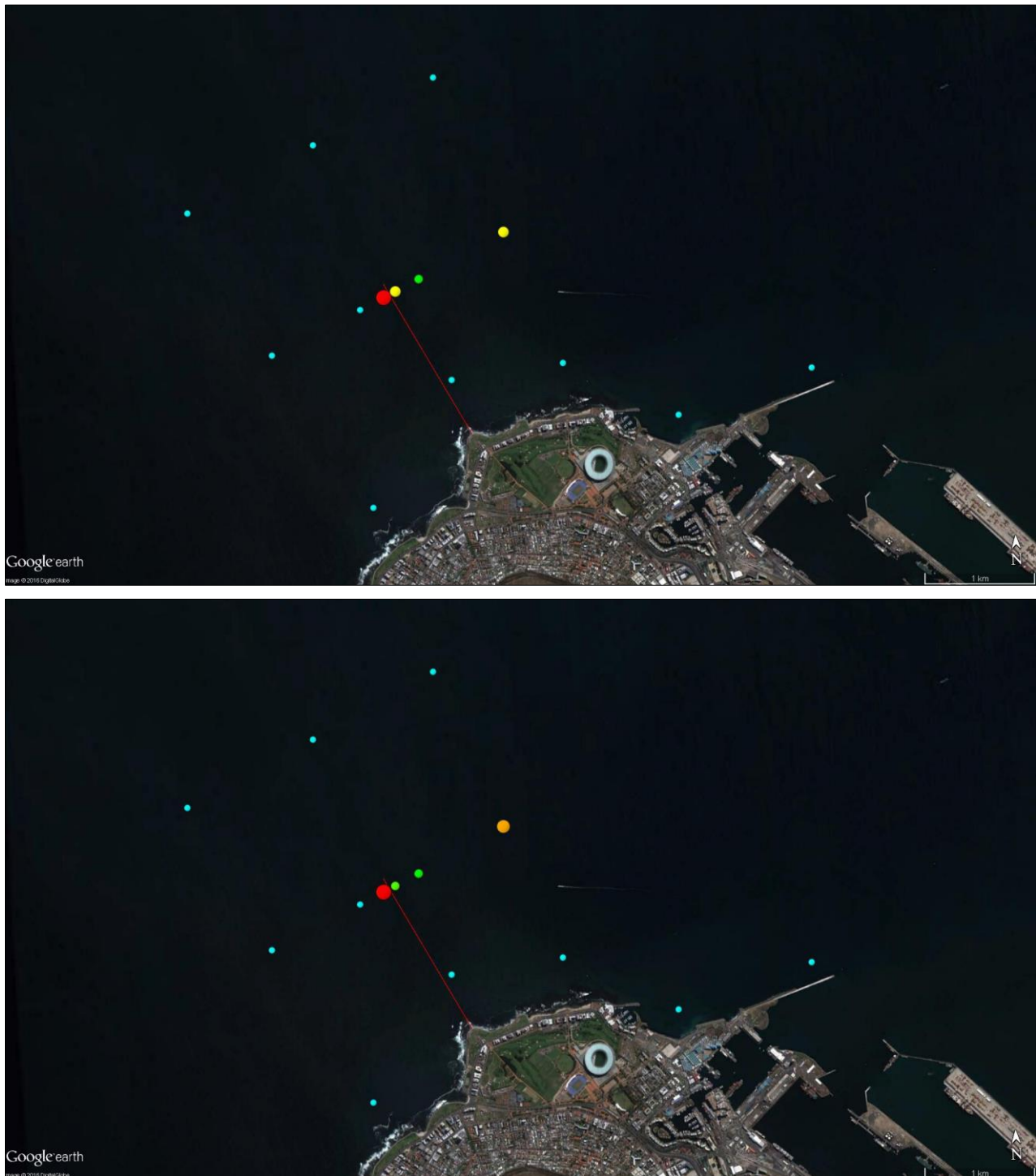


Figure 4.8. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 23 May 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

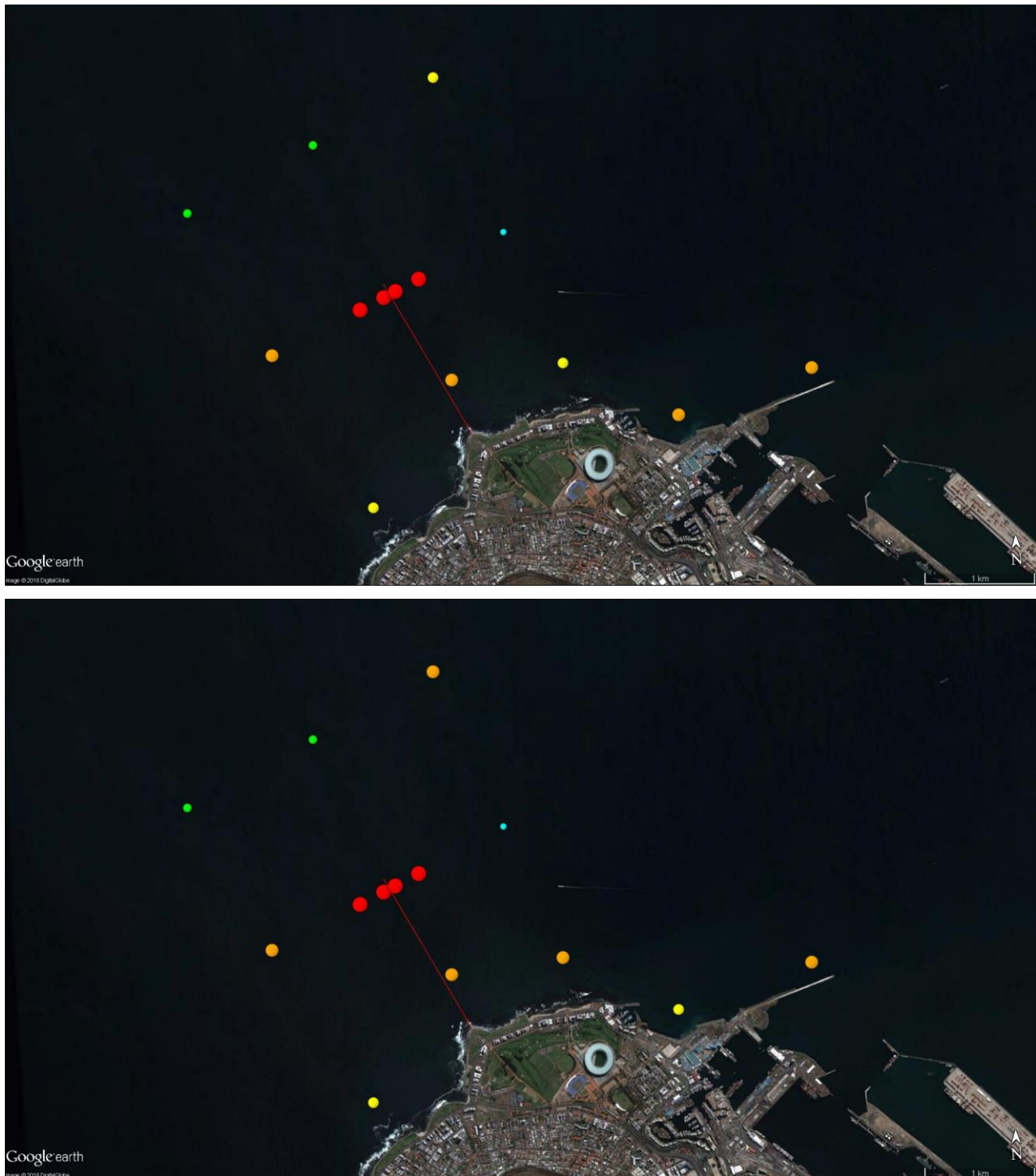


Figure 4.9. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 20 June 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

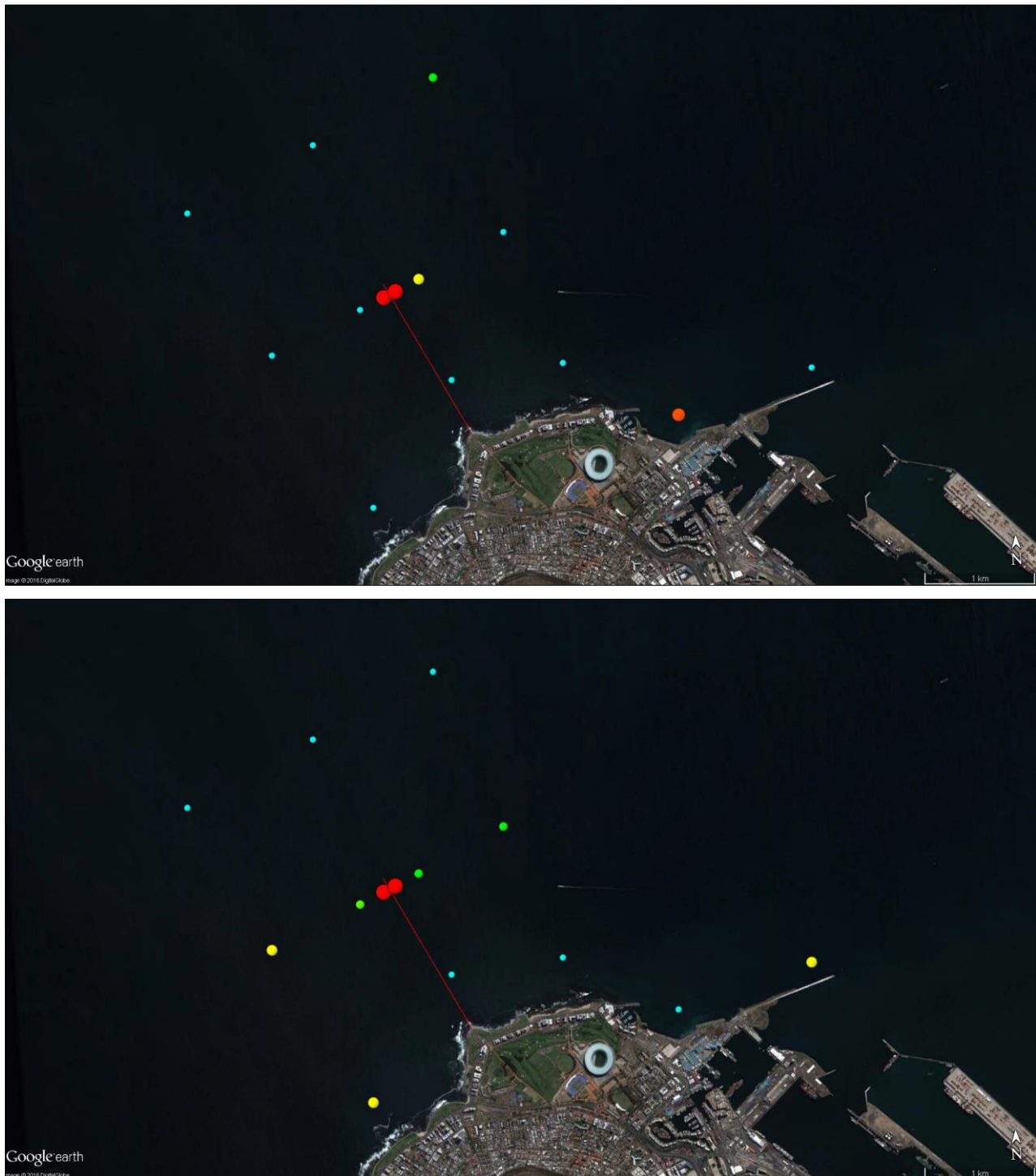


Figure 4.10. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 11 July 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

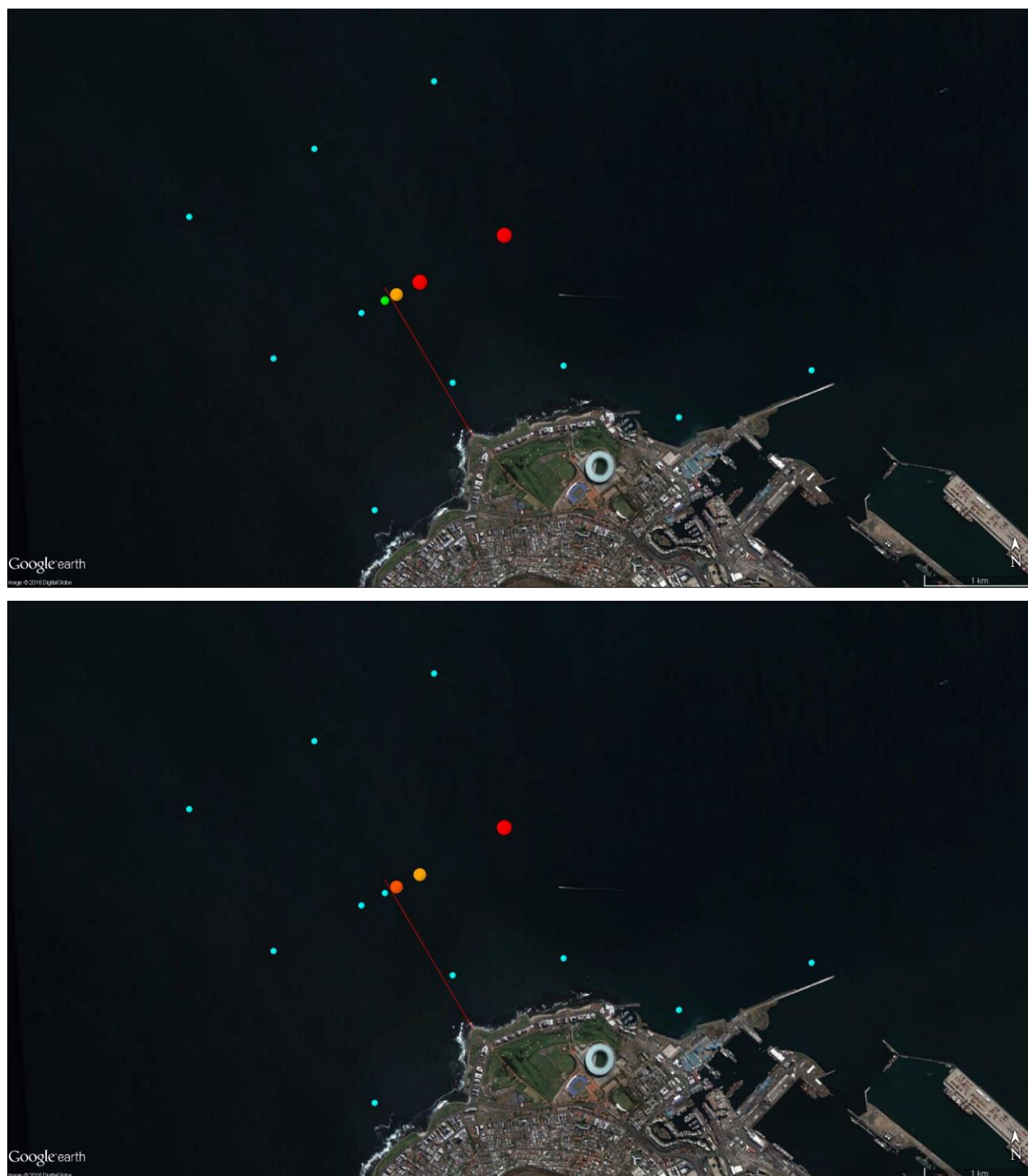


Figure 4.11. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 16 August 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.12. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 13 September 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

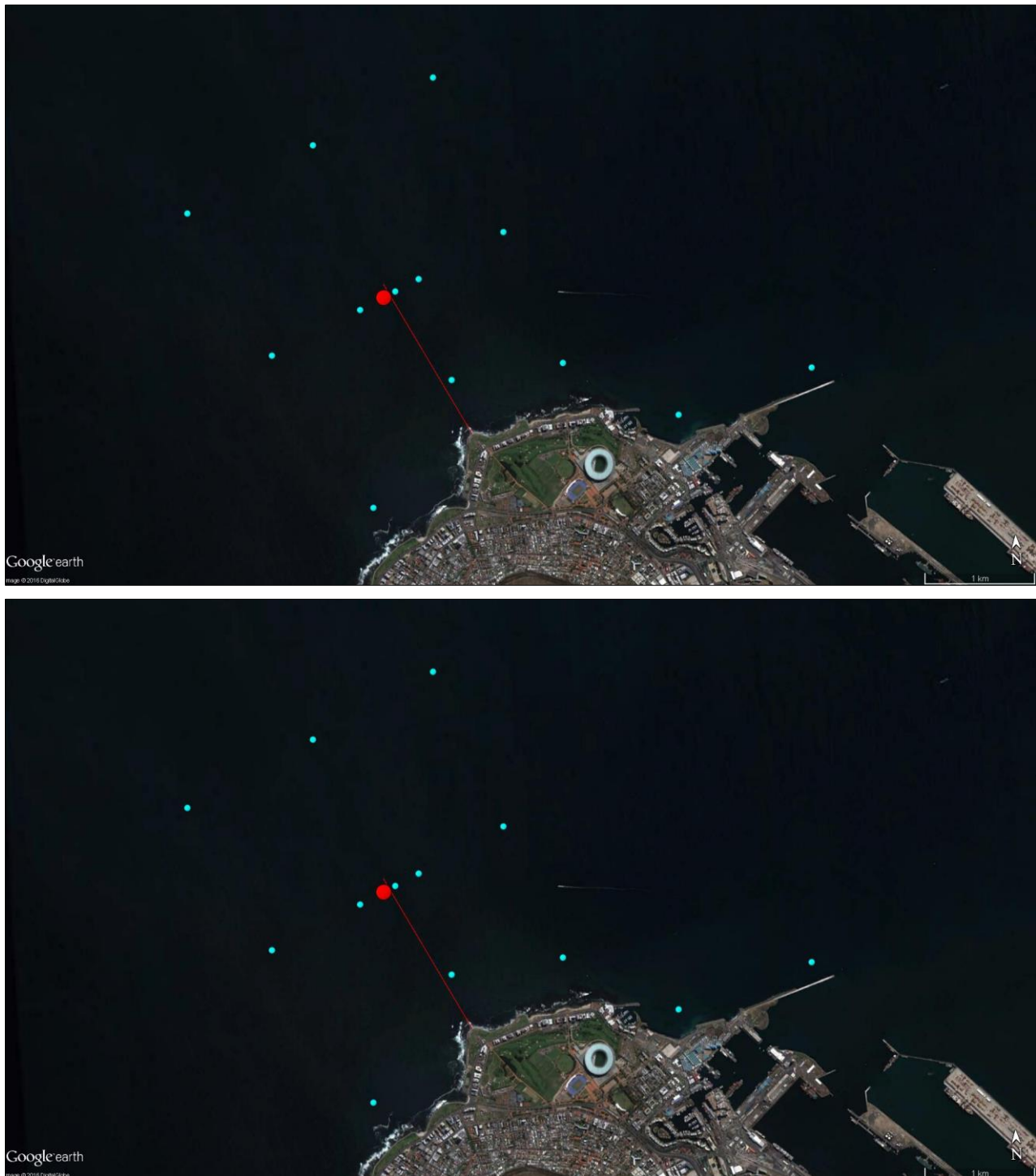


Figure 4.13. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 25 October 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

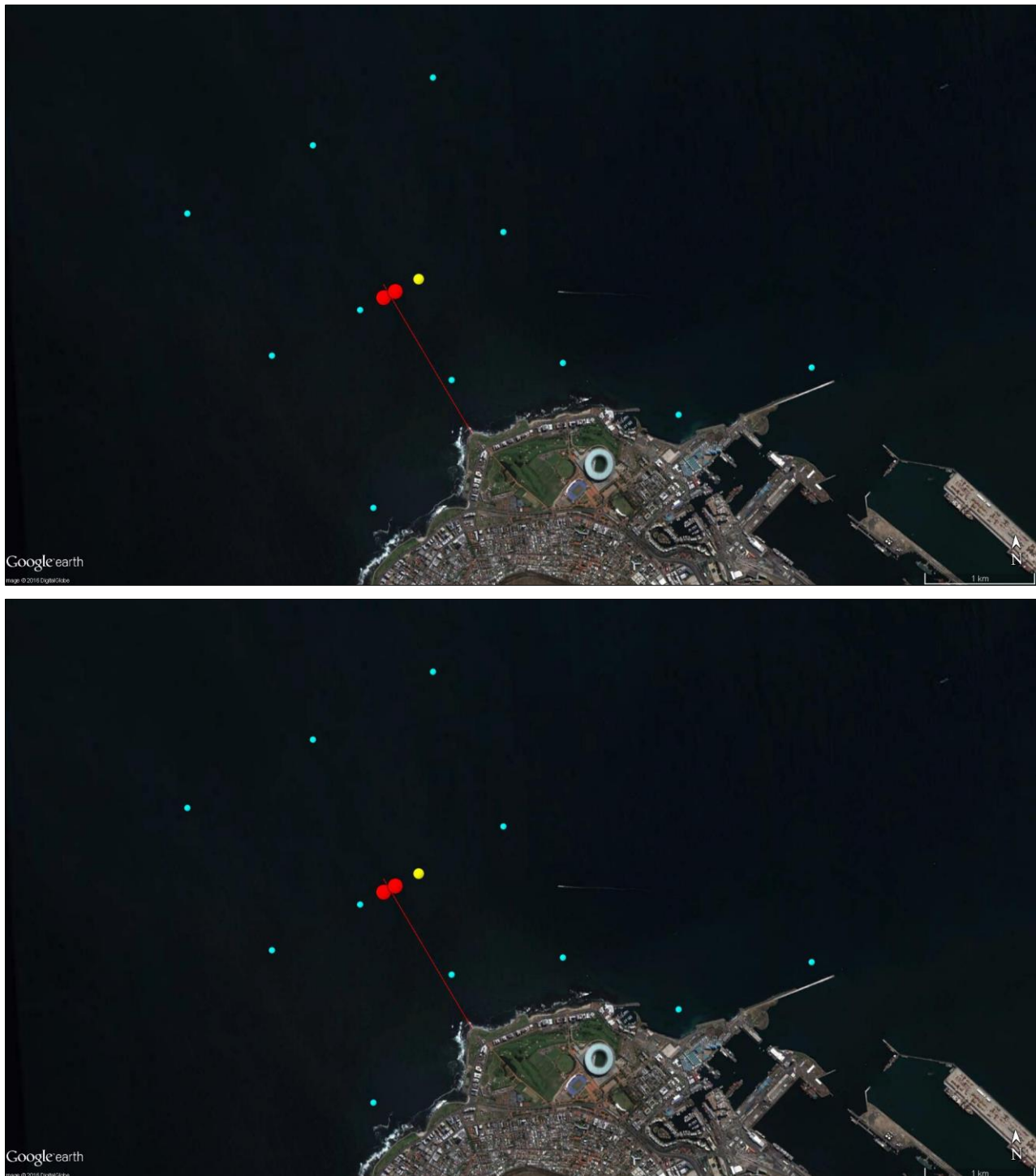


Figure 4.14. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 8 November 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.15. Aerial view of the Green Point area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 8 December 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

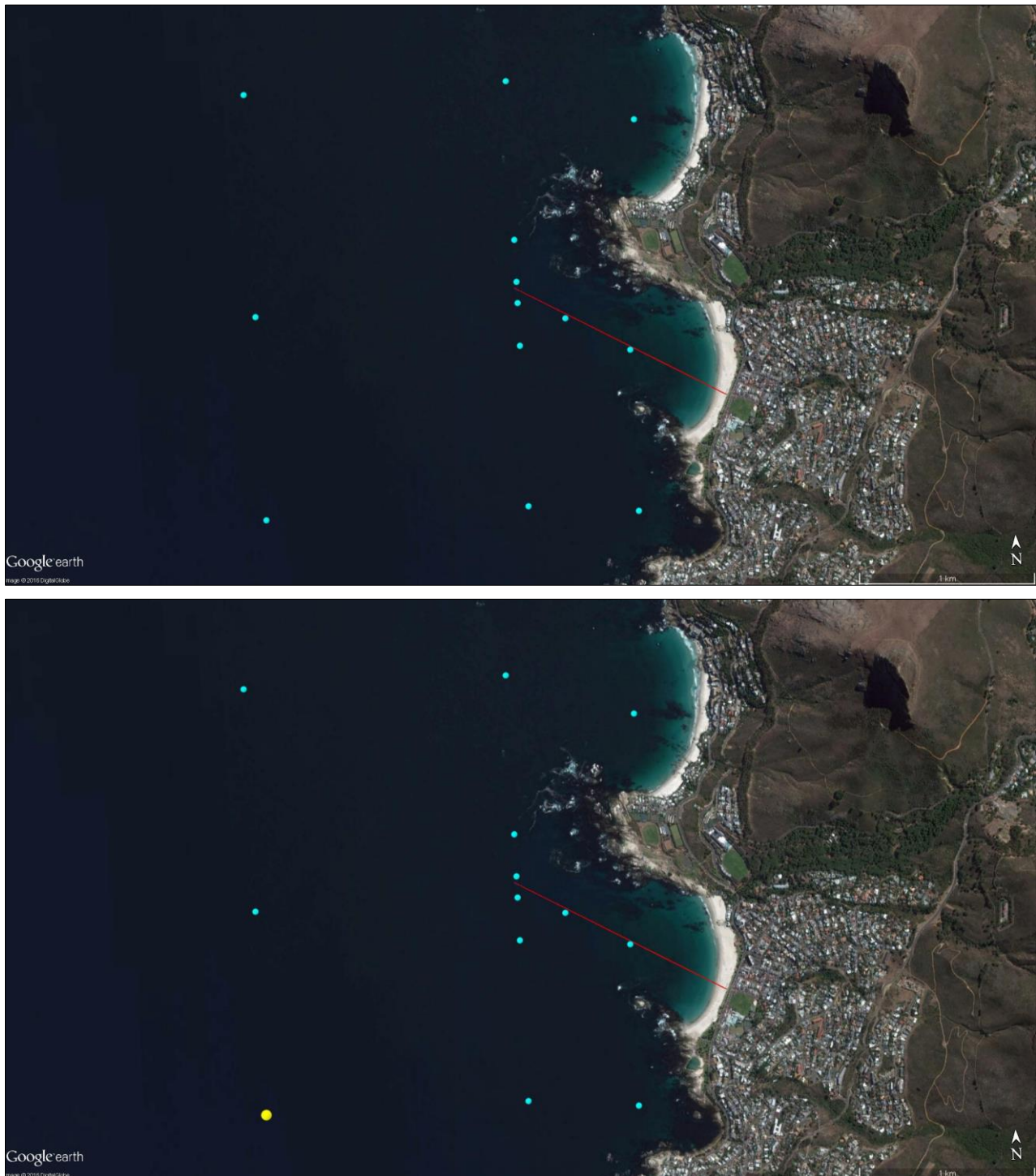


Figure 4.16. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 25 January 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

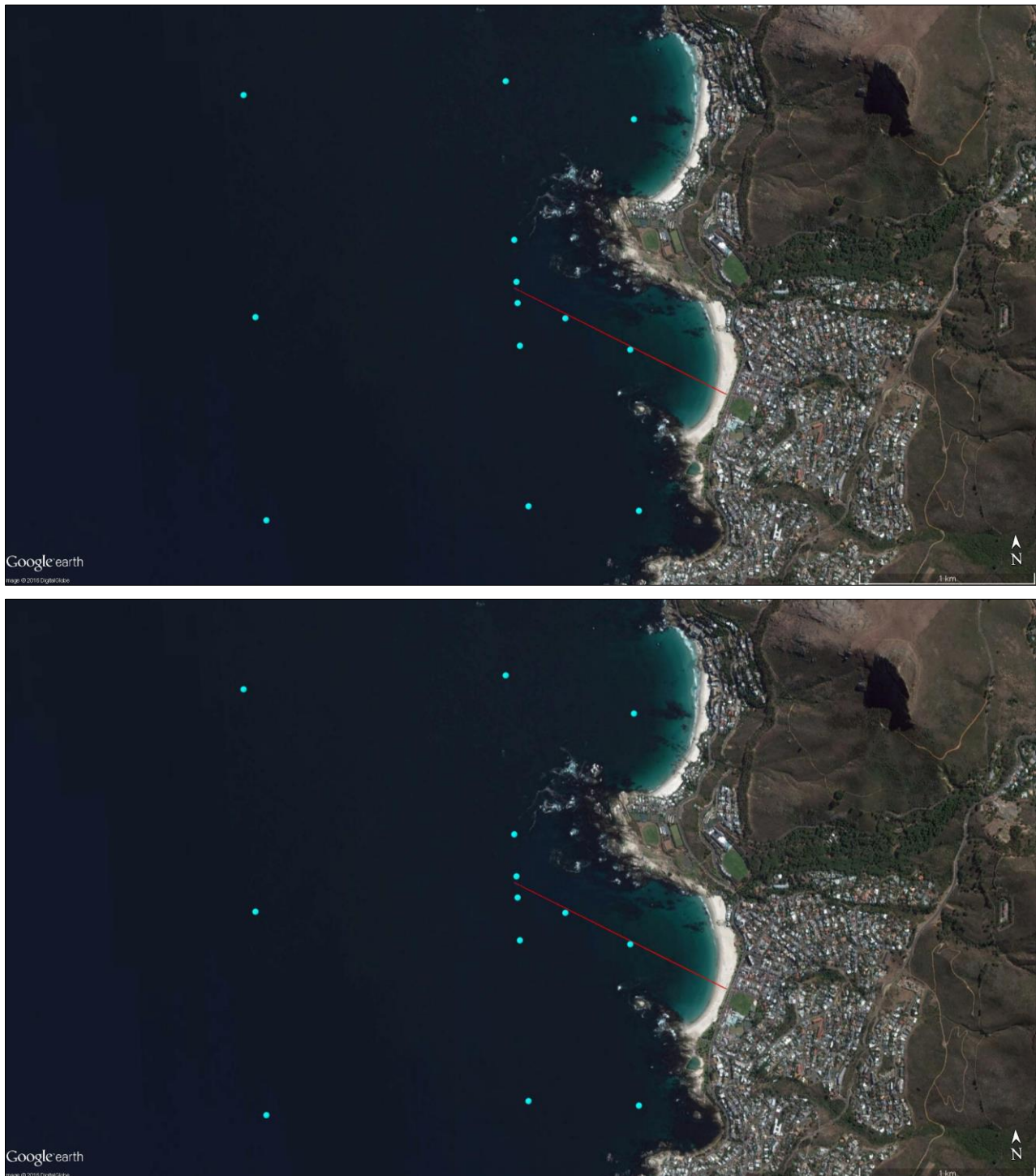


Figure 4.17. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 29 February 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

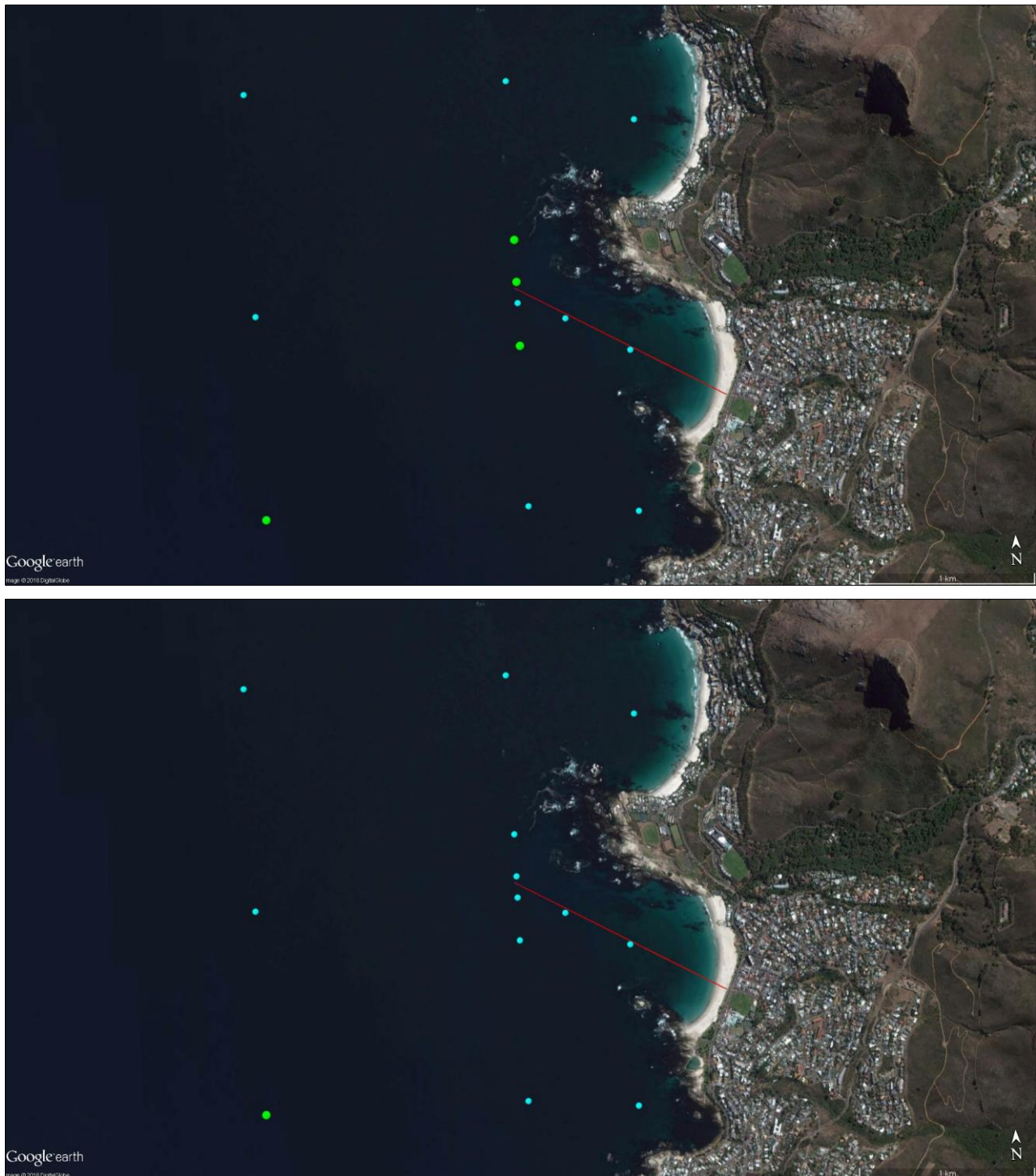


Figure 4.18. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 5 April 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

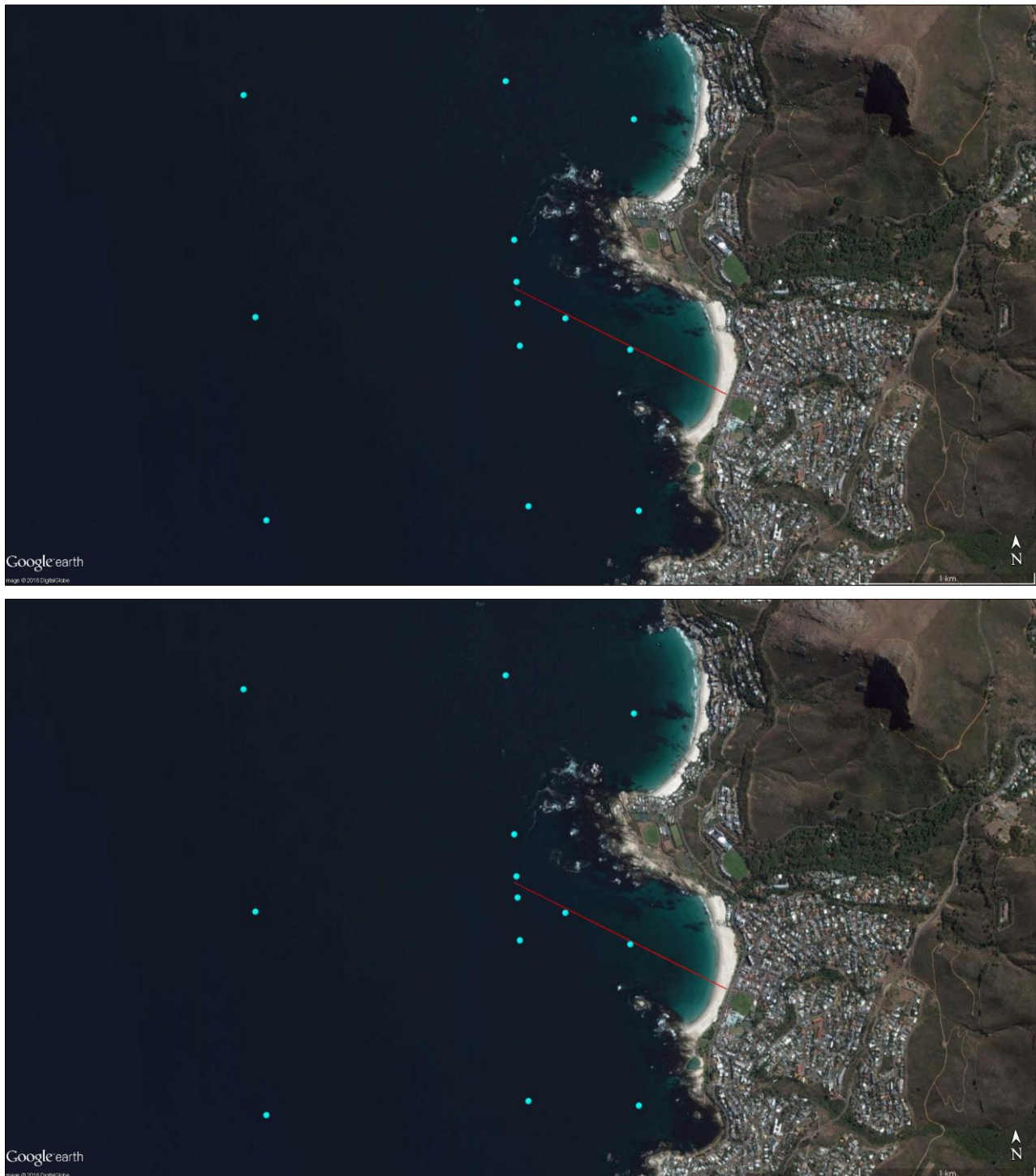


Figure 4.19. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 18 April 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

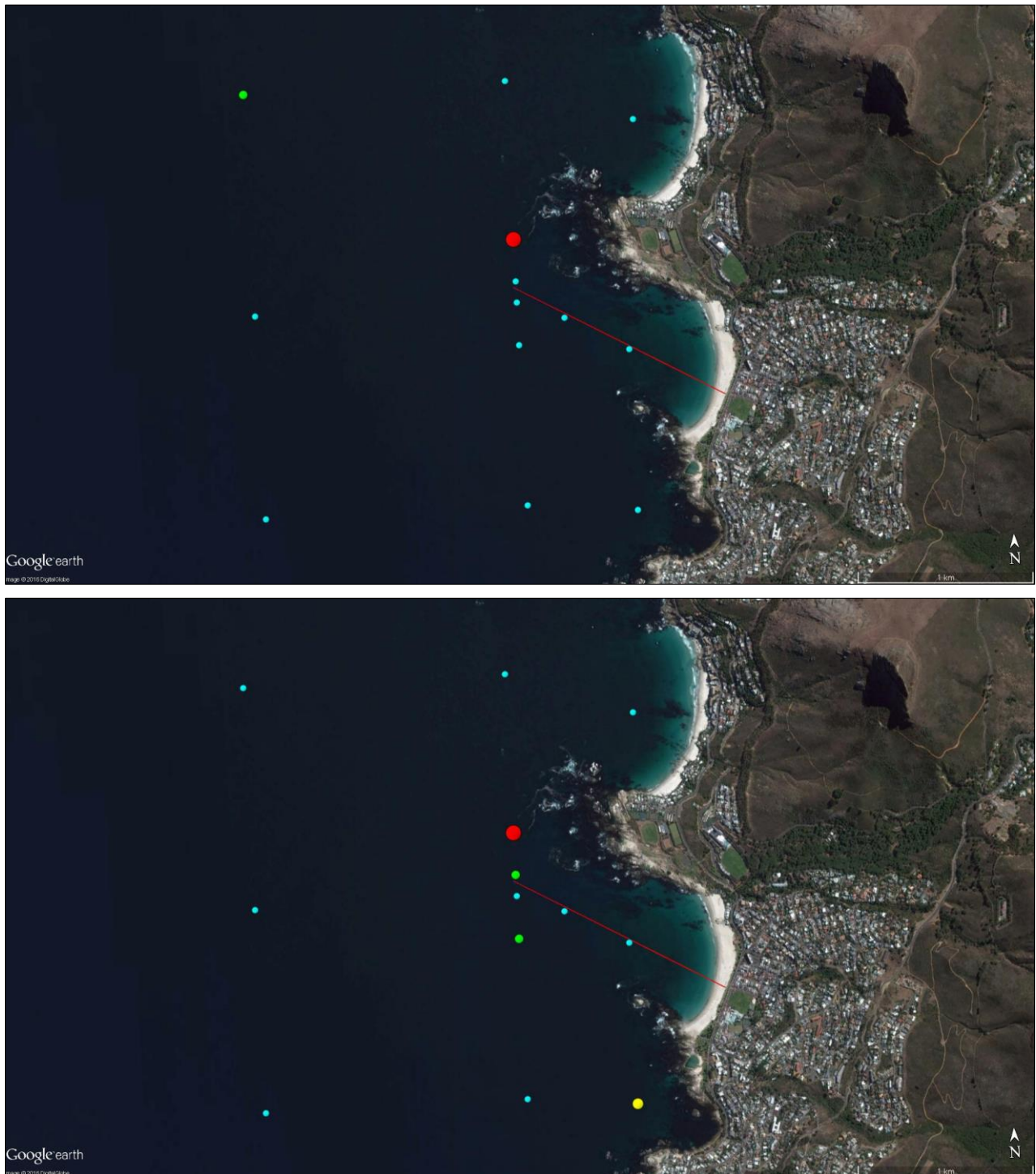


Figure 4.20. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 16 June 2016. Cyan = <20 colony forming units.100 ml⁻¹, Green = ≥20 - <50 colony forming units.100 ml⁻¹, Yellow = ≥50 - <100 colony forming units.100 ml⁻¹, Orange = ≥100 - <500 colony forming units.100 ml⁻¹, Red = ≥500 colony forming units.100 ml⁻¹.

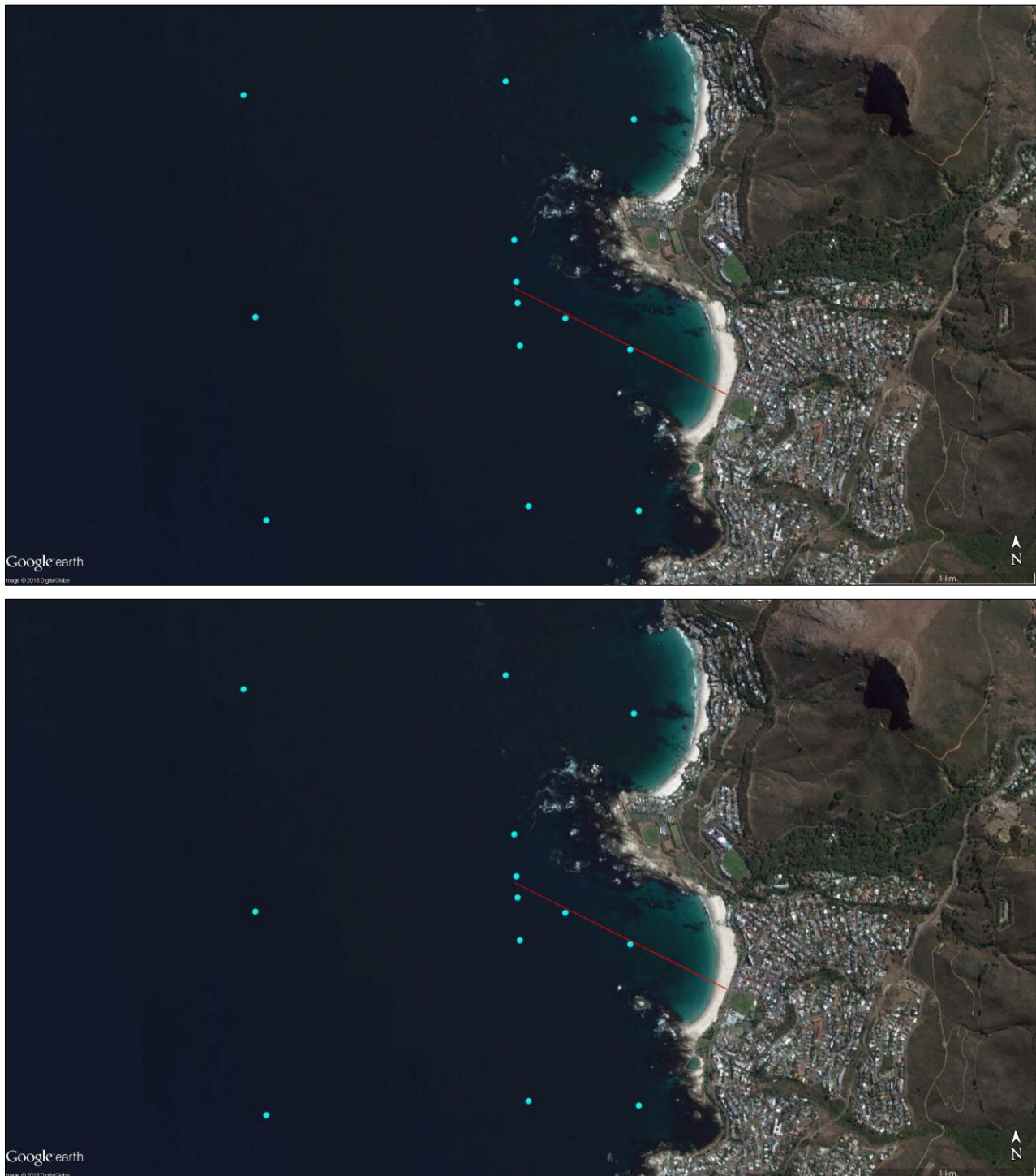


Figure 4.21. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 28 June 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

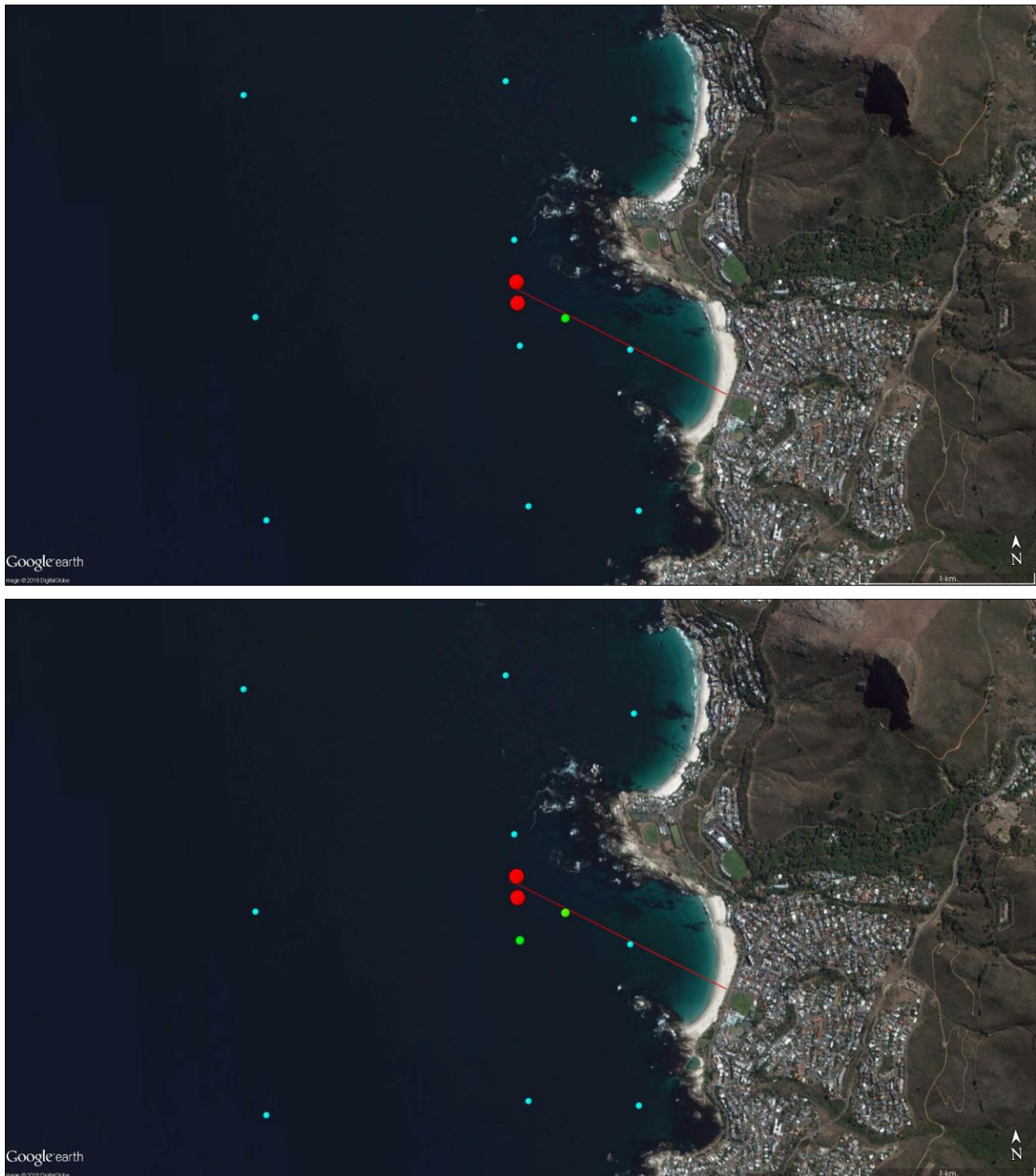


Figure 4.22. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 18 July 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

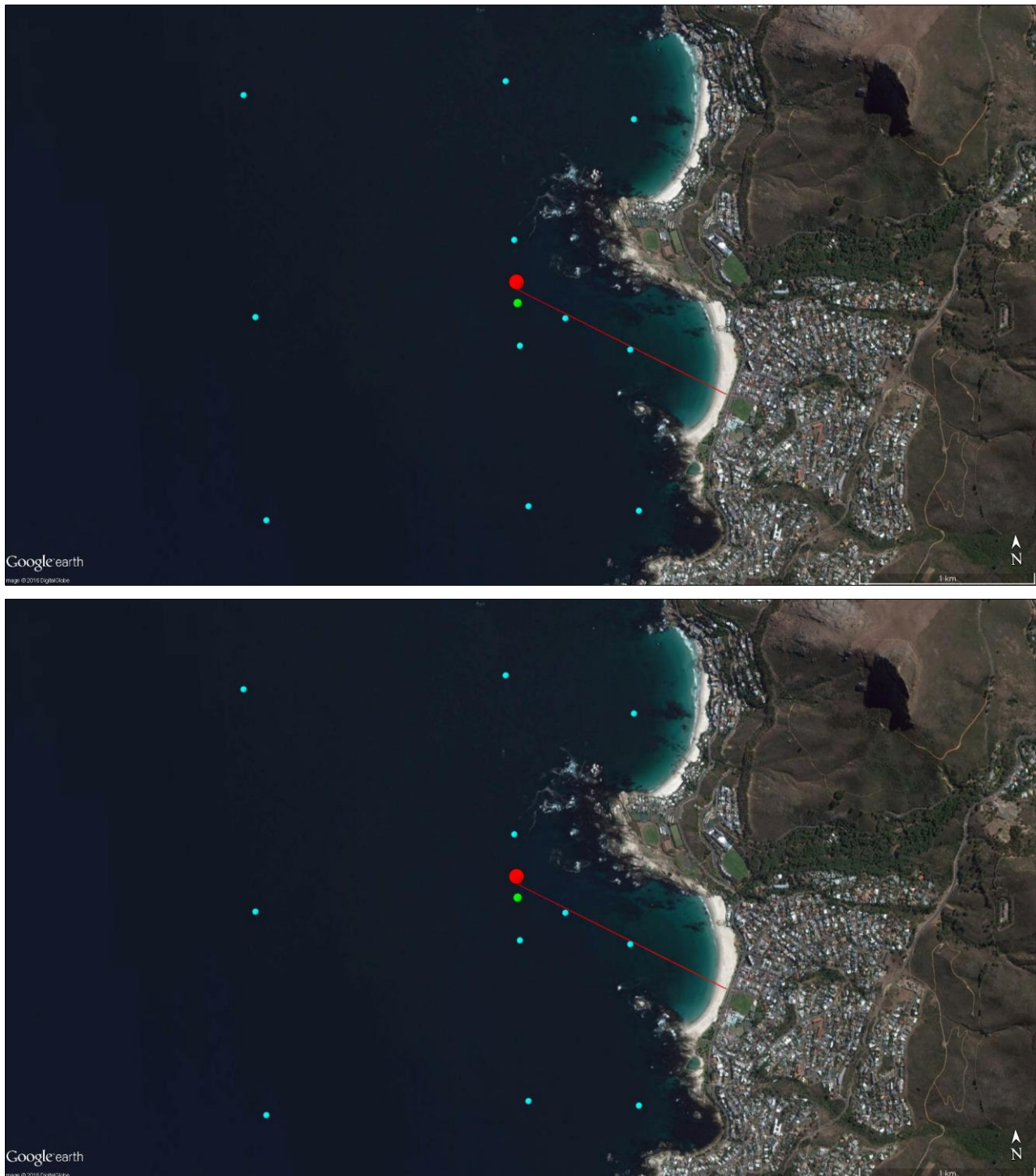


Figure 4.23. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 30 August 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

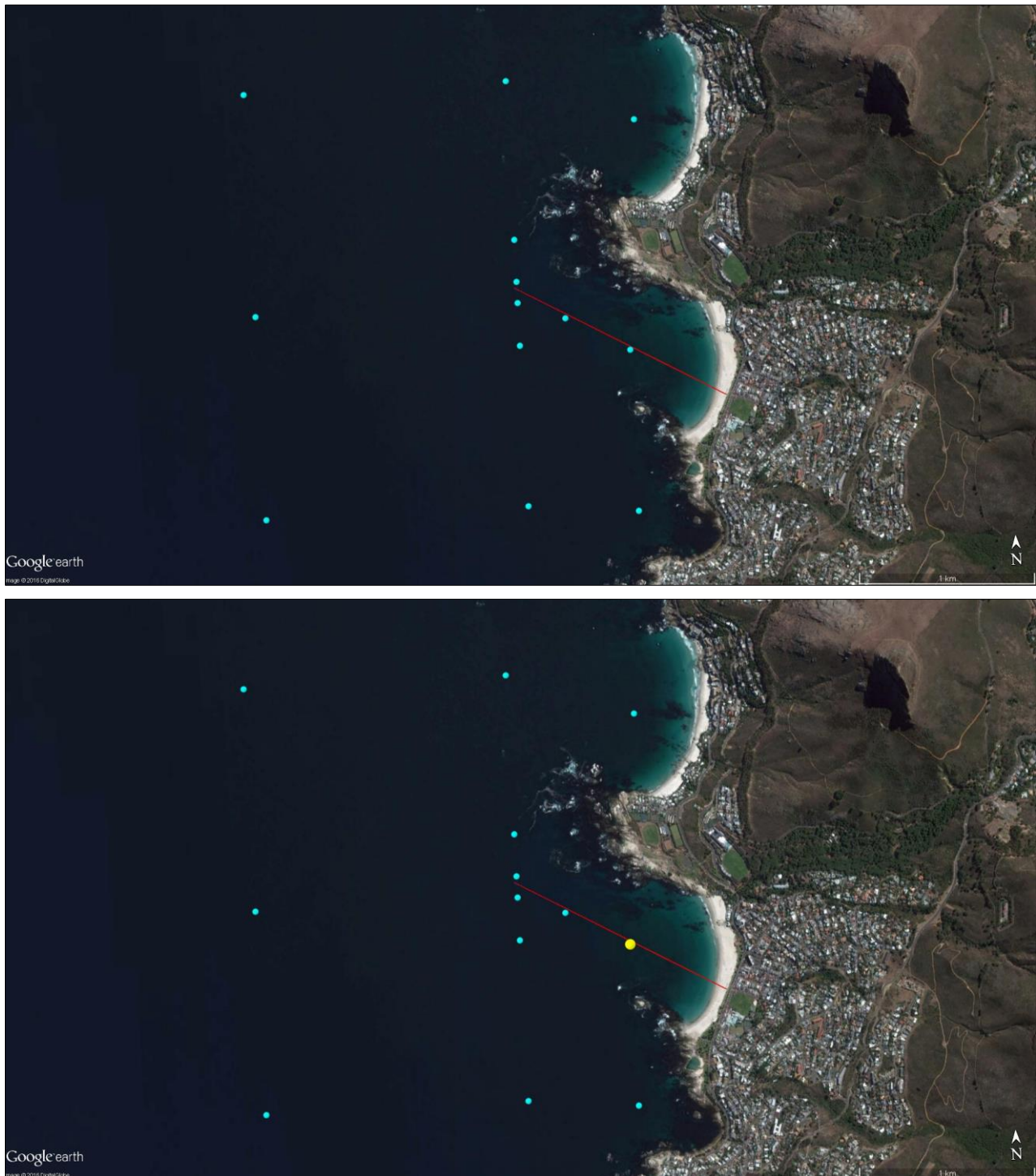


Figure 4.24. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 13 September 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

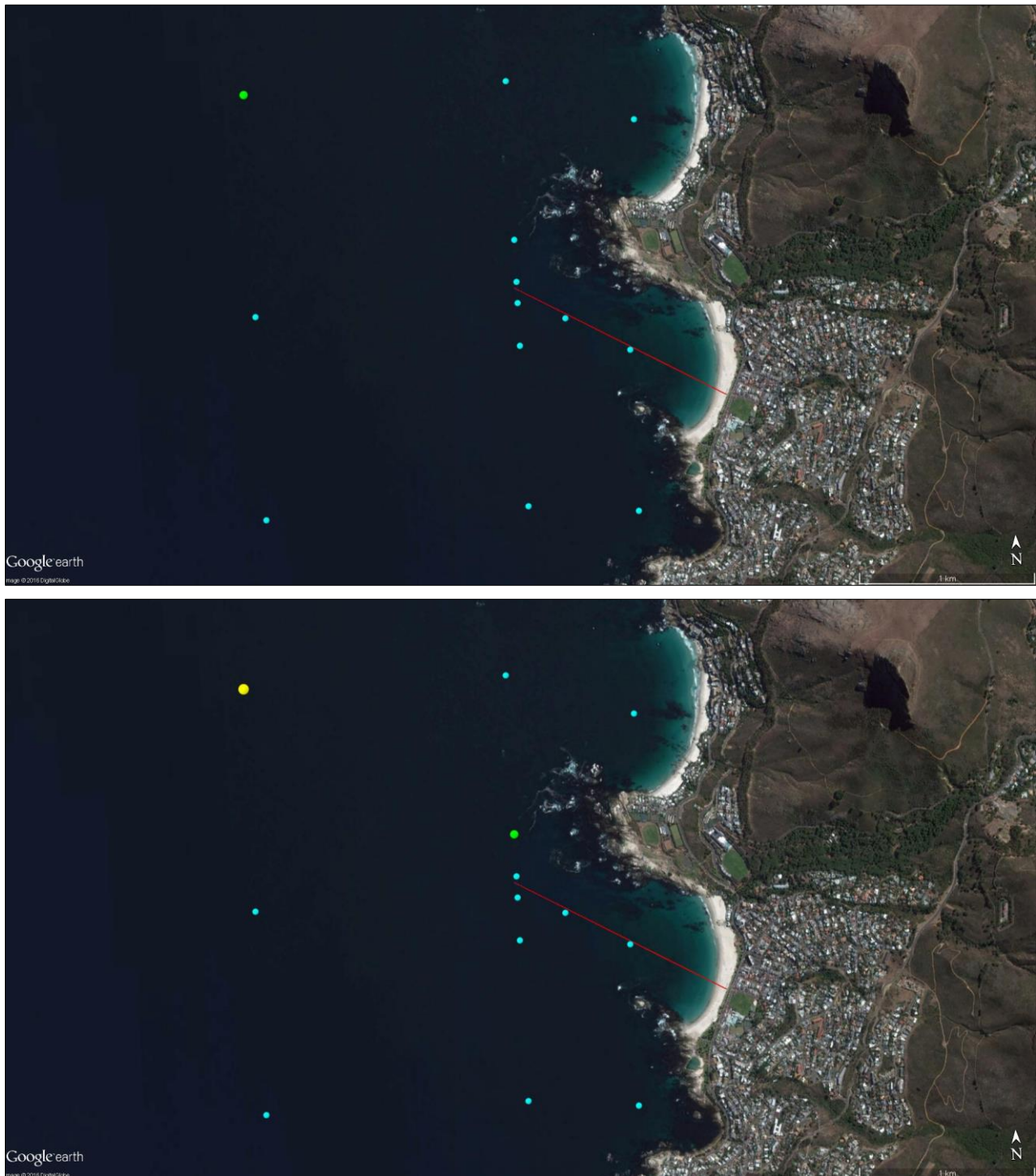


Figure 4.25. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 17 October 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

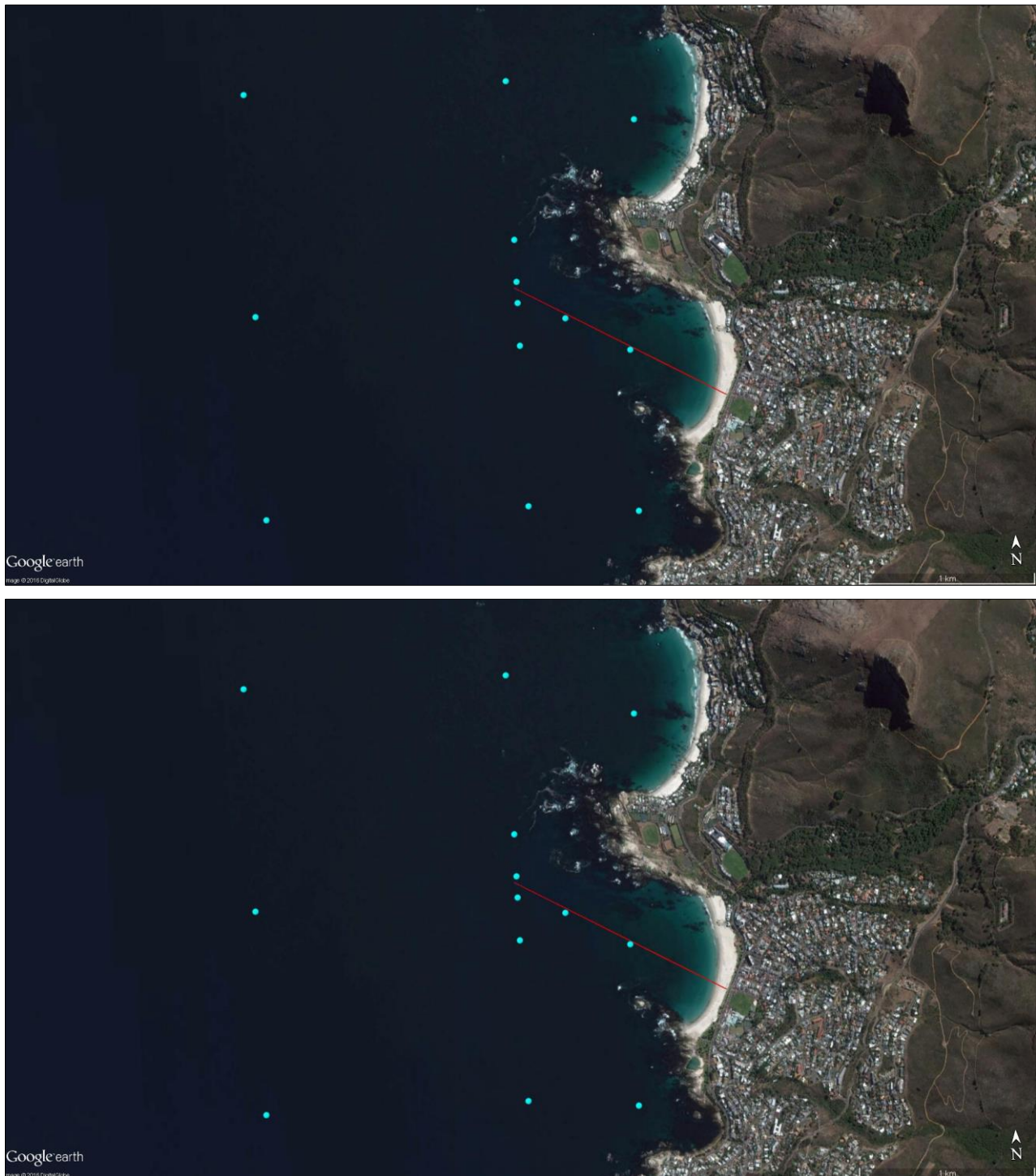


Figure 4.26. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 22 November 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

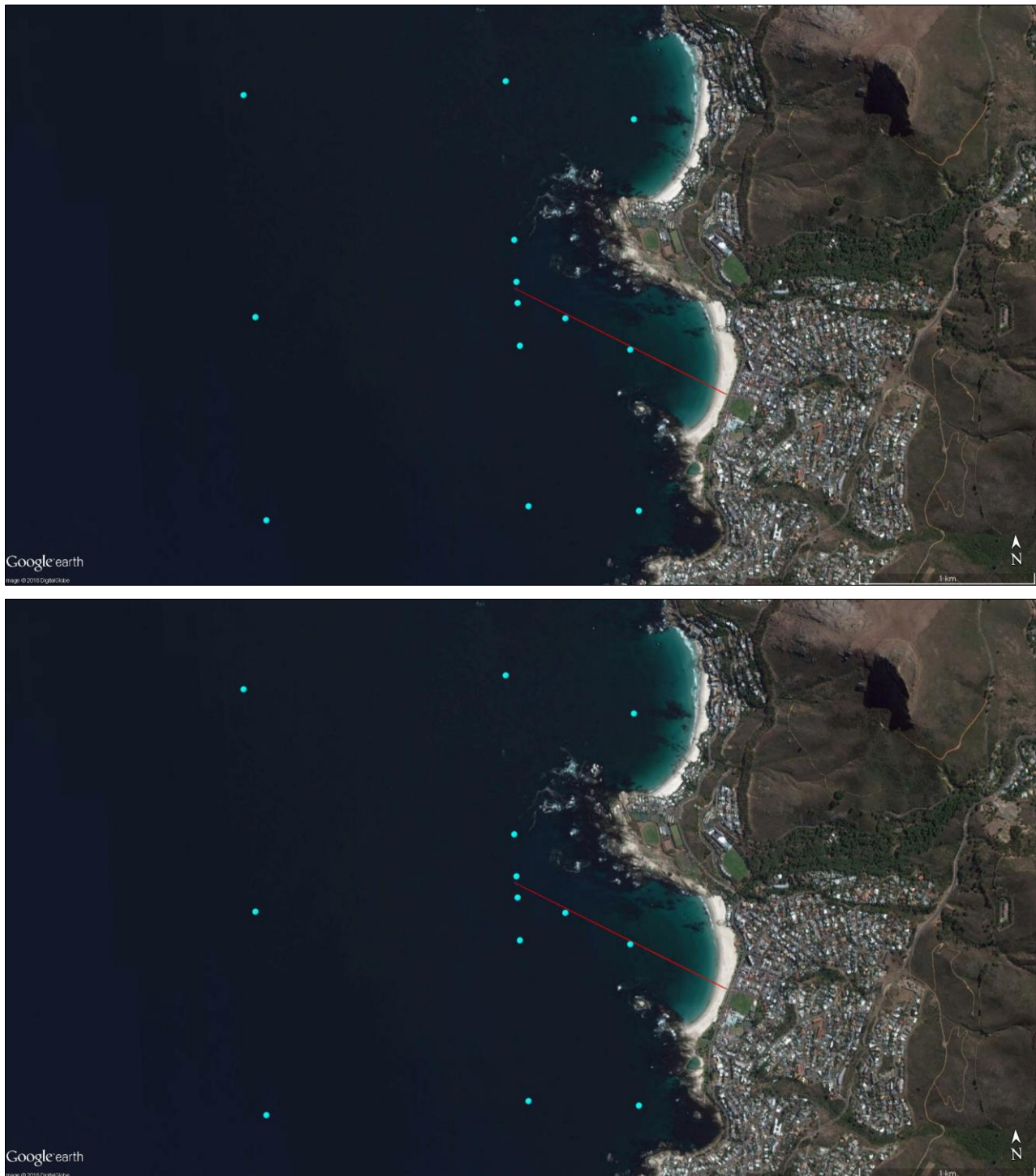


Figure 4.27. Aerial view of the Camps Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 6 December 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.28. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 25 January 2016. ● = <20 colony forming units.100 ml⁻¹, ● = $\geq 20 - <50$ colony forming units.100 ml⁻¹, ● = $\geq 50 - <100$ colony forming units.100 ml⁻¹, ● = $\geq 100 - <500$ colony forming units.100 ml⁻¹, ● = ≥ 500 colony forming units.100 ml⁻¹.



Figure 4.29. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 1 March 2016. Cyan = <20 colony forming units.100 ml⁻¹, Green = ≥20 - <50 colony forming units.100 ml⁻¹, Yellow = ≥50 - <100 colony forming units.100 ml⁻¹, Orange = ≥100 - <500 colony forming units.100 ml⁻¹, Red = ≥500 colony forming units.100 ml⁻¹.



Figure 4.30. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 30 March 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.31. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 19 April 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.32. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 17 June 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.33. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 28 June 2016. Cyan = <20 colony forming units.100 ml⁻¹, Green = ≥20 - <50 colony forming units.100 ml⁻¹, Yellow = ≥50 - <100 colony forming units.100 ml⁻¹, Orange = ≥100 - <500 colony forming units.100 ml⁻¹, Red = ≥500 colony forming units.100 ml⁻¹.



Figure 4.34. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 19 July 2016. Cyan = <20 colony forming units.100 ml⁻¹, Green = ≥20 - <50 colony forming units.100 ml⁻¹, Yellow = ≥50 - <100 colony forming units.100 ml⁻¹, Orange = ≥100 - <500 colony forming units.100 ml⁻¹, Red = ≥500 colony forming units.100 ml⁻¹.



Figure 4.35. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 29 August 2016. $\text{light blue} = <20$ colony forming units.100 ml⁻¹, $\text{green} = \geq 20$ - <50 colony forming units.100 ml⁻¹, $\text{yellow} = \geq 50$ - <100 colony forming units.100 ml⁻¹, $\text{orange} = \geq 100$ - <500 colony forming units.100 ml⁻¹, $\text{red} = \geq 500$ colony forming units.100 ml⁻¹.



Figure 4.36. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 12 September 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.37. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 10 October 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.38. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 29 November 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.



Figure 4.39. Aerial view of the Hout Bay area, showing the outfall (red line) and bubbles that represent ranges of *E. coli* (top) and faecal streptococci (bottom) colony forming unit counts for a survey on 13 December 2016. ● = <20 colony forming units.100 ml⁻¹, ● = ≥20 - <50 colony forming units.100 ml⁻¹, ● = ≥50 - <100 colony forming units.100 ml⁻¹, ● = ≥100 - <500 colony forming units.100 ml⁻¹, ● = ≥500 colony forming units.100 ml⁻¹.

Although the use of ranges diminishes the degree of apparent difference in colony forming unit counts between sites it is a convenient way of summarising the data in an easy to interpret format.

In many surveys fewer than 10 colony forming unit counts were recorded for *E. coli* and faecal streptococci bacteria in surface seawater samples collected at all or most sites for each outfall, providing little evidence effluent was reaching the surface at the time the surveys were performed. The *E. coli* and faecal streptococci bacteria colony forming unit count was in fact <1 in 65 and 53%, and ≤10 in 81 and 77% of all seawater samples analysed respectively. In other words, essentially none of the bacteria were present in more than half the samples and very few in about three-quarters of the samples. There was, however, clear evidence from faecal indicator bacteria counts and seawater colour observed in the field for effluent reaching the sea surface at the Green Point outfall in six of the 12 surveys (23 May - Figure 4.8, 20 June - Figure 4.9, 11 July - Figure 4.10, 16 August - Figure 4.11, 25 October - Figure 4.13, 8 November 2016 - Figure 4.14), in three of the 12 surveys for the Camps Bay outfall (16 June - Figure 4.19, 18 July - Figure 4.21, 30 August - Figure 4.22), and in two of the 12 surveys for the Hout Bay outfall (1 March - Figure 4.27, 19 July - Figure 4.32). In these surveys colony forming unit counts often exceeded 2 000, with a maximum of 51 000 for *E. coli* and in excess of 10 000 for faecal streptococci (count not confirmed in latter sample). There was also possible evidence for effluent reaching the sea surface at the Camps Bay outfall in the 5 April survey (Figure 4.17) and at Hout Bay outfall in the 28 June survey (Figure 4.31). In these surveys higher colony forming unit counts (but still ≤29) were measured in surface seawater samples collected at a few sites near the Camps Bay outfall diffuser section, but these were interspersed with sites where the counts were low, while the faecal streptococci count in one sample collected near the Hout Bay outfall diffuser section was relatively high (113), but counts for nearby sites were low (≤14). Such differences over a relatively small spatial scale may be the result of currents and turbulence influencing effluent dispersion in a non-linear (*i.e.* not unidirectional) manner.

High to very high faecal indicator bacteria colony forming unit counts were evident in surface seawater samples collected near (*i.e.* about 60 m) the outfall diffuser sections in those surveys when effluent clearly reached the sea surface, but in single surveys for each outfall at a distance of up to about 300 m from the diffuser section. In the 20 June survey for the Green Point outfall the sampling sites were not coincident with the most intense part of the effluent plume based on the visual observation of seawater discolouration at the sea surface. A surface seawater sample collected in the (visibly) most intense part of the plume yielded colony forming unit counts far higher than those at designated sampling sites, namely 44 000 colony forming units for *E. coli* and 7 100 colony forming units for faecal streptococci bacteria. These and the counts in six other surveys for the Green Point outfall, in three surveys for the Camps Bay outfall, and in two surveys for the Hout Bay outfall were high enough (*i.e.* considerably higher than Blue Flag guidelines) to suggest a risk to the health of humans exposed to seawater at the sea surface near the outfall diffuser sections. In the 20 June survey for the Green Point outfall there was in fact a risk to the health of humans exposed to seawater at the sea surface at most sites. Elevated (*i.e.* ≥100) colony forming unit counts were usually only detected at sites about 60 m from the Green Point outfall diffuser section, but in four surveys up to about 1 200 m. Elevated counts were detected about 40 m from the Camps Bay outfall diffuser section in some surveys, but up to about 270 m in one survey. Elevated counts were detected about 60 m from the Hout Bay outfall diffuser section in some surveys, but up to about 300 m in one survey.

In surveys where there was clear evidence for effluent reaching the sea surface, *E. coli* and faecal streptococci bacteria colony forming unit counts decreased sharply with distance from the outfall diffuser section. This clearly reflects rapid dilution of the effluent at the sea surface. For example, in the 8 November survey for the Green Point outfall, *E. coli* colony forming unit counts of 44 000 and 51 000 were detected at sites about 60 m either side the outfall diffuser section, but four or fewer colony forming units were evident at all other sites apart from a site about 300 m from the diffuser section, where the count was 82 (Figure 4.14).

Considering *E. coli* colony forming unit counts in raw wastewater are usually in the order of 3 - 10 million but may be much higher (e.g. Kay *et al.*, 2008), the colony forming unit counts in seawater samples collected in the effluent plume reflects considerable dilution of effluent by the time it reached the sea surface (*i.e.* after initial dilution). If the *E. coli* bacteria colony forming unit count in the effluents is taken as 10 million a count of 51 000 indicates a dilution of about 200. Conversely, if the count is taken as 3 million the dilution is about 60. The former dilution is the same as the minimum initial dilution considered for mass balance modelling in Chapter 2, but the latter dilution is far lower.

Faecal indicator bacteria colony forming unit counts at sites inshore of the outfall diffuser sections were low, with some exceptions. For the Camps Bay outfall, *E. coli* colony forming unit counts inshore of the outfall diffuser section were <20 in all but three surveys and never exceeded 67 colony forming units. In the 20 June survey for the Green Point outfall, however, *E. coli* and faecal streptococci colony forming unit counts at sites inshore of the outfall diffuser section were relatively high (up to 390; Figure 4.9). It is uncertain if this reflects wind and current assisted advection of effluent onshore or the introduction of these bacteria to nearshore waters via stormwater. The wind had a significant westerly component on the day of the survey, meaning this could conceivably have advected the bacteria onshore. However, as discussed below there is a possibility that stormwater was a source of the bacteria.

Stormwater is a significant vector for the introduction of faecal indicator bacteria to shoreline waters in cities in most parts of the world (e.g. Lee *et al.*, 2003, Converse *et al.*, 2011) and the City of Cape Town is no different. Studies (e.g. CoCT, 2000) have revealed high (several million) colony forming unit counts of faecal indicator bacteria in stormwater discharged onto the shoreline along the Atlantic and False Bay seaboard of Cape Town. There are several possible sources of faecal indicator bacteria in stormwater runoff, including the faeces of birds and household pets (e.g. dogs and cats). Furthermore, there are typically a fairly large number of households and businesses with

sewers illicitly or incorrectly connected to the stormwater reticulation system in most cities. As a result raw sewage is discharged with stormwater into aquatic ecosystems. The significance of stormwater as a vector for the introduction of faecal indicator bacteria to shoreline waters is twofold. First, there are a large number of points where stormwater is discharged onto the shoreline in the area between Green Point and Camps Bay. For example, there are 161 points between Duynfontein in Table Bay and Scarborough on the Cape Peninsula, and 69 over the approximately 12 km of shoreline between Granger Bay and Bakoven. Second, 1.6 and 7.6 mm of rain was recorded at the Cape Point weather station on 18 and 19 June, that is, the two days prior to the 20 June survey. Thus, there is a strong possibility the high colony forming unit counts measured in nearshore water samples in this survey were derived from stormwater, particularly as the lowest counts were generally detected furthest from the shoreline.

In Hout Bay, moderate faecal indicator bacteria colony forming unit counts (≤ 80) were detected inshore of the outfall diffuser section in the 30 March (Figure 4.28), 28 June (Figure 4.31) and 19 July surveys (Figure 4.32). In the two days preceding the 19 July survey, 3.8 and 1.2 mm of rain was recorded at the Cape Point weather station, but no rain was recorded in the few days preceding the surveys in March and June. This makes it difficult to determine if effluent reaching the surface was being dispersed over the wider bay or if there was a contribution from the Disa (Hout Bay) River and stormwater. It seems unlikely, but not impossible, the counts measured in samples collected in the 30 March and 28 June surveys reflect effluent advected to the shoreline since colony forming unit counts at sites intermediate between the diffuser section and the nearshore sites were usually lower. However, as stated above this may also reflect complex, non-linear dispersion of effluent by currents in the marine receiving environment.

The CSIR (1990) analysed faecal coliform colony forming unit counts in seawater samples collected in 36 surveys after the Green Point outfall was commissioned in 1985. The samples were collected at nine sites between the western breakwater for

the Port of Cape Town and Camps Bay. There was virtually no difference in the geometric mean or median colony forming unit count across the sites apart from Three Anchor Bay, where the count was consistently higher. The situation at all sites represented a marked improvement in the situation compared to the previous (550 m in length) outfall and this was attributed to the low proportion of time that the current flows onshore at the discharge position for the outfall (1 700 m in length). The situation at Three Anchor Bay was attributed to contaminated stormwater. The CSIR (1990) further interrogated the data to determine the relationship between bacteria colony forming unit counts and antecedent rainfall, which showed that at virtually all sites there was a marked increase in counts when rainfall exceeded 10 mm over the three days prior to a survey compared to surveys when the rainfall was less than 10 mm over this period.

In conclusion, there was clear evidence for effluent reaching the sea surface near the diffuser sections of the Green Point, Camps Bay and Hout Bay outfalls in certain surveys performed in 2016. Effluent reached the sea surface more often at the Green Point outfall than the Camps Bay and Hout Bay outfalls. There was no clear evidence that effluent was impinging on the shoreline apart possibly for one survey for the Green Point outfall, but stormwater could not be discounted as a source of the bacteria (at least in the nearshore) in this survey. In surveys when effluent reached the sea surface its dilution was rapid with the possible exception of the abovementioned survey for the Green Point outfall, as reflected in the typically very low faecal indicator bacteria colony forming unit counts beyond about 60 m of the outfall diffuser sections. This is not to say effluent constituents never impinge on the shoreline but that there was no clear evidence for this on the dates the surveys were made in 2016.

4.3.2. Faecal Indicator Bacteria - Shoreline

Most strains of *E. coli* and faecal streptococci do not cause human illness, that is, they are not human pathogens. Rather they indicate the presence of faecal contamination. Nevertheless, faecal indicator bacteria are used across the world as surrogates for pathogenic microorganisms that

may be found in shoreline waters used for recreational purposes. This is because pathogens often co-occur with bacterial indicators of faecal contamination. Generally, a high faecal indicator bacteria count reflects a greater possibility for the presence of pathogens. Faecal indicator bacteria are also usually more abundant in effluent than pathogenic microorganisms and are easier, safer and cheaper to analyse in the laboratory.

Studies have revealed that faecal streptococci colony forming unit counts are significantly correlated to human illness at marine beaches impacted by point source pollution (Prüss, 1998; Wade *et al.*, 2003; Wade *et al.*, 2010). However, a similar correlation has not been identified for marine beaches impacted by non-point source pollution, or for subtropical marine beaches impacted by point and non-point source pollution (e.g. Haile *et al.*, 1999; Prüss, 1998; Wade *et al.*, 2003; Colford *et al.*, 2007; Jiang *et al.*, 2007; Fewtrell and Kay, 2015). The failure to consistently demonstrate a link between faecal streptococci and human illness at non-point source beaches has called into question the utility of using these as an indicator of pathogenic microorganisms. The lack of a correlation is understandable considering indicator microbes, such as faecal streptococci, may come from relatively low-risk sources of faecal pollution (e.g. animal faeces) and may thus not be related to human or other high-risk sources of faecal pollution and pathogenic microorganisms (Boehm *et al.*, 2008). Grant *et al.* (2001), for example, demonstrated that faecal streptococci in stormwater impacted by bird faeces confounded the assessment of possible bather risk at southern California beaches. It has also been shown that in subtropical and temperate climates faecal indicator bacteria, under specific conditions, can persist in the marine environment for longer than expected based on laboratory experiments and under the right conditions may even multiply, resulting in a false impression of increased microbial pollution and pathogen presence (Desmaris *et al.*, 2002; Shibata *et al.*, 2004; Alm *et al.*, 2006; Beversdorf *et al.*, 2007; Fries *et al.*, 2008; Hartz *et al.*, 2008). Environmental factors such as tide, rain, and solar radiation can also have significant and varying effects on the abundance of faecal indicator and pathogenic microorganisms (Fujioka *et al.*, 1981;

Jiang *et al.*, 2007). Nevertheless, as stated above faecal indicator bacteria are widely used as indicators of shoreline water quality impairment for the protection of recreational user health.

The City of Cape Town analyses *E. coli* and faecal streptococci colony forming unit counts in seawater samples that are collected at approximately two week intervals at a large number of shoreline sites in Table Bay and along the Atlantic seaboard of the Cape Peninsula (Figure 4.40) (shoreline sites in False Bay are also monitored but were not considered for this study). Considering a major concern amongst Capetonians appears to be if effluent constituents are reaching the shoreline and posing a risk to the health of recreational users of beaches and nearshore waters it is worthwhile examining the incidence of faecal bacteria impairment of shoreline water quality as revealed through the monitoring. This could provide insight into the likelihood that effluent constituents are reaching the shoreline and the frequency thereof.

Figure 4.41 provides *E. coli* and faecal streptococci colony forming unit counts for 31 of the 40 sites where seawater samples are collected on the shoreline between Silwerstroom Tidal Pool in Table Bay and Scarborough Beach on the Cape Peninsula for the period 25 July 2007 to 29 June 2016. Between 228 and 235 surveys were performed over this period at 34 of the 40 sites, but never fewer than 202 surveys apart from a site outside the tidal pool at Saunders Rock (Bantry Bay), where 75 surveys were made. Colony forming unit counts reported as below the method detection limit (<2 and <1 colony forming unit counts for *E. coli* and faecal streptococci respectively) were replaced by a count equivalent to the method detection limit. In some cases the Scientific Services Branch of the City of Cape Town reports colony forming unit counts as exceeding a certain count (*e.g.* >5 000 colony forming units). In these instances (115 samples) the count was replaced with an equivalent value. In instances (21 samples) where there was over-growth of the culture plate and the measurement was not repeated this was not replaced with a surrogate count.

The Blue Flag programme provides guidelines, which are based on World Health Organisation

guidelines, for water quality at recreational beaches and in small vessel marinas seeking accreditation to the programme. These guidelines were used to identify impaired seawater quality at the sites monitored by the City of Cape Town, by considering 250 or more colony forming unit counts for *E. coli* and 100 or more colony forming unit counts for faecal streptococci as indicative of impairment (*i.e.* failure of Blue Flag guidelines). The guidelines are identical to those for an excellent water quality classification in the updated South African Water Quality Guidelines for Coastal Marine Waters: Recreational Use (DEA, 2012). Within these limits there is an approximately 2.9% risk of a person contracting a gastrointestinal illness as a result of exposure to pathogenic microorganisms. The reader should note that the way the South African Water Quality Guidelines for Coastal Marine Waters: Recreational Use (DEA, 2012) are used to classify water quality and the way the Blue Flag programme accredits beaches is not based on the results of all seawater samples analysed. Rather, the 95th percentile of the results is used to determine compliance. In other words, a small degree (5%) of latitude is allowed for the periodic exceedance of a guideline. The Blue Flag programme also permits 15% of non-compliant results or one sample per bathing season, whichever is greater to be discounted provided there is a follow-up survey within seven days of the non-compliance and the results for this survey are compliant. There is thus recognition that there may periodically be circumstances (*e.g.* after heavy rain and associated stormwater discharge) that result in an elevated faecal indicator bacteria count in the short-term.

It is beyond the scope of this report to discuss the trends in faecal indicator bacteria colony forming unit counts for each shoreline site in detail. Several points are, however, worth noting. The proportion of surveys in which *E. coli* and faecal streptococci colony forming unit counts exceeded Blue Flag guidelines for the period 1 January 2008 to 31 December 2015 (this period is the focus hereafter) is provided in Figure 4.42. By far the most frequent exceedances were for Lagoon Beach at the mouth of the Diep River/Milnerton Lagoon, at 47.1% of surveys for *E. coli* and 34.6% of surveys for faecal streptococci. There is little doubt this reflects the



Figure 4.40. Aerial view of the Table Bay and Cape Peninsula shoreline, showing the positions where shoreline water samples were collected for faecal indicator bacteria analysis by the Scientific Services division of the City of Cape Town. The Green Point outfall is denoted by the red line.

discharge of faecal indicator bacteria impaired water from the river/lagoon, wherein bacterial impairment of water quality is known to be significant and to present a human health risk from a recreational use perspective (Jackson *et al.*, 2011). Other sites with a relatively high proportion of *E. coli* and faecal streptococci exceedances of Blue Flag guidelines were Three Anchor Bay in Sea Point (21.7% and 25.6% of surveys), the area

immediately outside Milton tidal pool in Sea Point (20.2% and 25.5% of surveys), the beach at Saunders Rock in Bantry Bay (27.5% and 30.4% of surveys), and the area immediately outside the Saunders Rock tidal pool in Bantry Bay (23.0% and 26.7% of surveys). The poor microbiological quality of seawater at Three Anchor Bay is not new and was already commented on by the CSIR in 1990 (CSIR, 1990), which concluded this was a result of



Figure 4.40 continued. Aerial view of the Table Bay and Cape Peninsula shoreline, showing the positions where shoreline water samples were collected for faecal indicator bacteria analysis by the Scientific Services division of the City of Cape Town. The Camps Bay outfall is denoted by the red line.

bacteria introduced via stormwater rather than effluent discharge via the Green Point outfall. The fewest exceedances were for the Silwerstroom tidal pool in Table Bay (2.9 and 3.0% of surveys) and Long Beach in Kommetjie (2.9 and 2.9% of surveys) on the Cape Peninsula.

At 27 and 20 of the 40 sites the *E. coli* and faecal streptococci colony forming unit count exceeded

the Blue Flag guideline in fewer than 10% of surveys. The proportion was generally lowest for the shoreline between Silwerstroom tidal pool and Milnerton Lighthouse in Table Bay, and with some exceptions (e.g. Hout Bay, Kommetjie) for the shoreline between (and including) Clifton 4th Beach and Scarborough Beach on the Cape Peninsula (Figure 4.42). Exceedances were somewhat higher at sites in the Green Point, Sea Point and Bantry



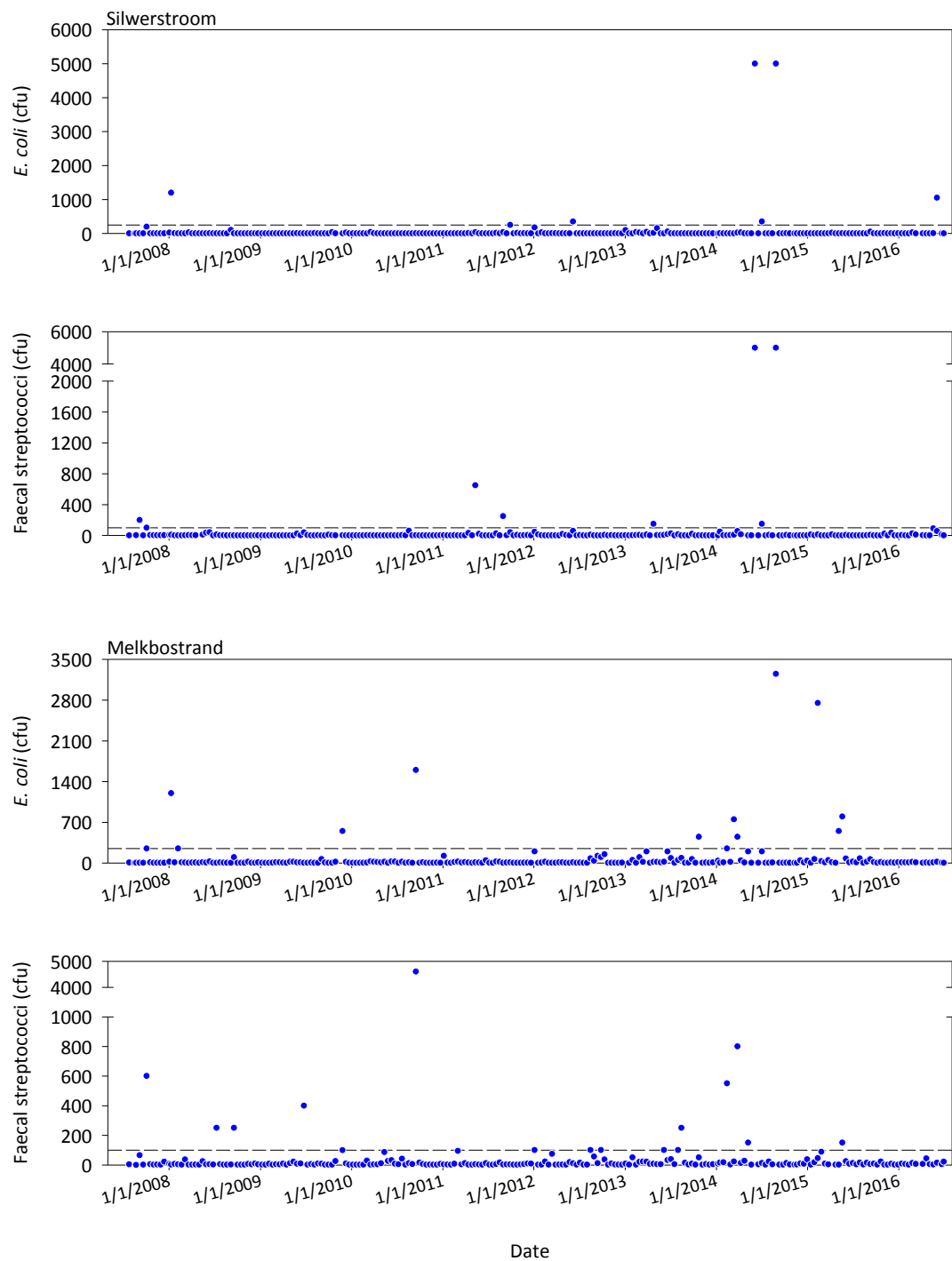
Figure 4.40 continued. Aerial view of the Table Bay and Cape Peninsula shoreline, showing the positions where shoreline water samples were collected for faecal indicator bacteria analysis by the Scientific Services division of the City of Cape Town. The Hout Bay outfall is denoted by the red line.

Bay areas. Interestingly, colony forming unit counts for *E. coli* and faecal streptococci at Kommetjie, which outwardly appears to be on a pristine part of the Cape Peninsula coastline, exceeded guidelines in 16.3 and 21.6% surveys respectively. To place this into perspective this is as, or more frequent than at some sites between Granger Bay and Saunders Rock (Figure 4.42). This is interesting since amongst the lowest frequency of Blue Flag guideline exceedances was for Long Beach in Kommetjie, about 800 m as the crow flies from the Kommetjie site (third lowest *E. coli* and second lowest proportion of faecal streptococci exceedances). The Kommetjie site is in a shallow embayment that is probably weakly flushed by tides, and this and other features that promote bacterial persistence probably influences water quality at this site. This site is also frequented by a large number of birds (personal communication with G Oelofse, City of Cape Town), which may be contributing bacteria through their faeces.

Some jurisdictions prescribe lower *E.coli* and faecal streptococci targets than those recommended by the Blue Flag programme and Department of Environmental Affairs (DEA, 2012). The USEPA (2012), for example, recommends a geometric mean of 35 colony forming units for faecal

streptococci based on five surveys in a 30 day period, a single day criterion of 104 colony forming units in this period, and a statistical threshold of 130 colony forming units that should not be exceeded more than 10% of the time. If it is argued the Blue Flag guidelines are not sufficiently protective, halving the guidelines (*i.e.* 125 colony forming units for *E. coli* and 50 colony forming unit counts for faecal streptococci) results in an increase in the frequency of exceedance by a median of 2.4% (range = 0.0 - 8.2%) for *E. coli* and 6.3% (range = 1.1 - 16.9%) for faecal streptococci (Figure 4.43), with the trend amongst sites generally comparable to that if Blue Flag guidelines are used as the target criteria (see Figure 4.42). In other words, faecal indicator bacteria counts at many sites fell infrequently into the range 125 - 250 colony forming units for *E. coli* and 50 - 100 colony forming units for faecal streptococci (see further discussion below).

Colony forming unit counts of faecal streptococci exceeded Blue Flag guidelines more often than *E. coli* at 34 of the 40 sites, with the opposite true at four sites and no difference at two sites. If the lower (halved) 'guidelines' are considered then faecal streptococci colony forming unit counts exceeded the Blue Flag guideline more frequently



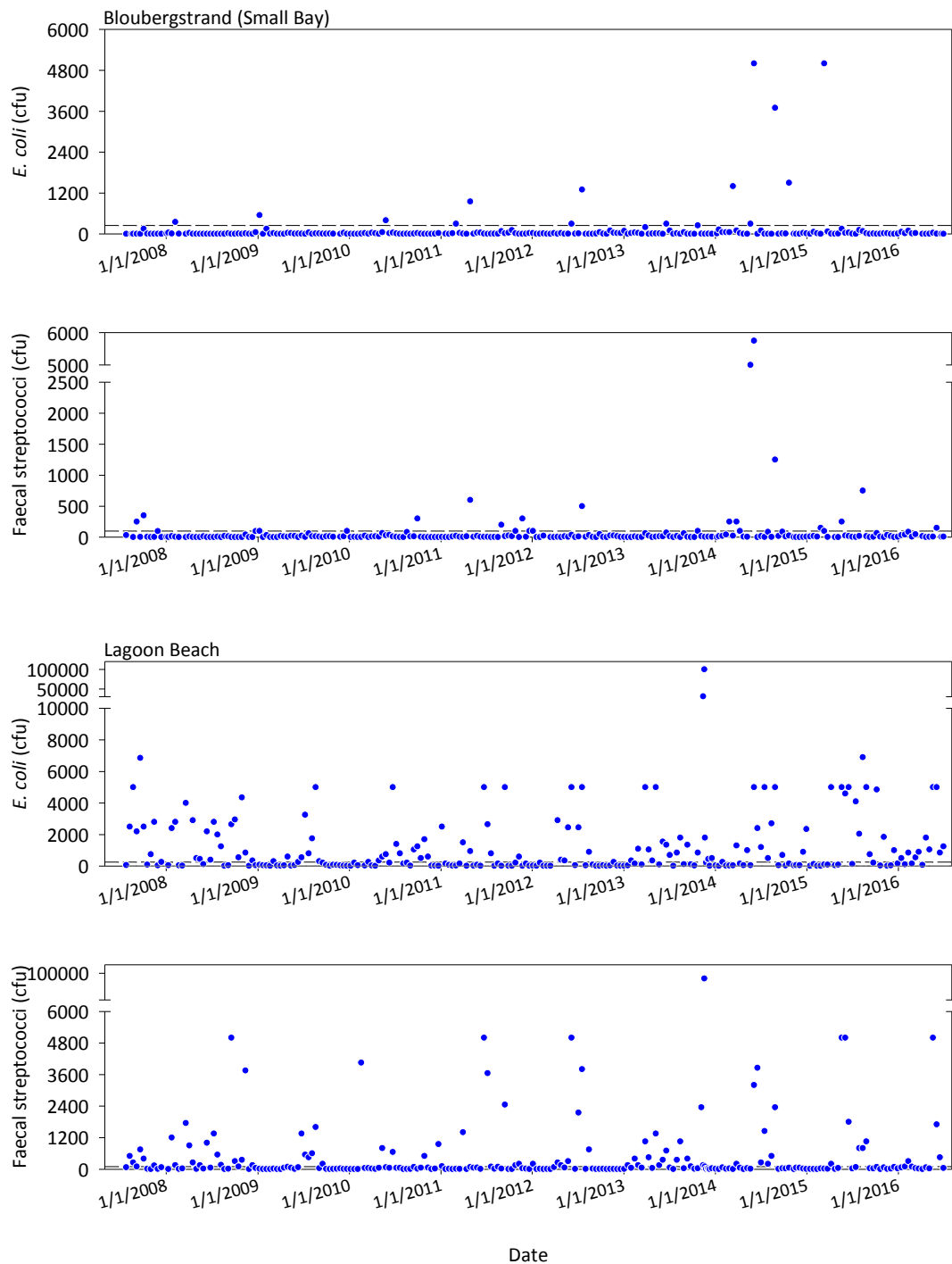


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

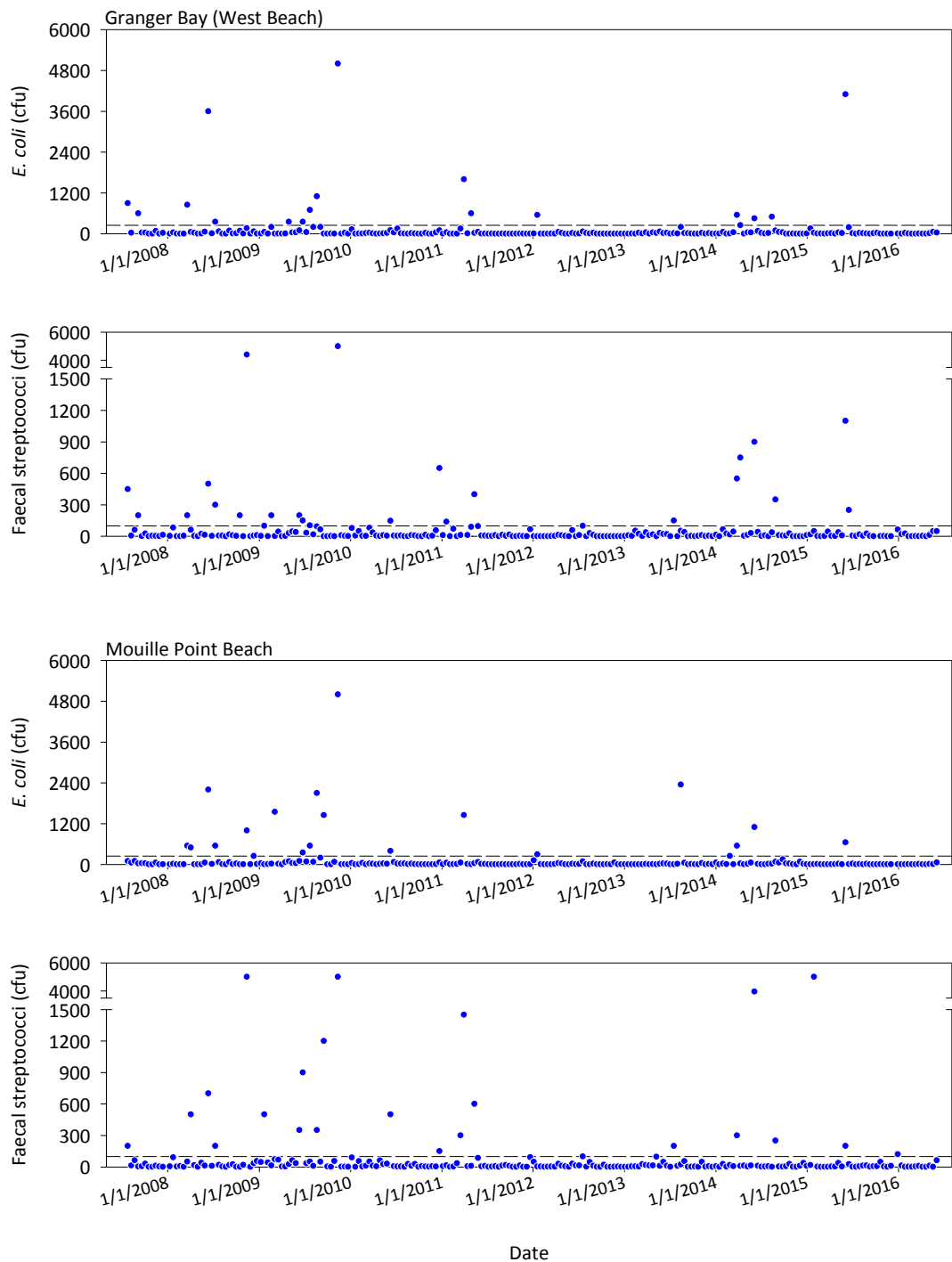


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

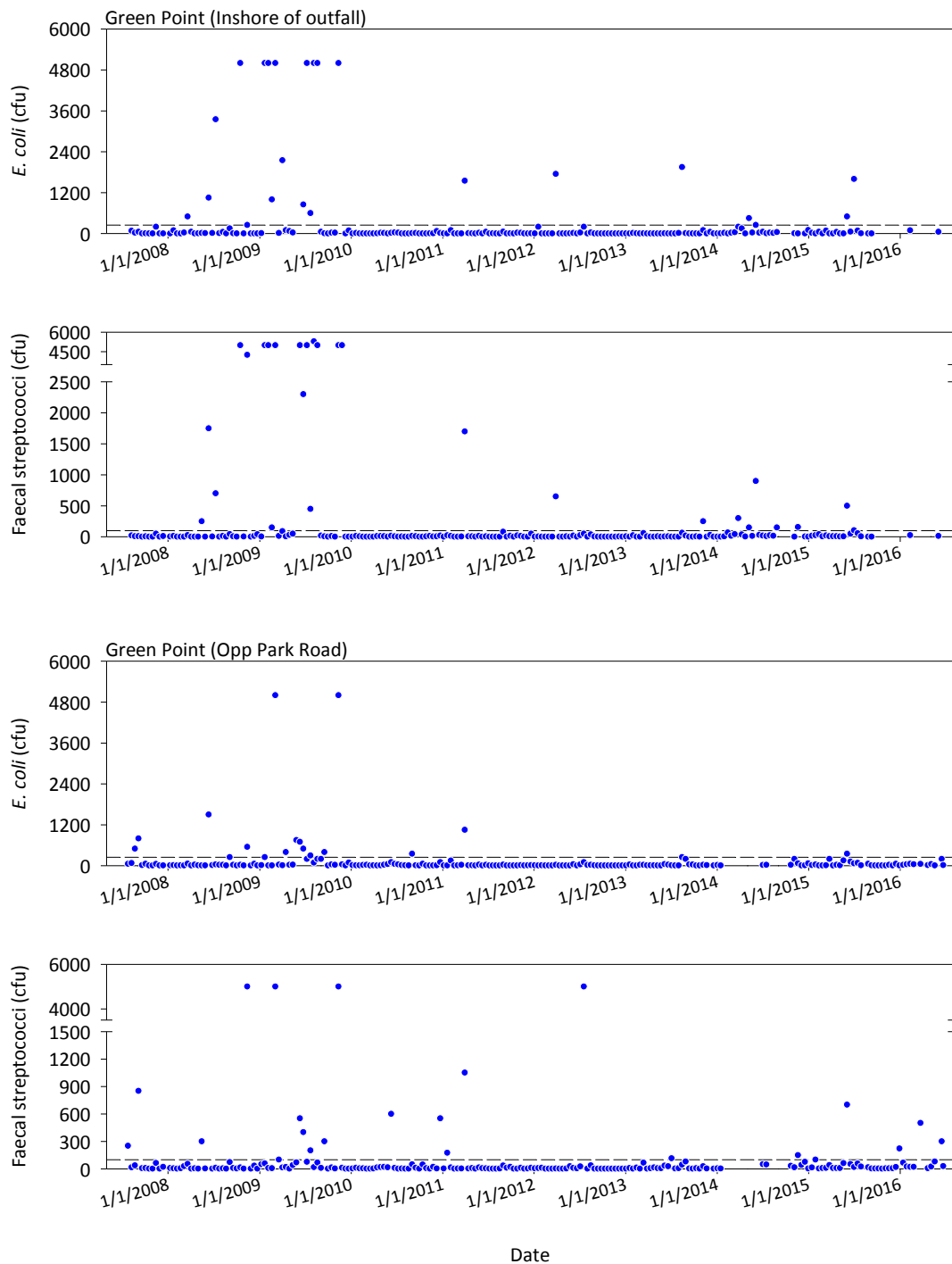


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

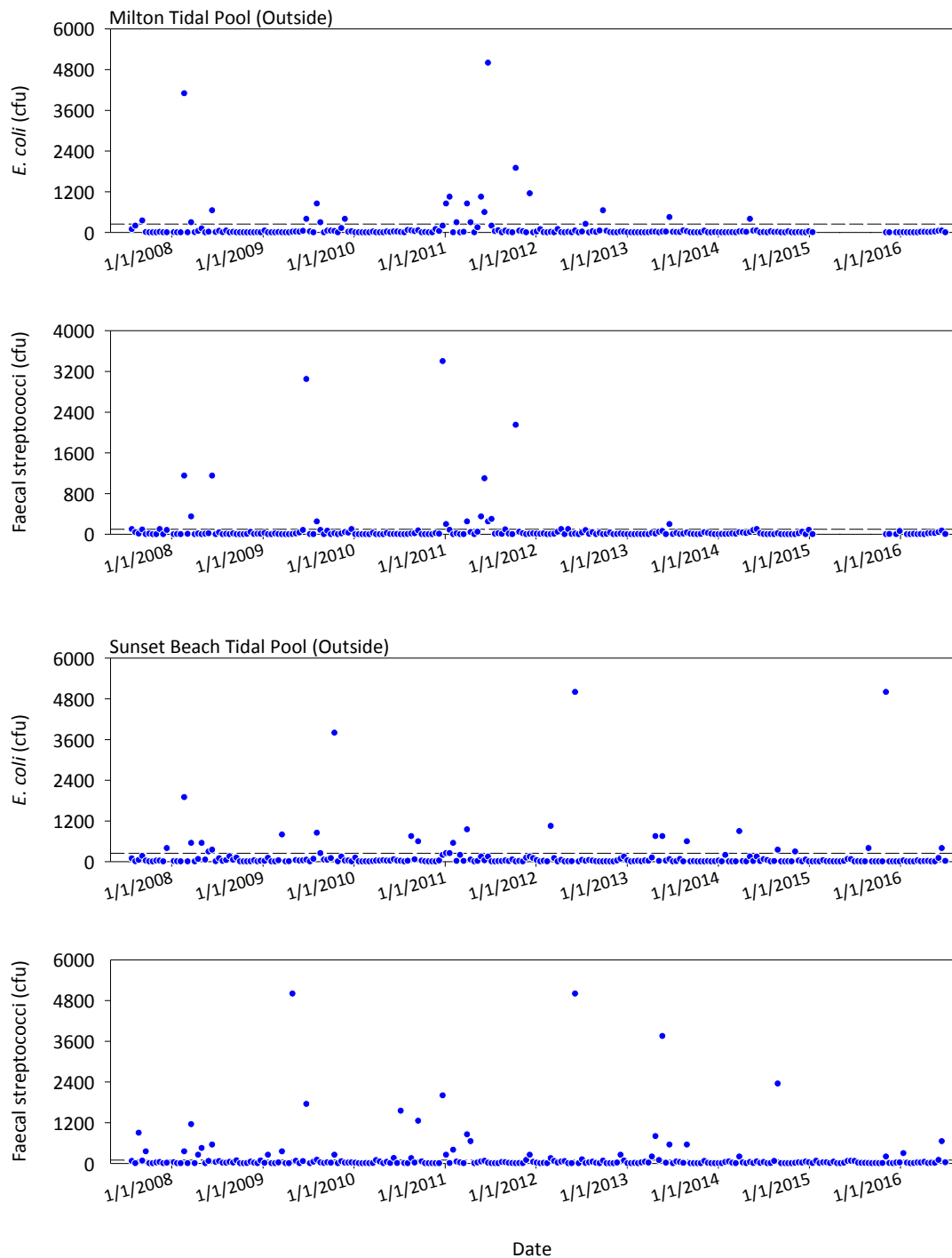


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

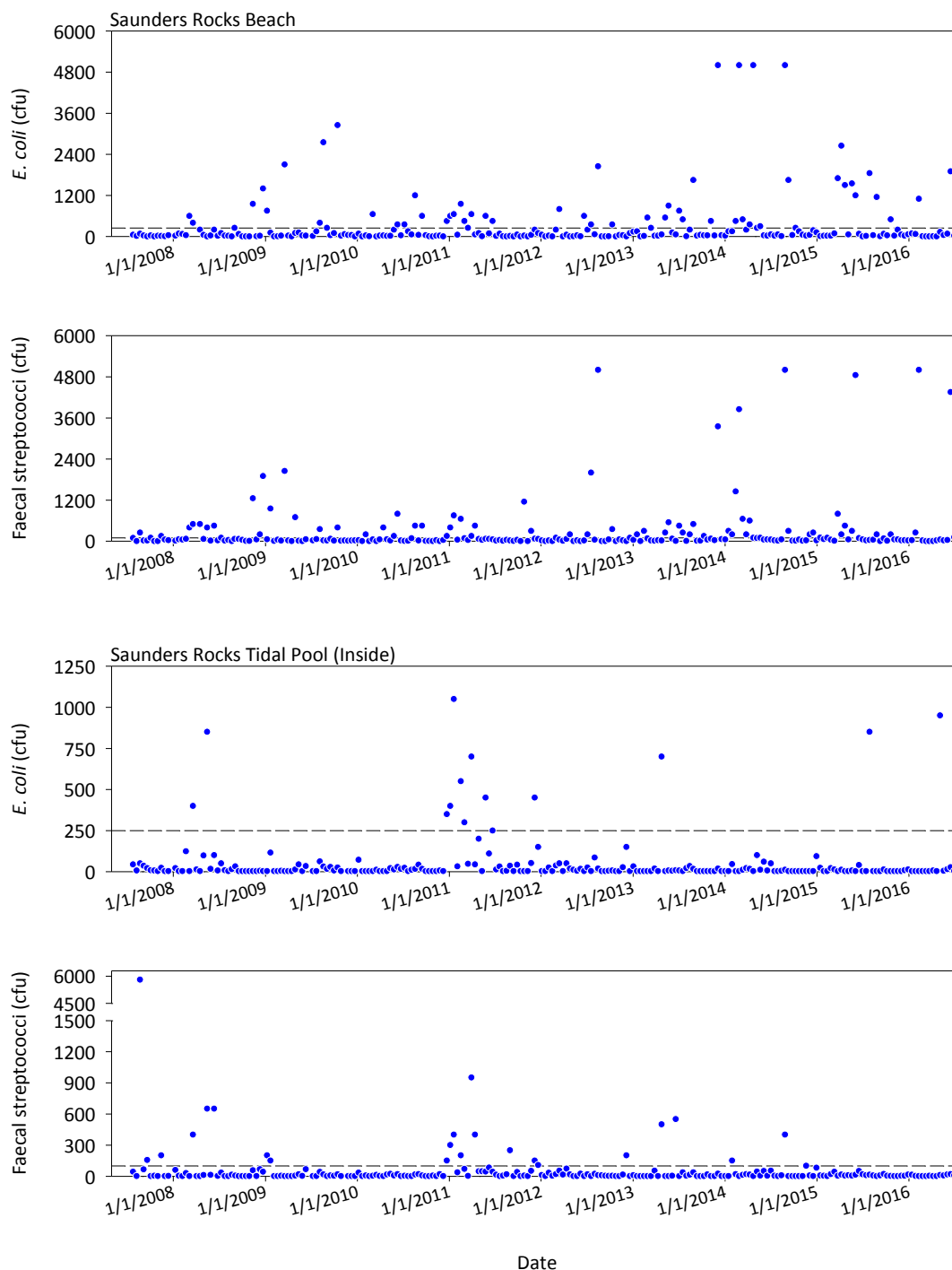


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

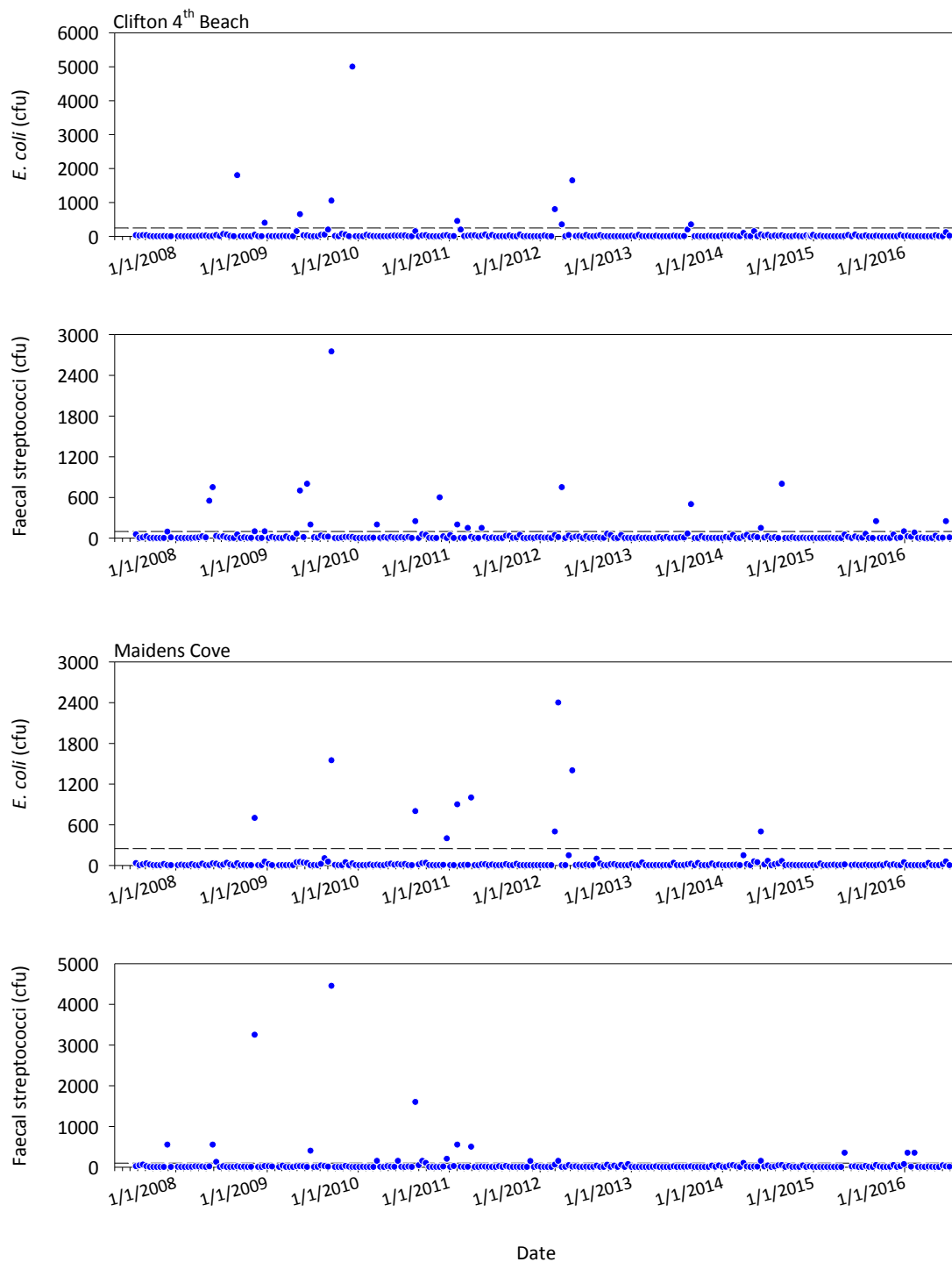


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

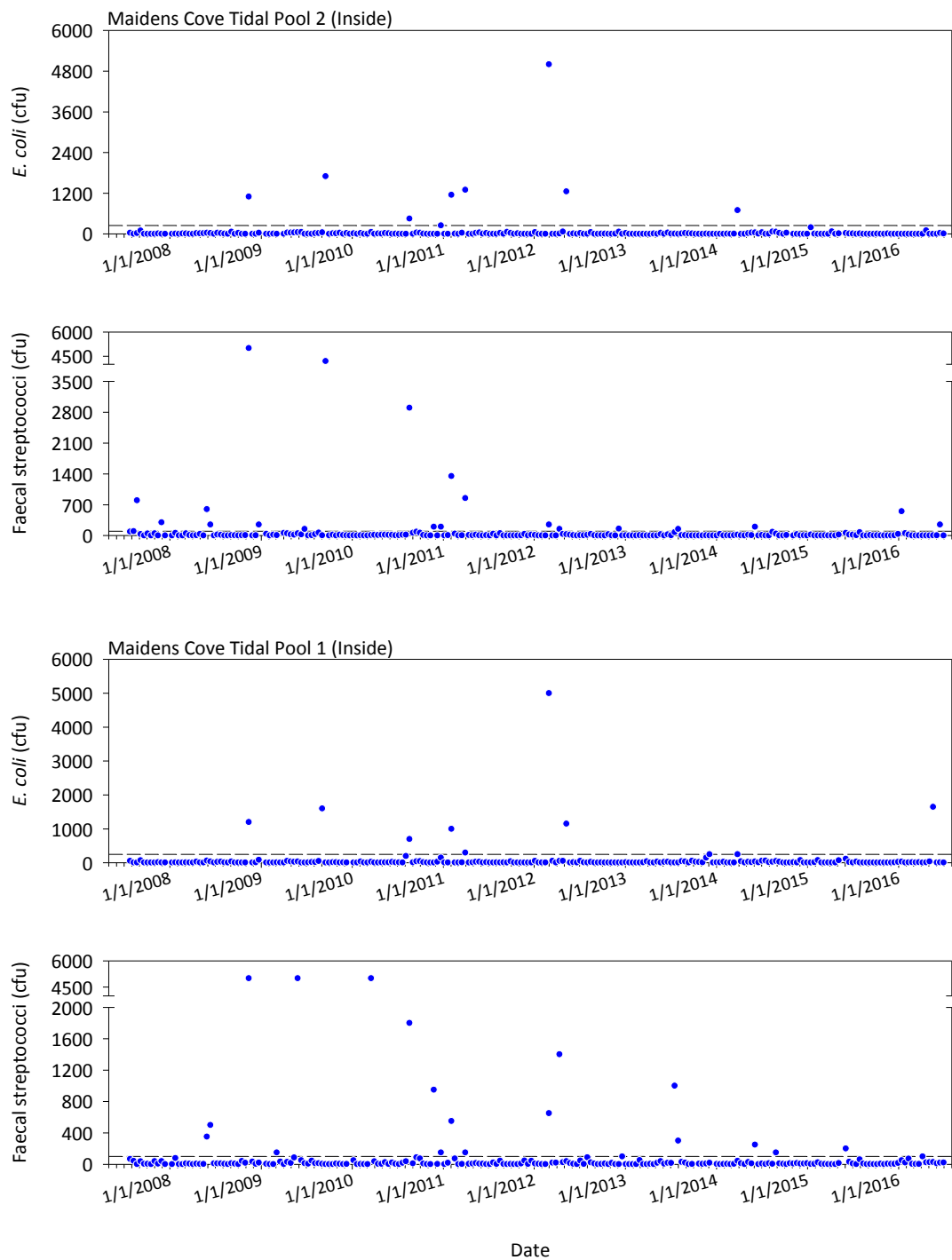


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

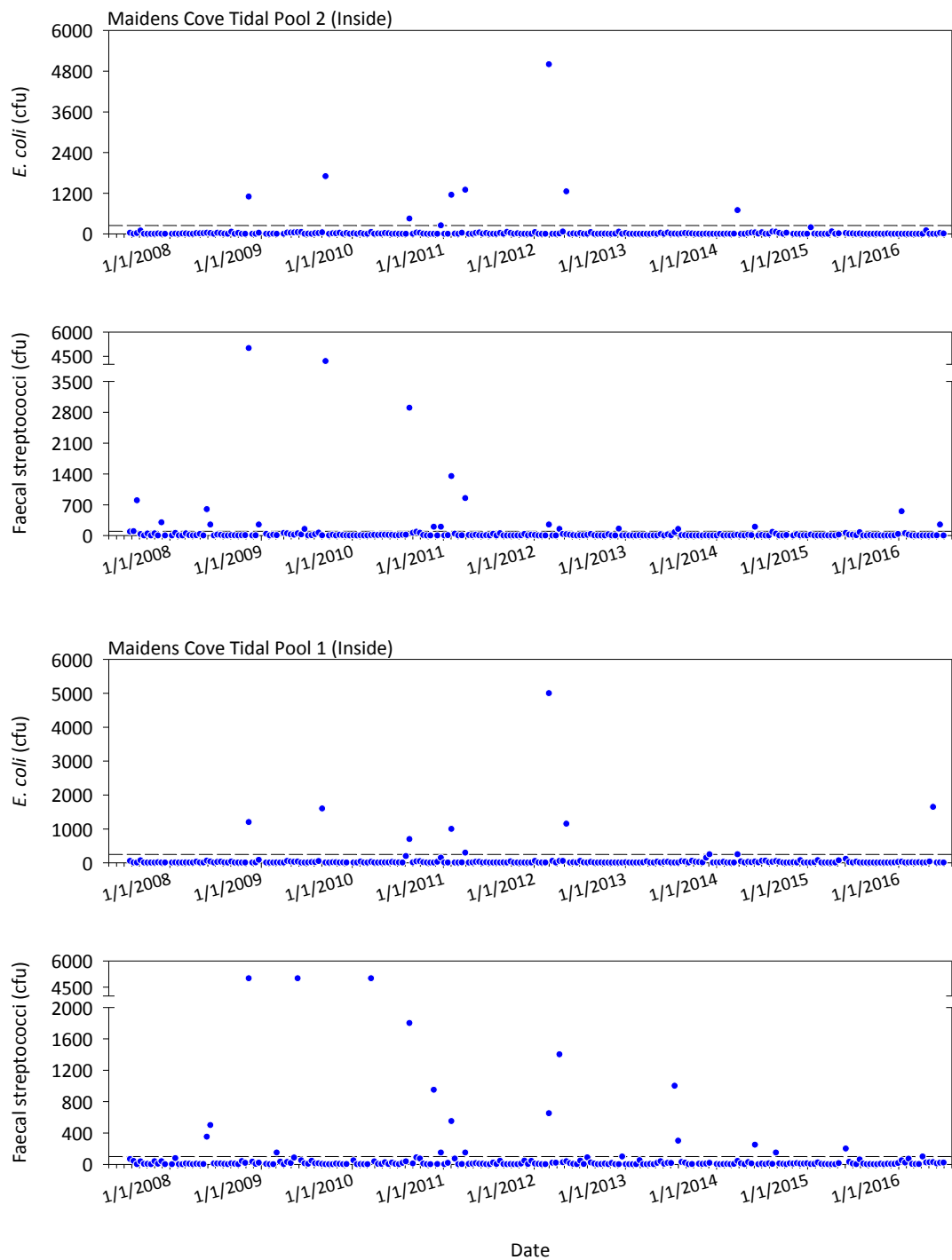


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

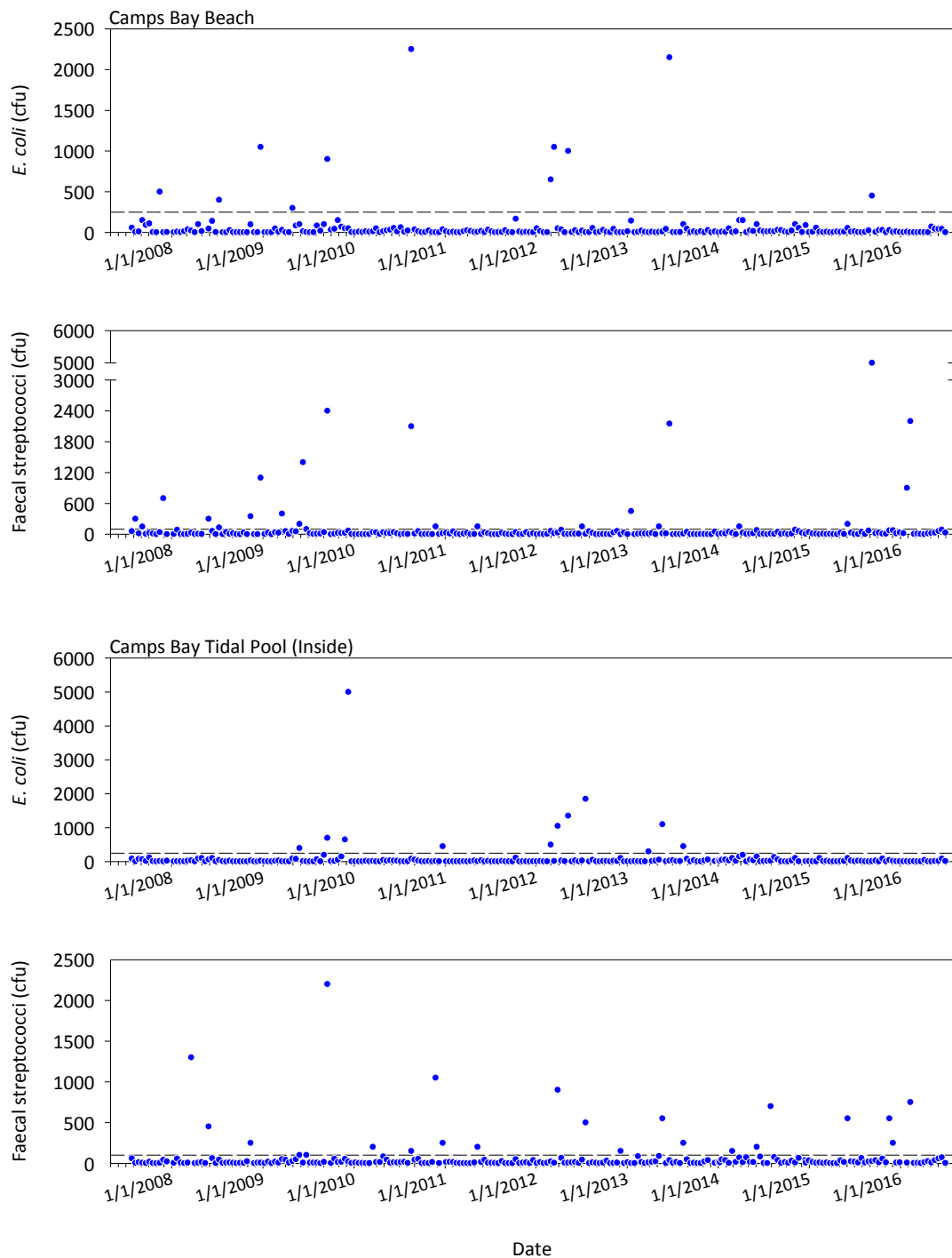


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

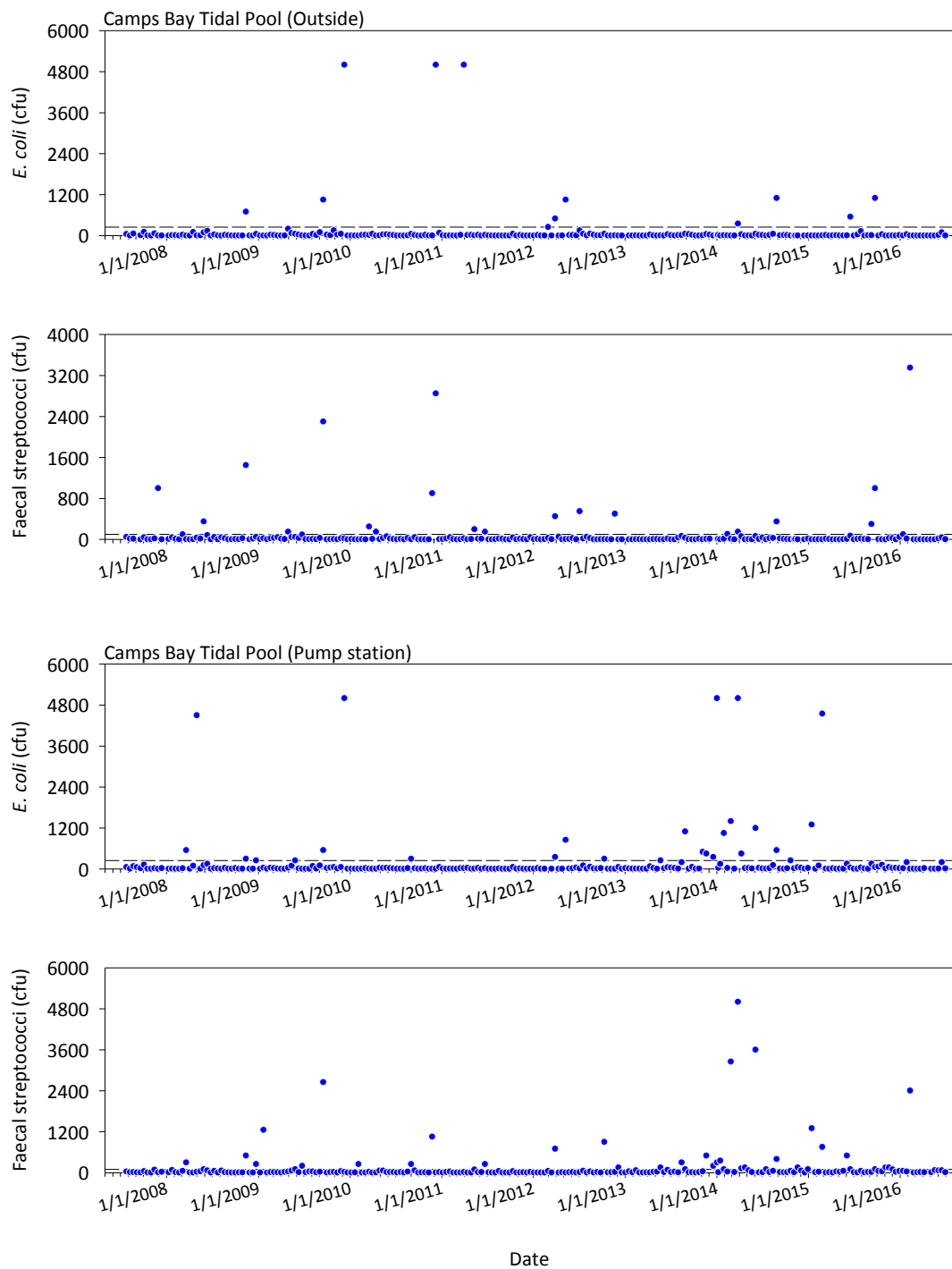


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

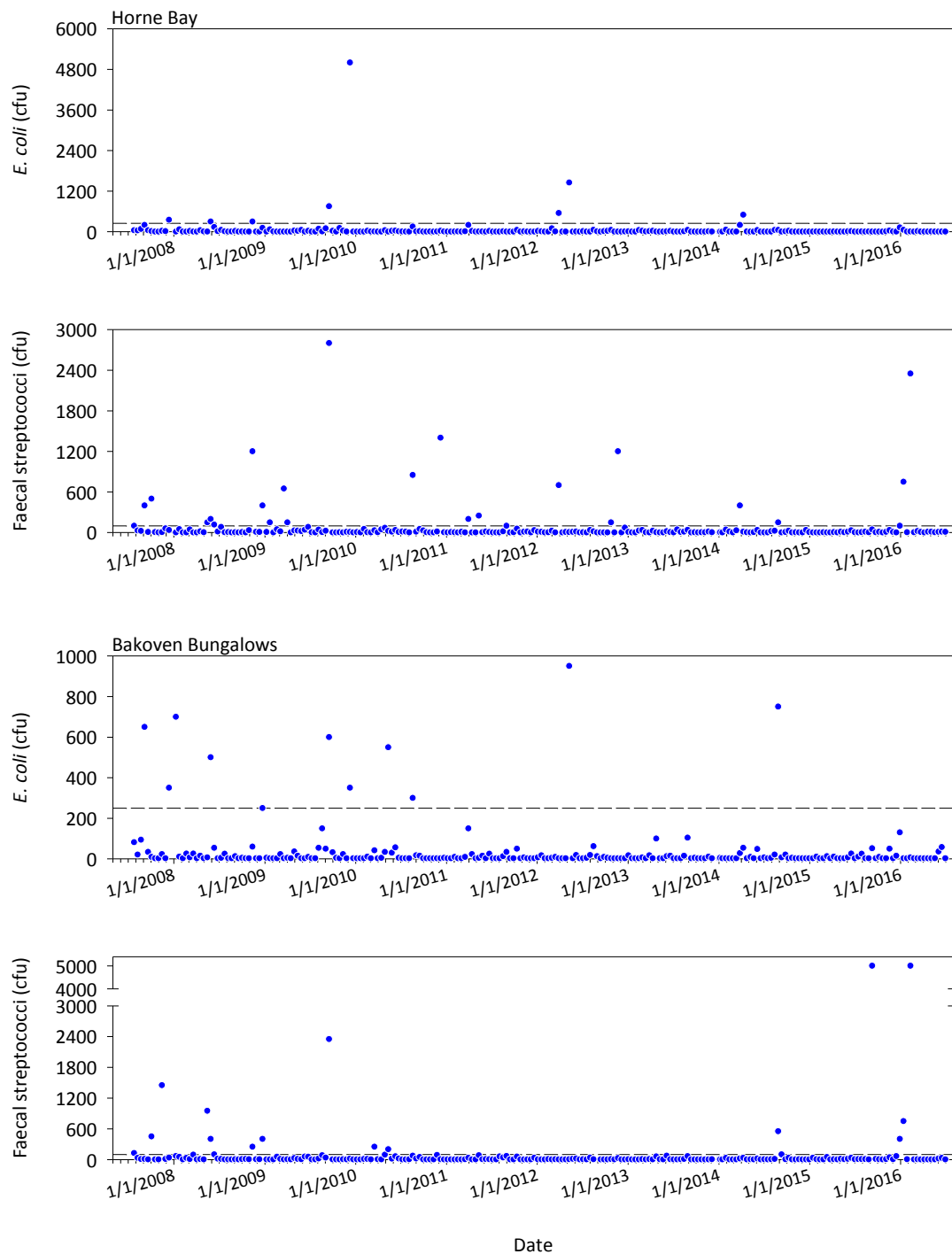


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

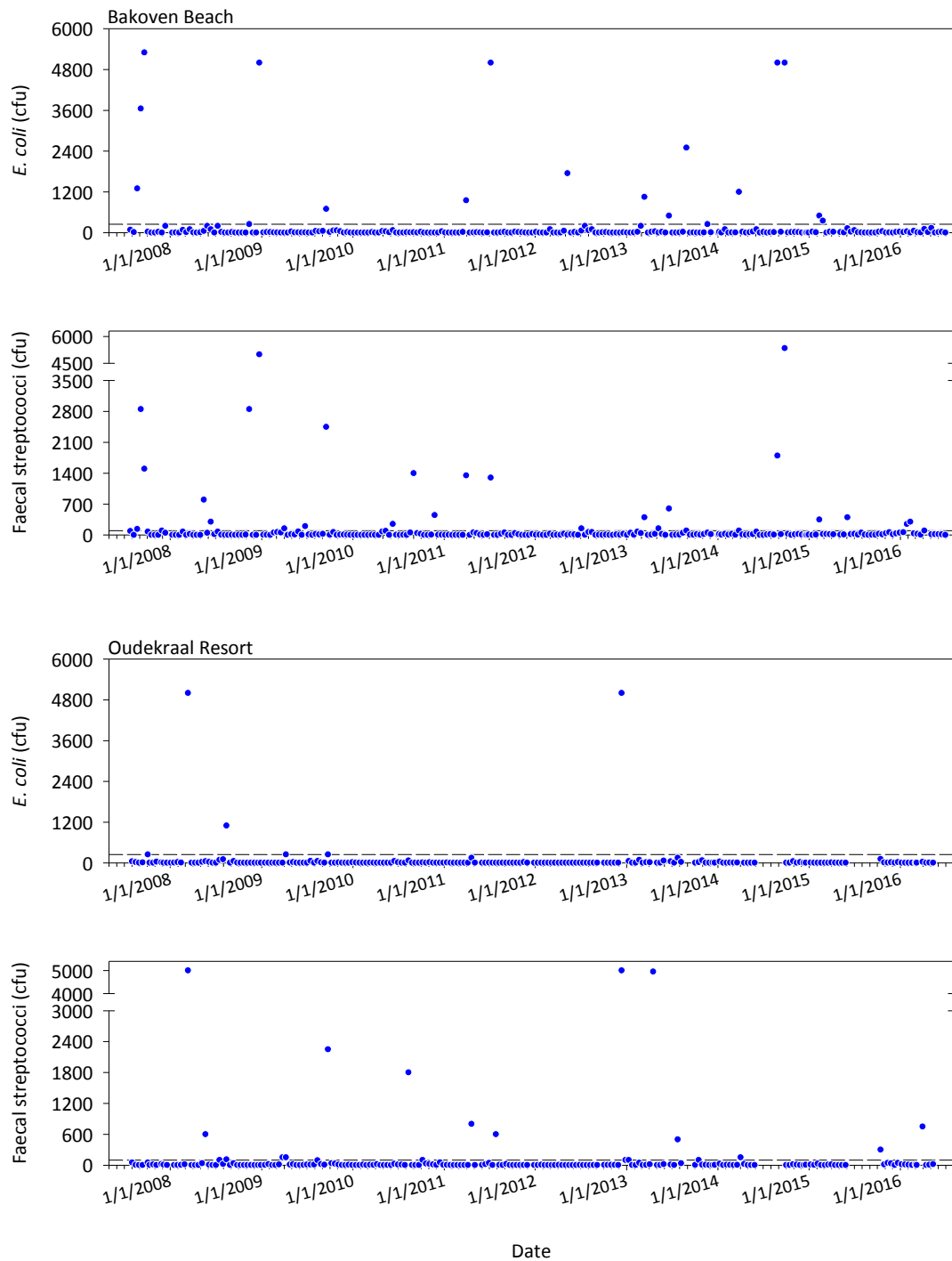


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

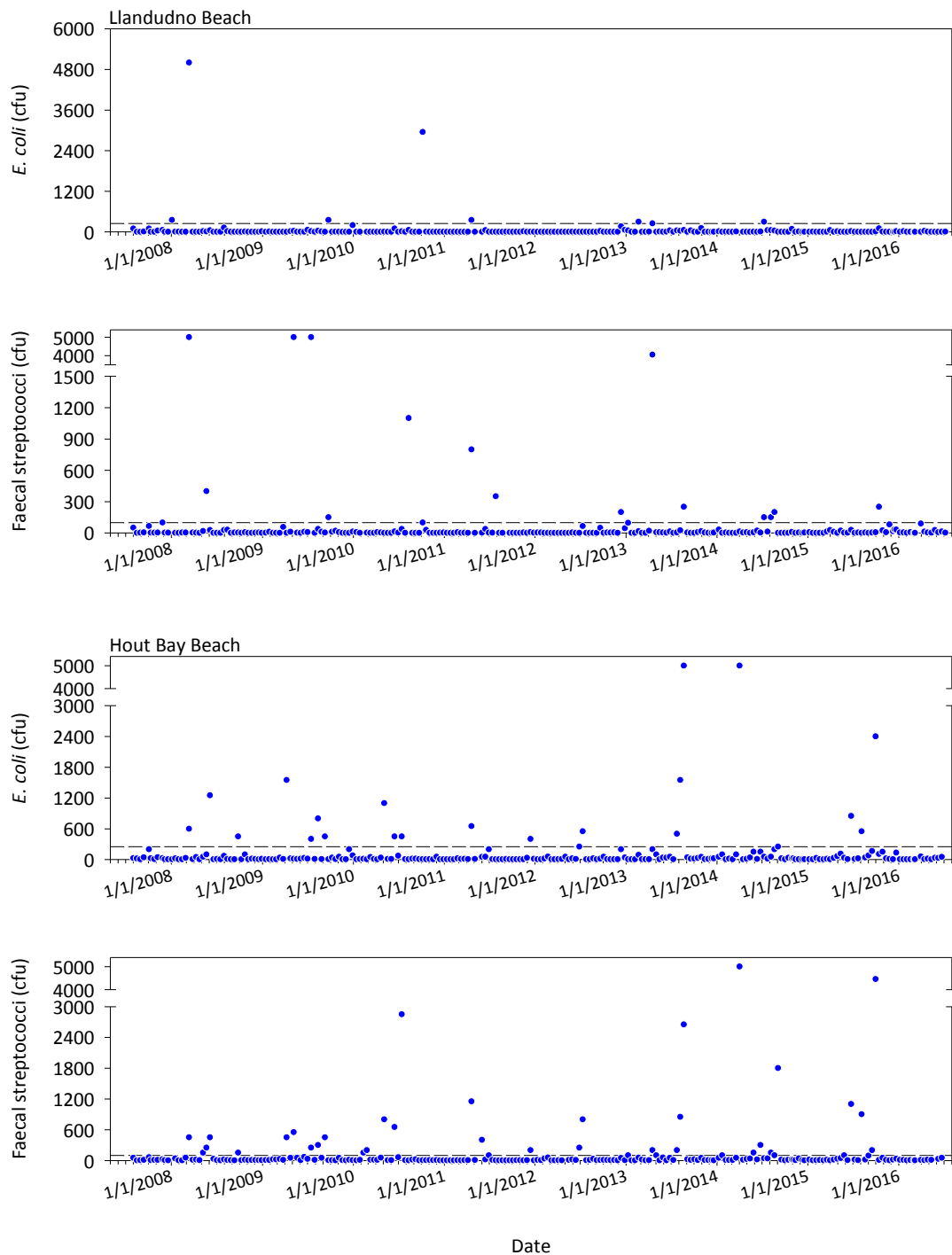


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

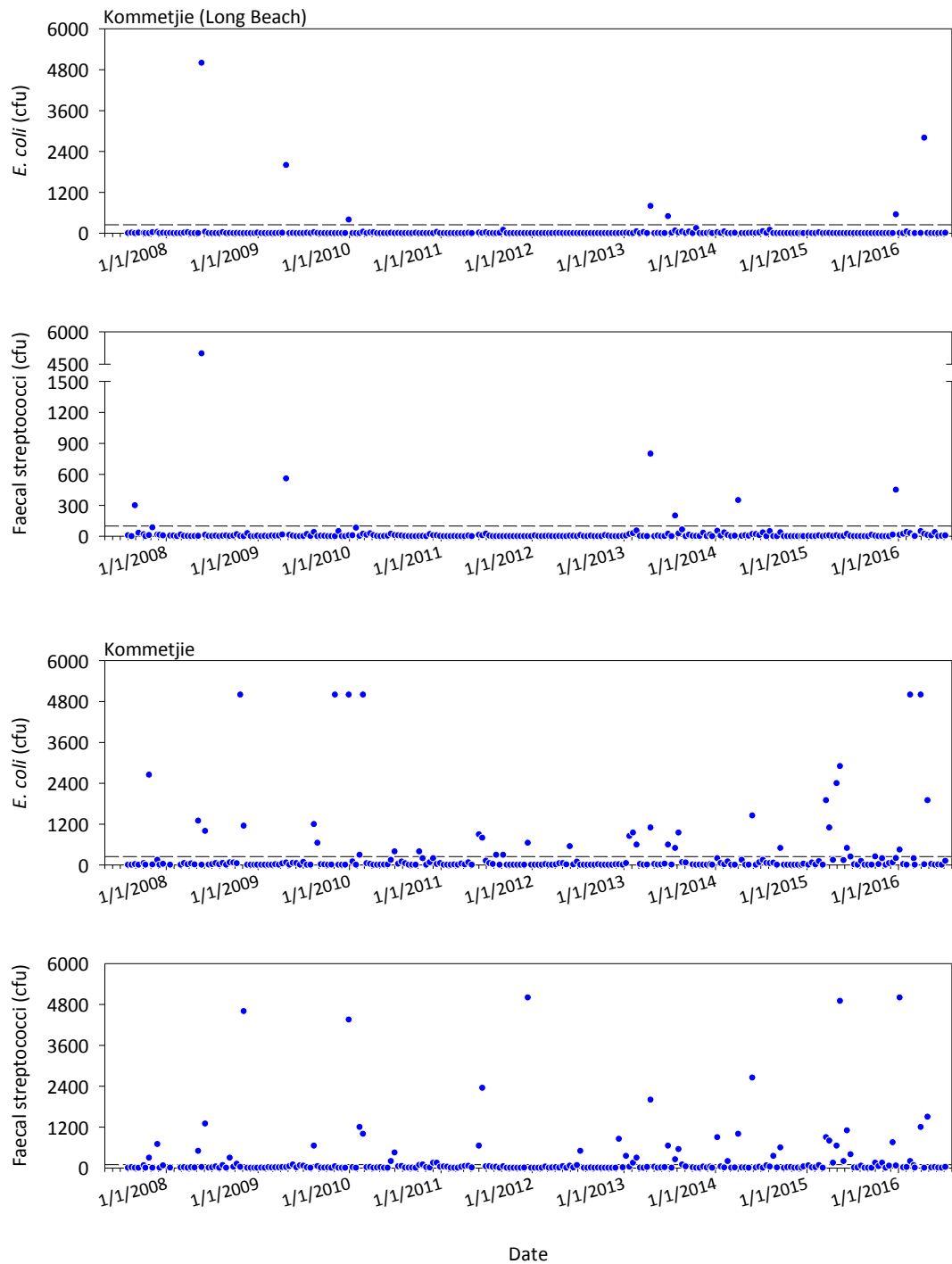


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

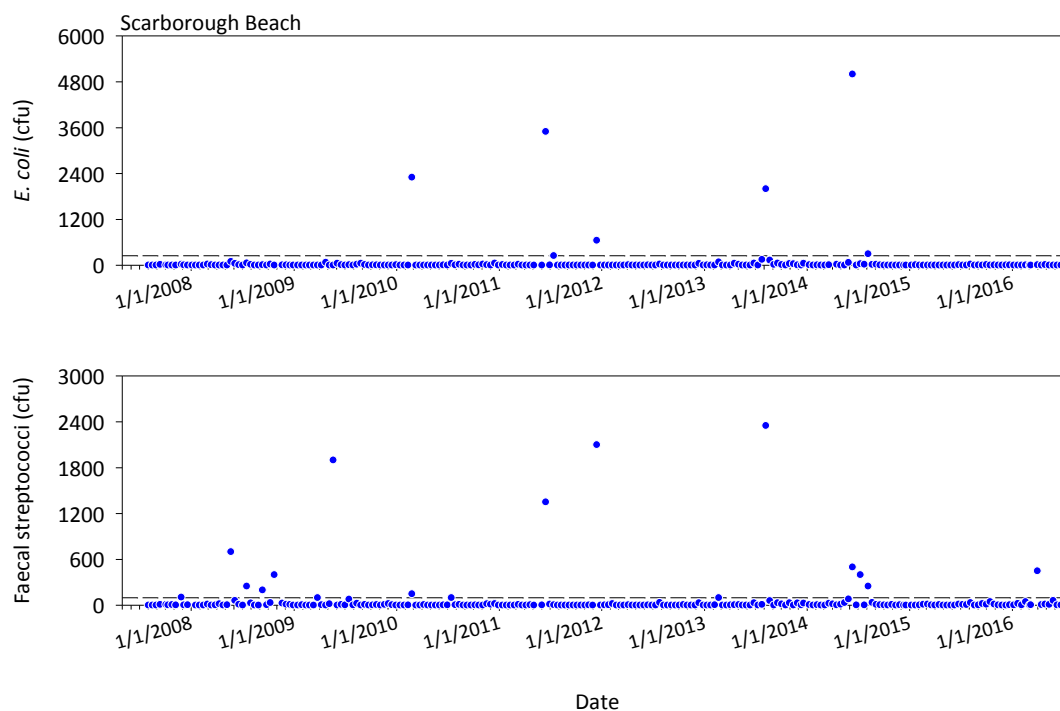


Figure 4.41 continued. *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 25 July 2007 and 6 July 2016. The horizontal dashed lines represent Blue Flag guidelines for faecal indicator bacteria, at 250 colony forming unit counts for *E. coli* and 100 colony forming unit counts for faecal streptococci.

than *E. coli* at 38 of the 40 sites, with the opposite true at the remaining sites. A possible explanation for the higher frequency of faecal streptococci exceedance of the guidelines is that these bacteria survive longer in the marine environment due to their higher tolerance of salinity than *E. coli*. Hanes and Fragala (1967) found that *E. coli* survival in marine water was about 0.8 days while faecal streptococci survival was about 2.4 days. Noble *et al.* (2004) provide a T_{90} (time to reduce population to 90% of original count) for *E. coli* and faecal streptococci of 109.7 and 143.9 hrs respectively at 14°C, and 76.7 and 121.2 hrs at 20°C respectively. Sieracki (1980) found that *E. coli* also degraded more rapidly with increased sunlight intensity than faecal streptococci, a finding confirmed by Noble *et al.* (2001) and Noble *et al.* (2004).

The proportion of Blue Flag guideline exceedances at sites inshore of the Green Point and Camps Bay outfalls (highlighted by red bars in Figures 4.42 and 4.43), where effluent constituents could outwardly be expected to reach the shoreline more often if wind and surface current advection is an important transport mechanism for faecal indicator bacteria at the sea surface, was generally not inordinately higher or lower than at nearby sites. Exceedances

at Hout Bay were, in contrast, higher than at 'nearby' sites (*i.e.* Llandudno and Kommetjie (Long Beach)). The lack of a marked difference in guideline exceedance between sites inshore of the outfalls and those nearby does not prove or disprove that effluent constituents are reaching the shoreline, but it does suggest the frequency of faecal indicator bacteria impairment of shoreline water quality is not entirely attributable to effluent discharge unless the impingement of effluent on the shoreline is more widespread than considered above (and in Figures 4.42 and 4.43). There are other potential sources of faecal indicator bacteria to shoreline waters in cities, including stormwater runoff and the faeces of birds (*e.g.* Converse *et al.*, 2012; Lee *et al.*, 2013), dogs and other warm blooded animals (*e.g.* seals; *e.g.* Zhu *et al.*, 2011), and human bather shedding (*e.g.* Elmir *et al.*, 2007, 2009). Human bather shedding may occur through direct release of bacteria from faecal material in the anal area and through the transfer of bacteria in beach sand adhering onto their bodies to seawater when they bathe (*e.g.* Elmir *et al.*, 2007, 2009). However, human shedding is considered a minor source of faecal indicator bacteria in shoreline waters compared to other sources.

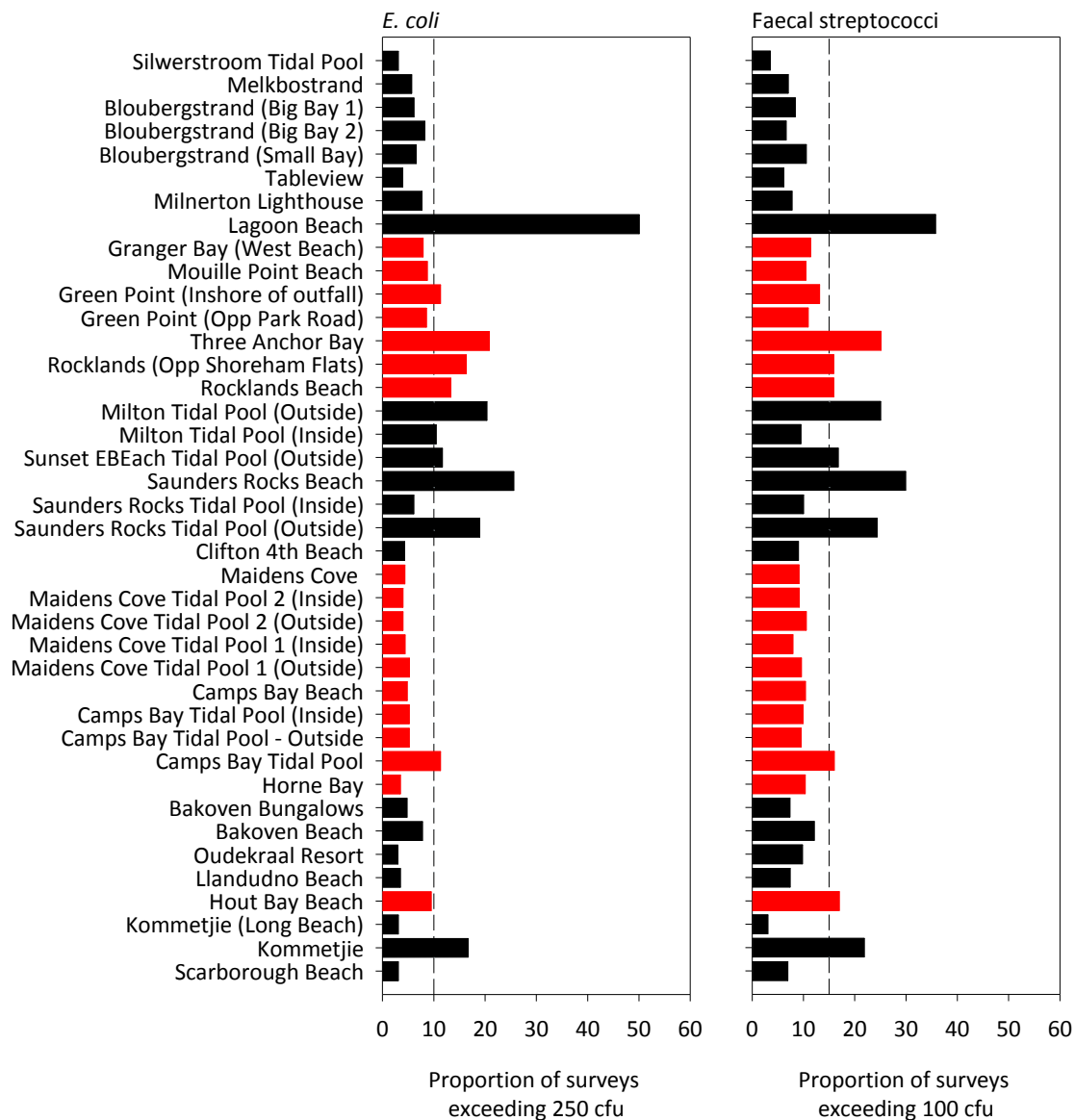


Figure 4.42. Proportion of surveys in which *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula (Atlantic seaboard) shoreline between 1 January 2008 and 31 December 2016 exceeded Blue Flag guidelines. The dashed line represents 10% and is included for reference purposes. The red bars denote sites potentially most impacted by effluent discharge.

Historically, the opinion was that faecal indicator bacteria survive for a relatively short period outside the intestinal system of mammals and birds. There is, however, ever increasing evidence that these bacteria can survive for relatively long periods outside the host intestinal system under suitable conditions (e.g. Desmarais *et al.*, 2002; Yamahara *et al.*, 2007; Yamahara *et al.*, 2009; Abdelzaher *et al.*, 2010; Sabino *et al.*, 2014; Whitman *et al.*, 2014; Zhang *et al.*, 2015). Faecal indicator bacteria have been shown to persist in beach sand, which may act as a reservoir of bacteria and pathogenic microorganisms. Release of these microorganisms may occur at each rise of the tide, resulting in regular impairment of shoreline water quality even in the absence of stormwater flow and so on (e.g.

Yamahara *et al.*, 2007; Phillips *et al.*, 2011; Halliday *et al.*, 2014; Abreu *et al.*, 2016; Vogel *et al.*, 2016). Epidemiological studies of sand contact among beachgoers also suggest there is an increased risk of gastrointestinal illness (in the order of 20 - 50% depending on age and type of sand exposure) amongst beachgoers that dig or are buried in the sand (Heaney *et al.*, 2009; Whitman *et al.*, 2009; Heaney *et al.*, 2012; Heaney *et al.*, 2014; Sabino *et al.*, 2014).

Since shoreline monitoring was performed at about two week intervals it could be argued the surveys did not coincide with periods when faecal indicator bacteria were more likely to be transported onshore by wind induced currents at the sea

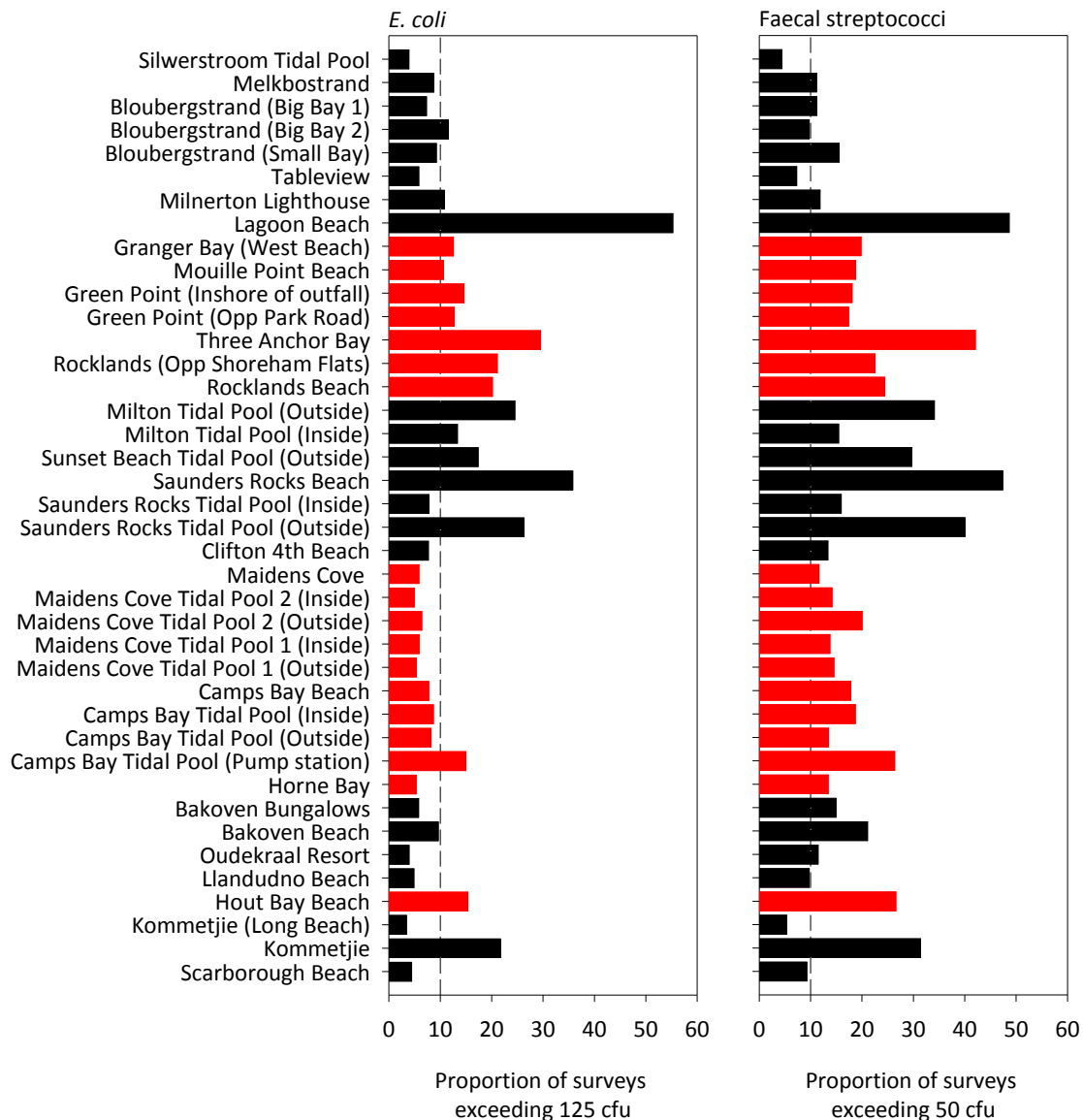


Figure 4.43. Proportion of surveys in which *E. coli* and faecal streptococci bacteria colony forming unit counts (cfu) in seawater samples collected along the Table Bay and Cape Peninsula (Atlantic seaboard) shoreline between 1 January 2008 and 31 December 2016 exceeded 125 and 50 colony forming units. The dashed line represents 10% and is included for reference purposes. The red bars denote sites potentially most impacted by effluent discharge.

surface, or by sub-surface currents. However, it is presumed the survey dates coincide with a random set of possible wind directions and strengths, antecedent rainfall, and sea states. The wind blew from the south-southwest to north-northeast (*i.e.* onshore direction) on 43.7% of the survey dates for at least 4 hrs and on 36.6, 25.2 and 18.1% of the dates for at least 8, 12 and 16 hrs. The wind blew from the south-southwest to north-northeast for at least 4 hrs on the day prior to 45.7% of the survey dates and for 39.8, 29.1 and 18.1% of the survey dates for at least 8, 12 and 16 hrs. The surveys thus include periods when the wind was blowing in directions that are more likely to transport faecal indicator bacteria in effluent reaching the sea

surface onshore.

The number of days in a month or year that *E. coli* and faecal streptococci colony forming unit counts could conceivably exceed Blue Flag guidelines cannot be estimated using the results from the City of Cape Town monitoring programme. This is because only two or occasionally three surveys were performed in a month, and about 24 surveys in a year. This is in accordance with Blue Flag guidelines, which require a minimum of one survey every 30 days but recommend two surveys per month and additional seawater sample analysis in the event of guideline exceedance. Although the results of surveys might adequately reflect trends

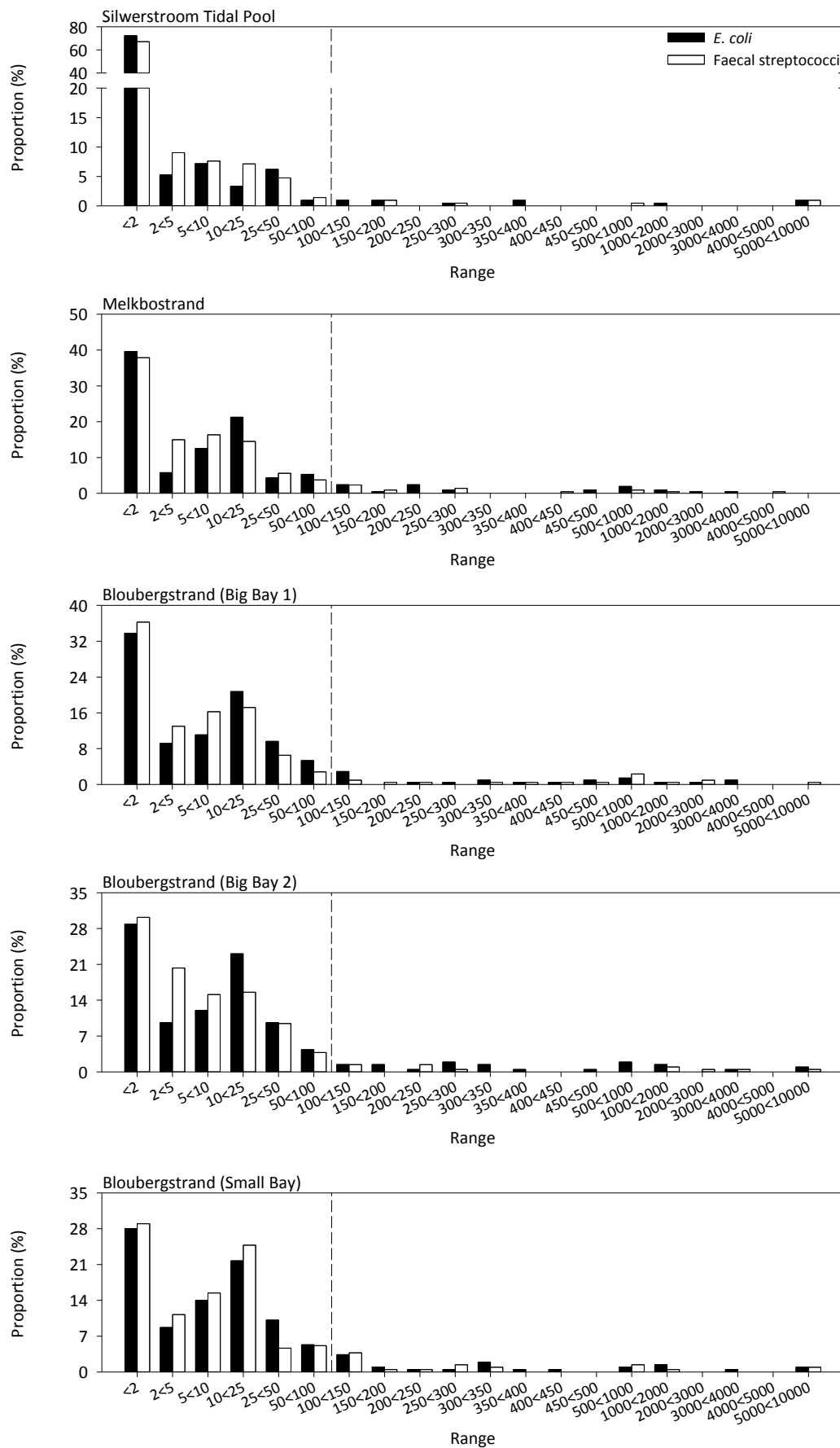


Figure 4.44. Proportion of seawater samples collected from the shoreline at various positions in Table Bay and along the Cape Peninsula between 2008 and 2015 with *E. coli* and faecal streptococci bacteria colony forming unit counts falling into different ranges. For reference purposes the vertical dashed line represents 100 colony forming unit counts.

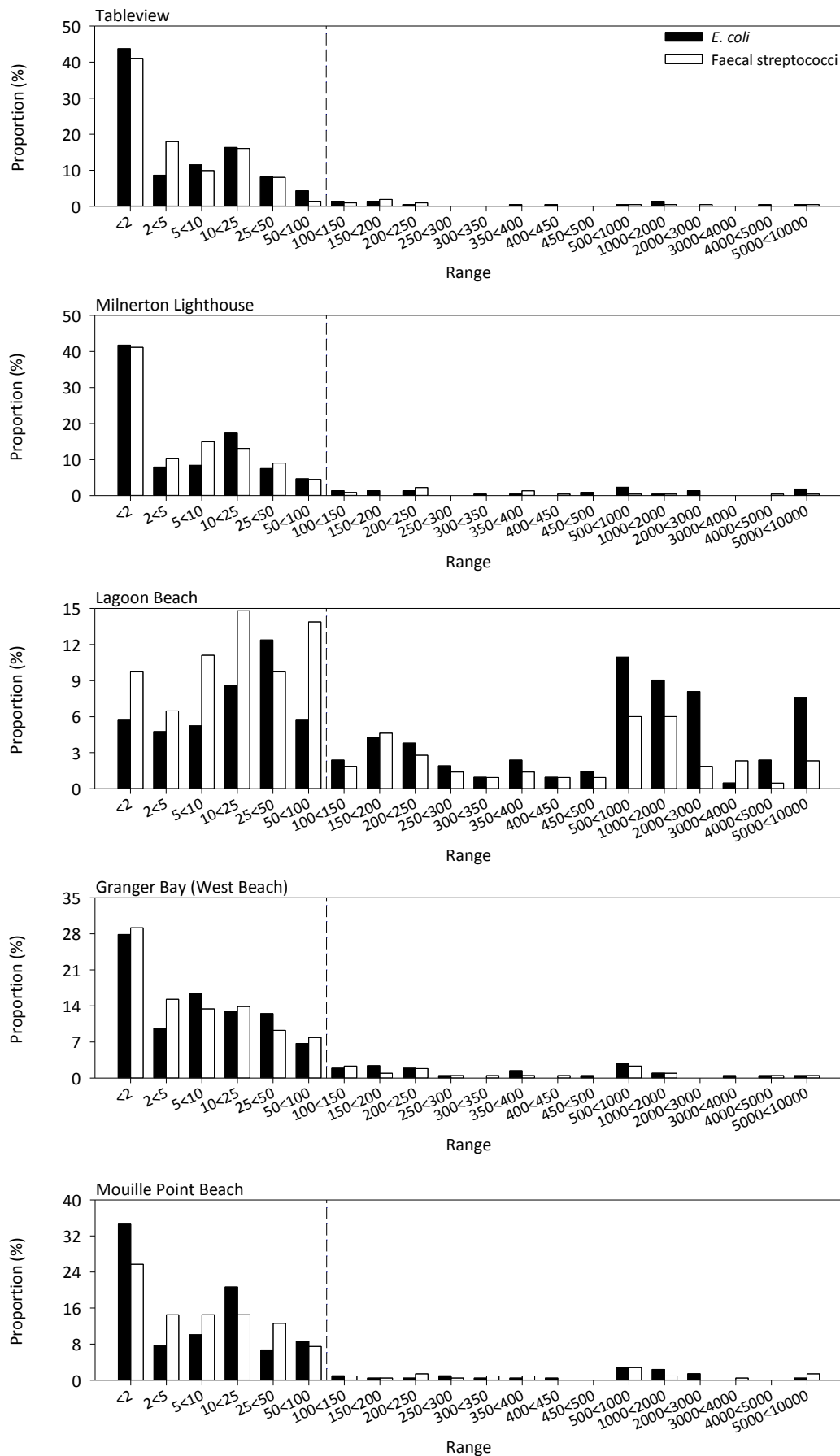


Figure 4.44 continued. Proportion of seawater samples collected from the shoreline at various positions in Table Bay and along the Cape Peninsula between 2008 and 2015 with *E. coli* and faecal streptococci bacteria colony forming unit counts falling into different ranges. For reference purposes the vertical dashed line represents 100 colony forming unit counts.

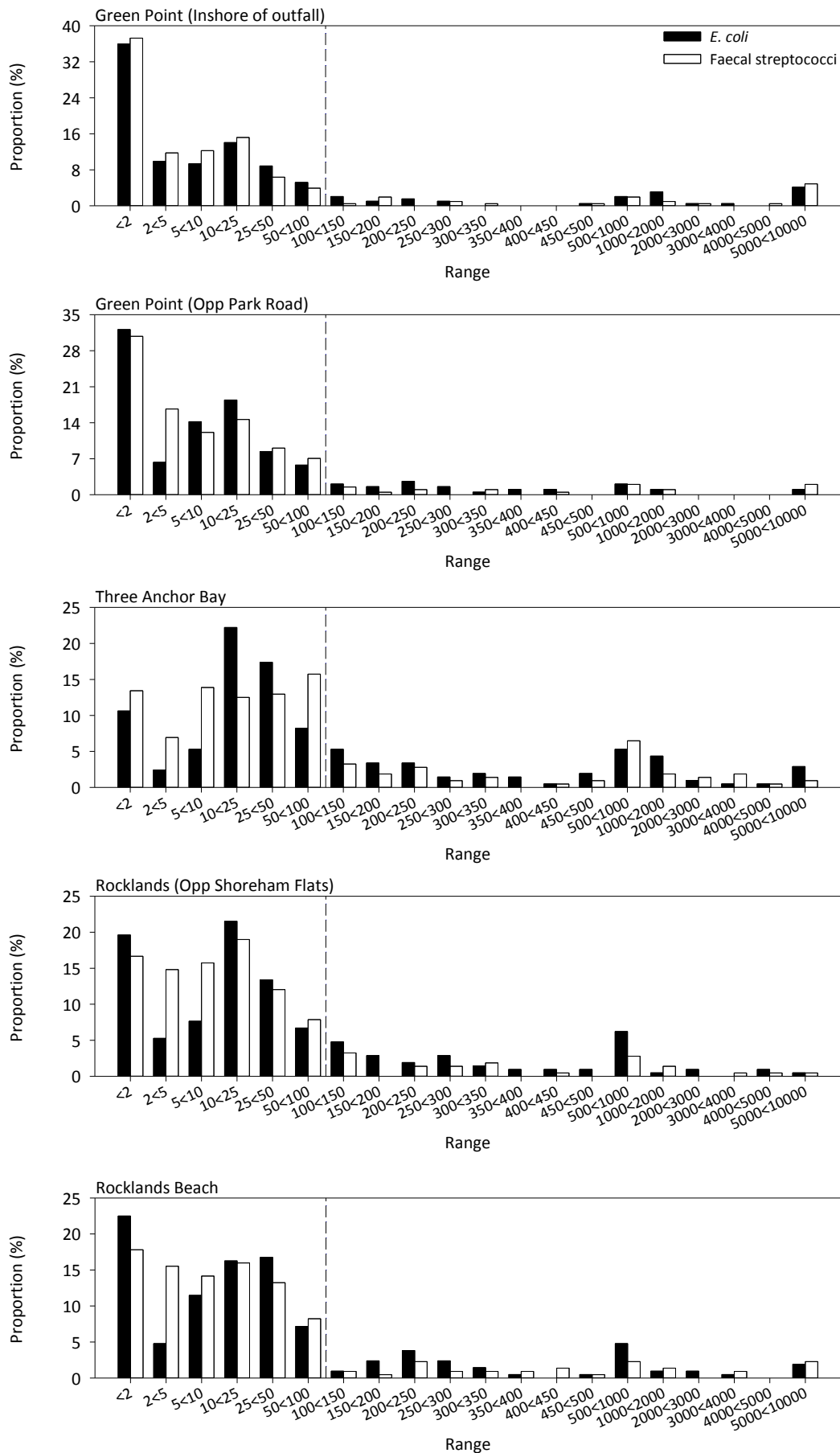


Figure 4.44 continued. Proportion of seawater samples collected from the shoreline at various positions in Table Bay and along the Cape Peninsula between 2008 and 2015 with *E. coli* and faecal streptococci bacteria colony forming unit counts falling into different ranges. For reference purposes the vertical dashed line represents 100 colony forming unit counts.

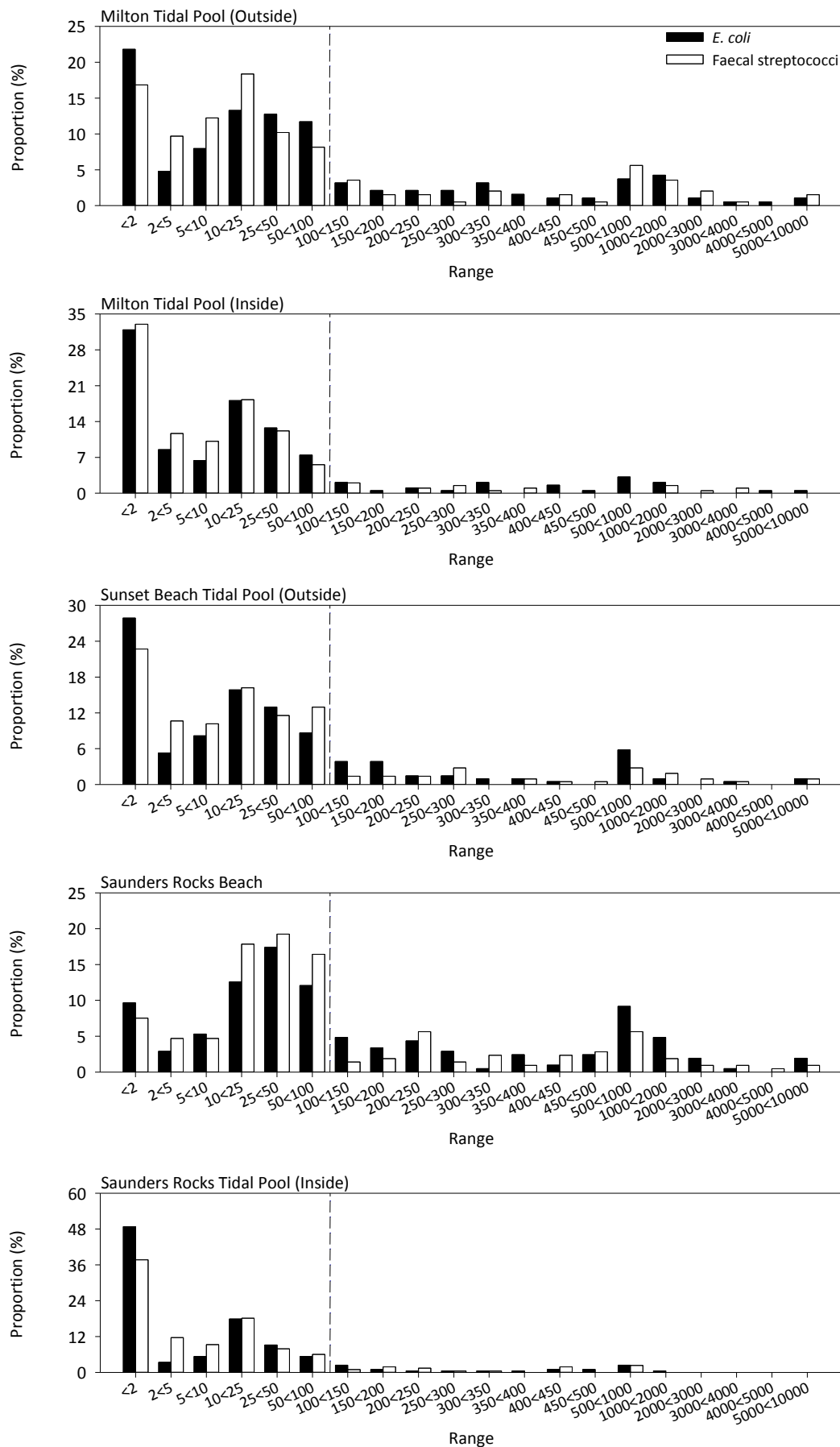


Figure 4.44 continued. Proportion of seawater samples collected from the shoreline at various positions in Table Bay and along the Cape Peninsula between 2008 and 2015 with *E. coli* and faecal streptococci bacteria colony forming unit counts falling into different ranges. For reference purposes the vertical dashed line represents 100 colony forming unit counts.

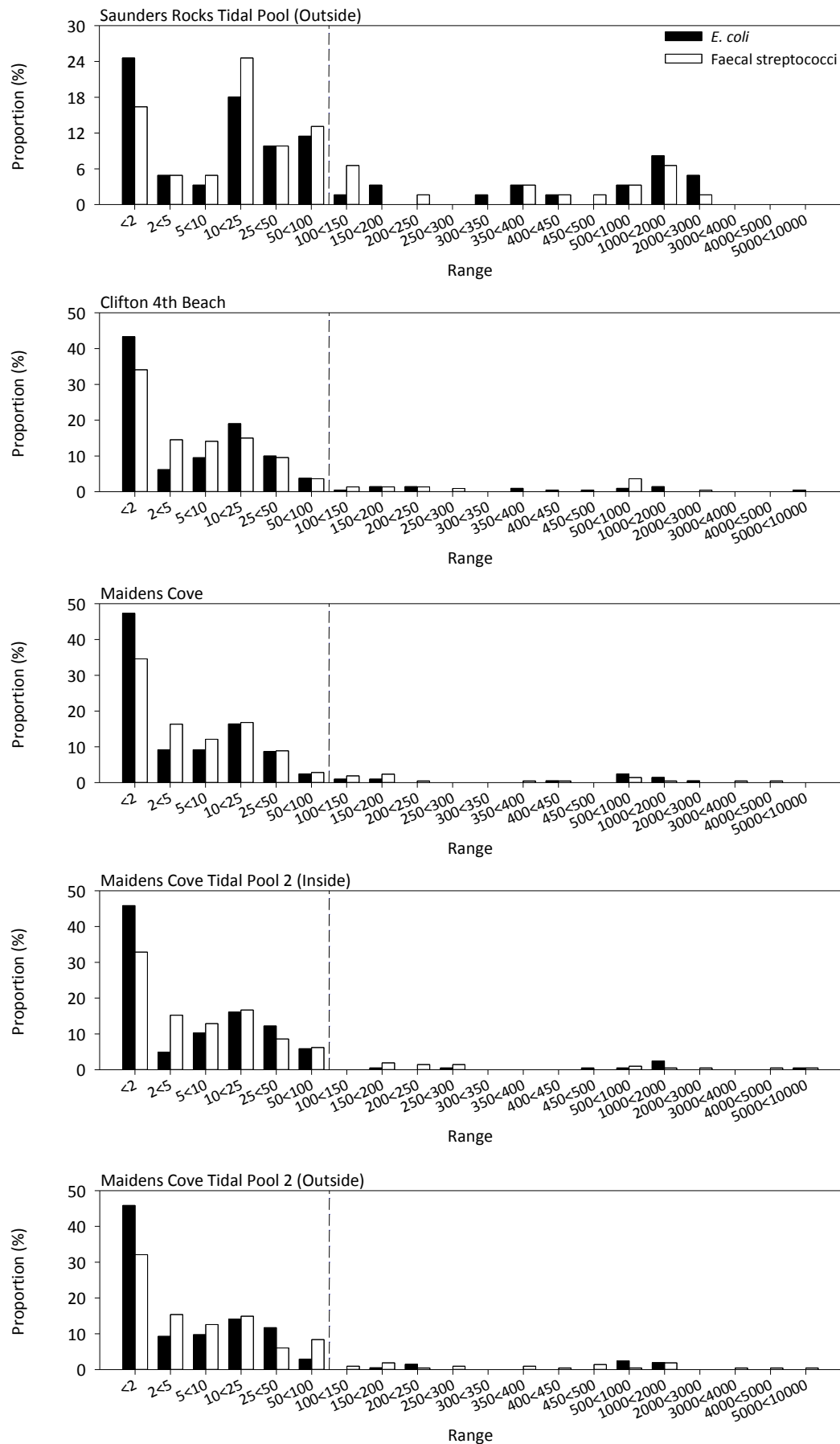


Figure 4.44 continued. Proportion of seawater samples collected from the shoreline at various positions in Table Bay and along the Cape Peninsula between 2008 and 2015 with *E. coli* and faecal streptococci bacteria colony forming unit counts falling into different ranges. For reference purposes the vertical dashed line represents 100 colony forming unit counts.

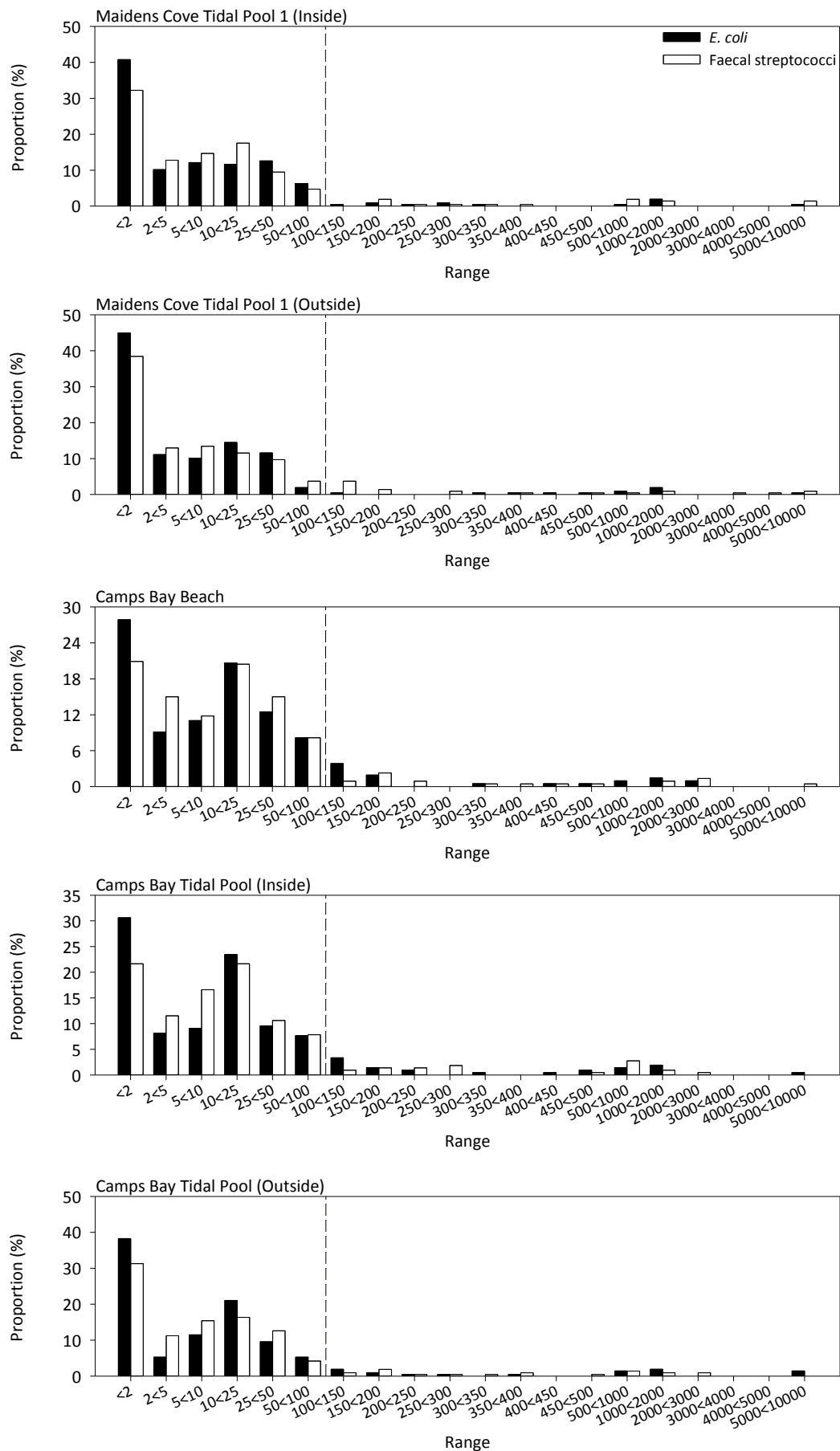


Figure 4.44 continued. Proportion of seawater samples collected from the shoreline at various positions in Table Bay and along the Cape Peninsula between 2008 and 2015 with *E. coli* and faecal streptococci bacteria colony forming unit counts falling into different ranges. For reference purposes the vertical dashed line represents 100 colony forming unit counts.

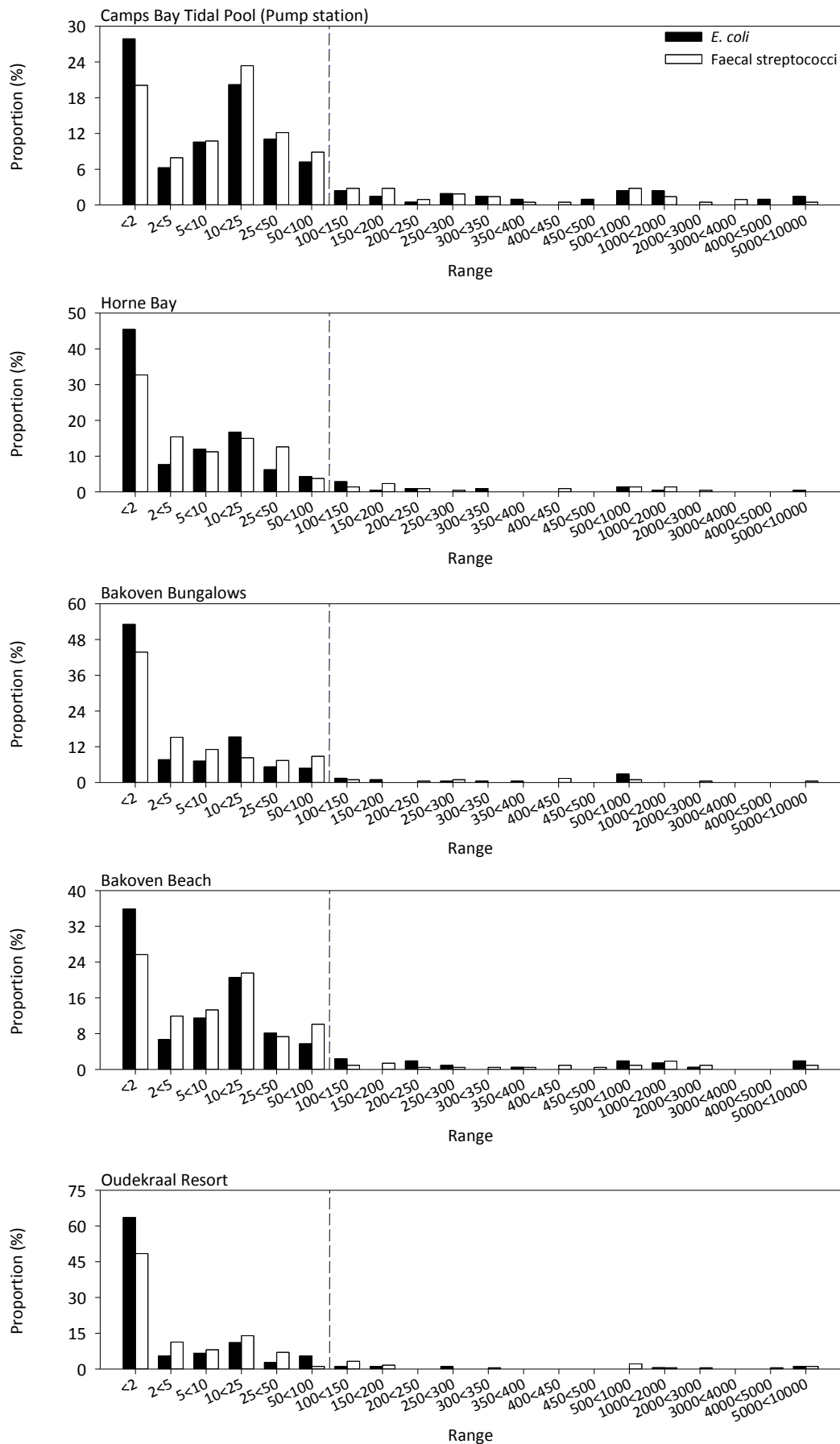


Figure 4.44 continued. Proportion of seawater samples collected from the shoreline at various positions in Table Bay and along the Cape Peninsula between 2008 and 2015 with *E. coli* and faecal streptococci bacteria colony forming unit counts falling into different ranges. For reference purposes the vertical dashed line represents 100 colony forming unit counts.

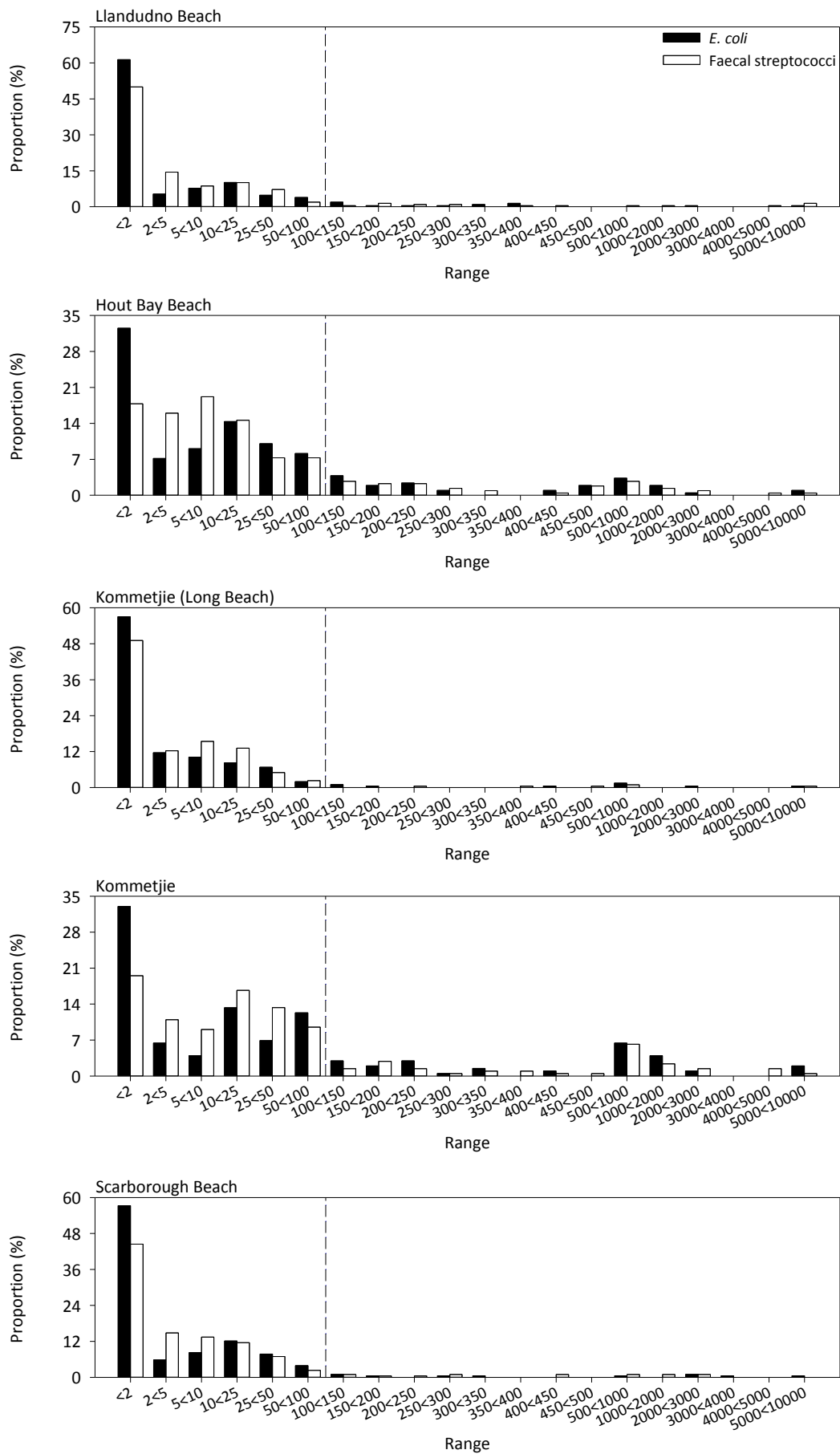


Figure 4.44 continued. Proportion of seawater samples collected from the shoreline at various positions in Table Bay and along the Cape Peninsula between 2008 and 2015 with *E. coli* and faecal streptococci bacteria colony forming unit counts falling into different ranges. For reference purposes the vertical dashed line represents 100 colony forming unit counts.

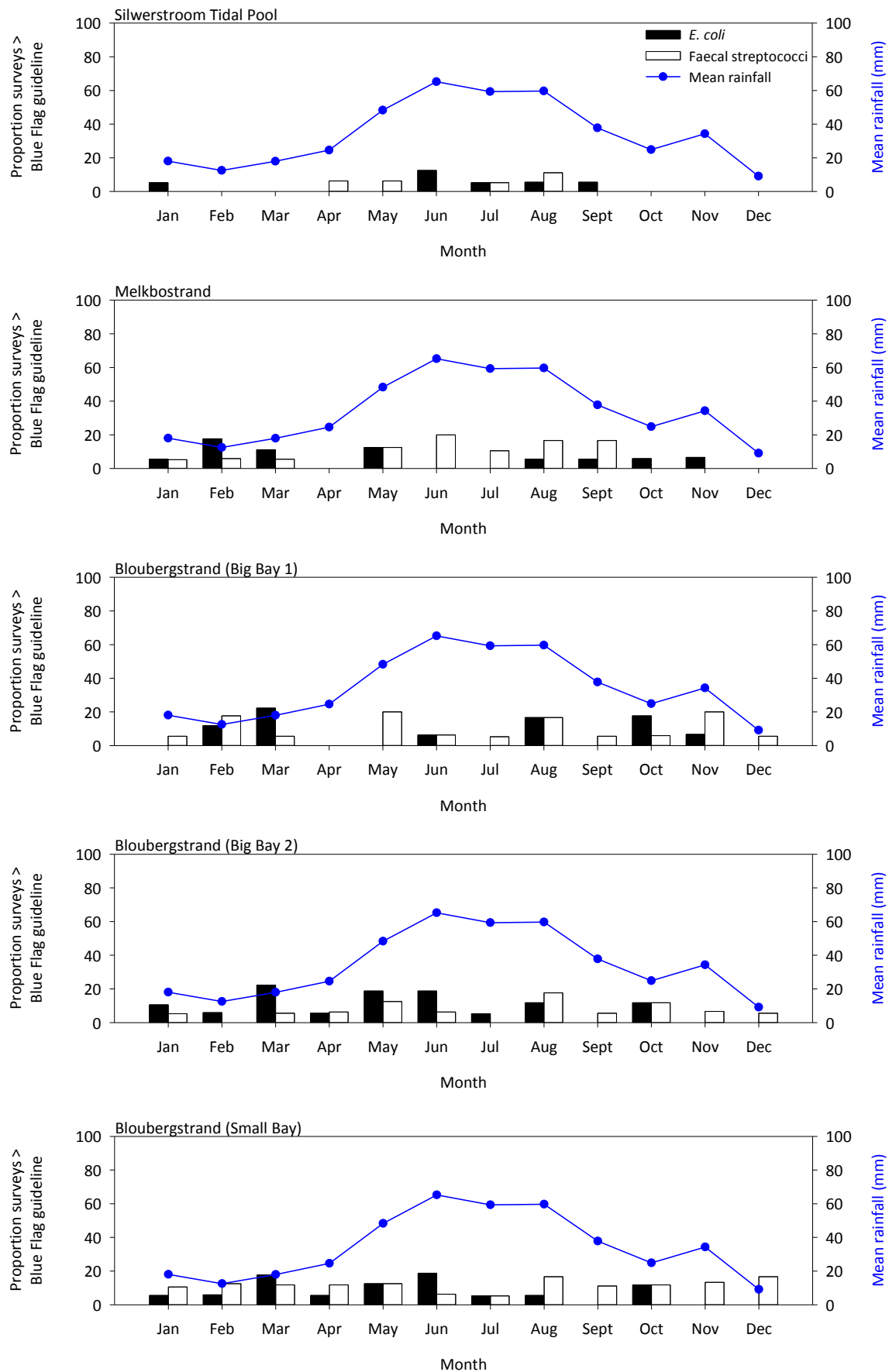


Figure 4.45. Proportion of surveys in months of the year that *E. coli* and faecal streptococci bacteria colony forming unit counts in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 2008 - 2015 exceeded the Blue Flag guideline. Average rainfall for each month for the period 1 January 2008 to 31 December 2015, as recorded at the Cape Point weather station, is included.

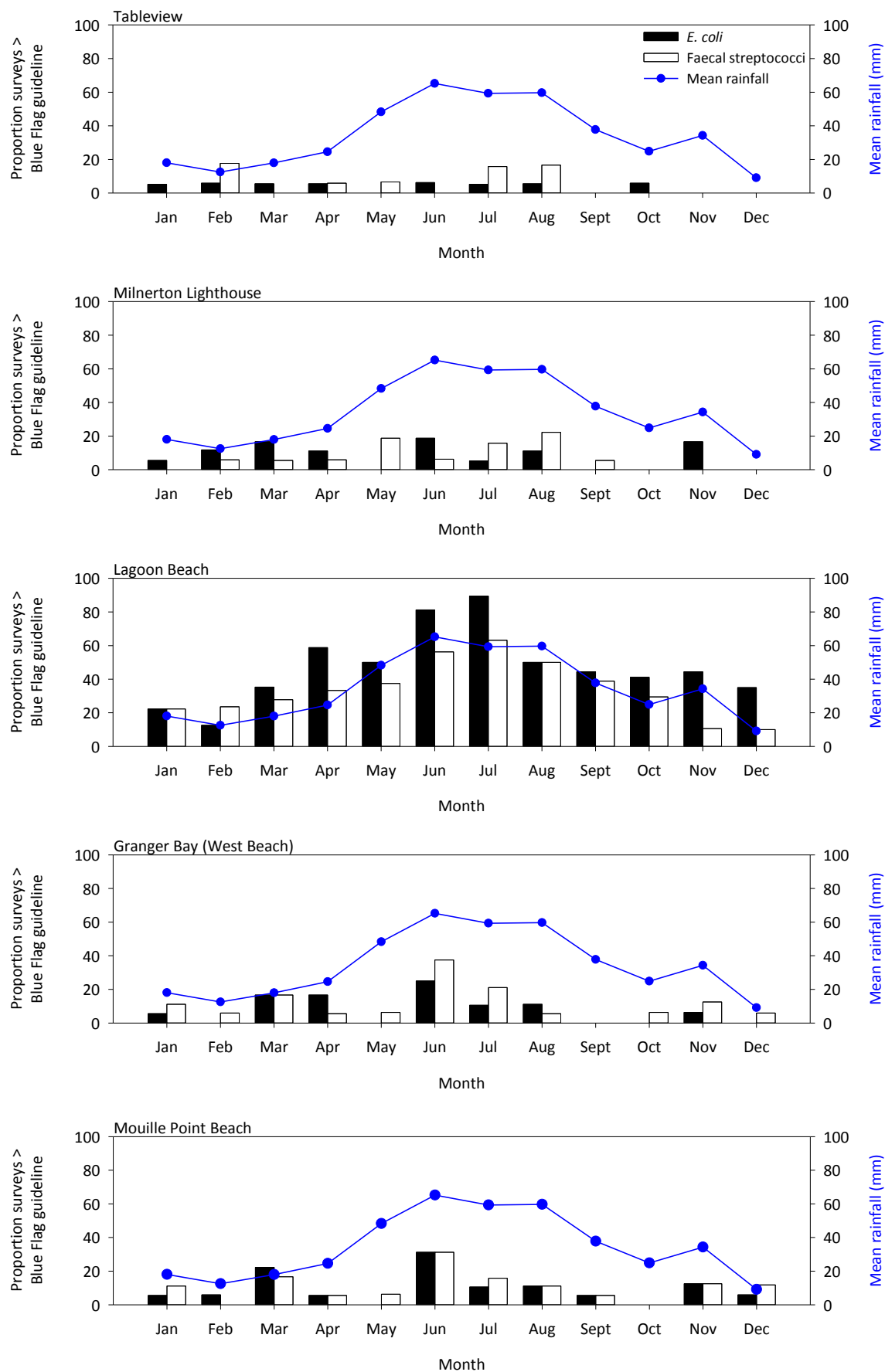


Figure 4.45 continued. Proportion of surveys in months of the year that *E. coli* and faecal streptococci bacteria colony forming unit counts in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 2008 - 2015 exceeded the Blue Flag guideline. Average rainfall for each month for the period 1 January 2008 to 31 December 2015, as recorded at the Cape Point weather station, is included.

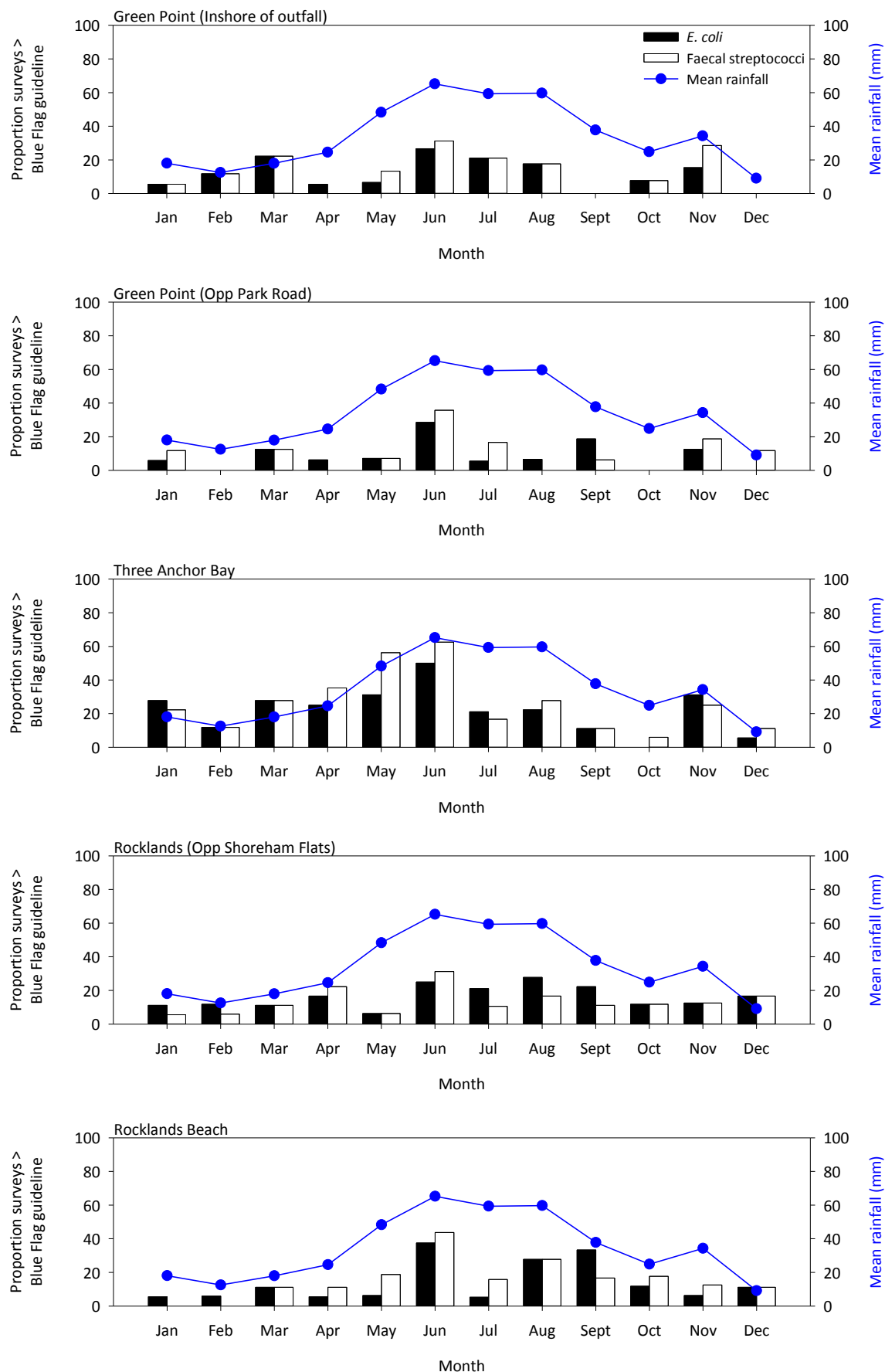


Figure 4.45 continued. Proportion of surveys in months of the year that *E. coli* and faecal streptococci bacteria colony forming unit counts in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 2008 - 2015 exceeded the Blue Flag guideline. Average rainfall for each month for the period 1 January 2008 to 31 December 2015, as recorded at the Cape Point weather station, is included.

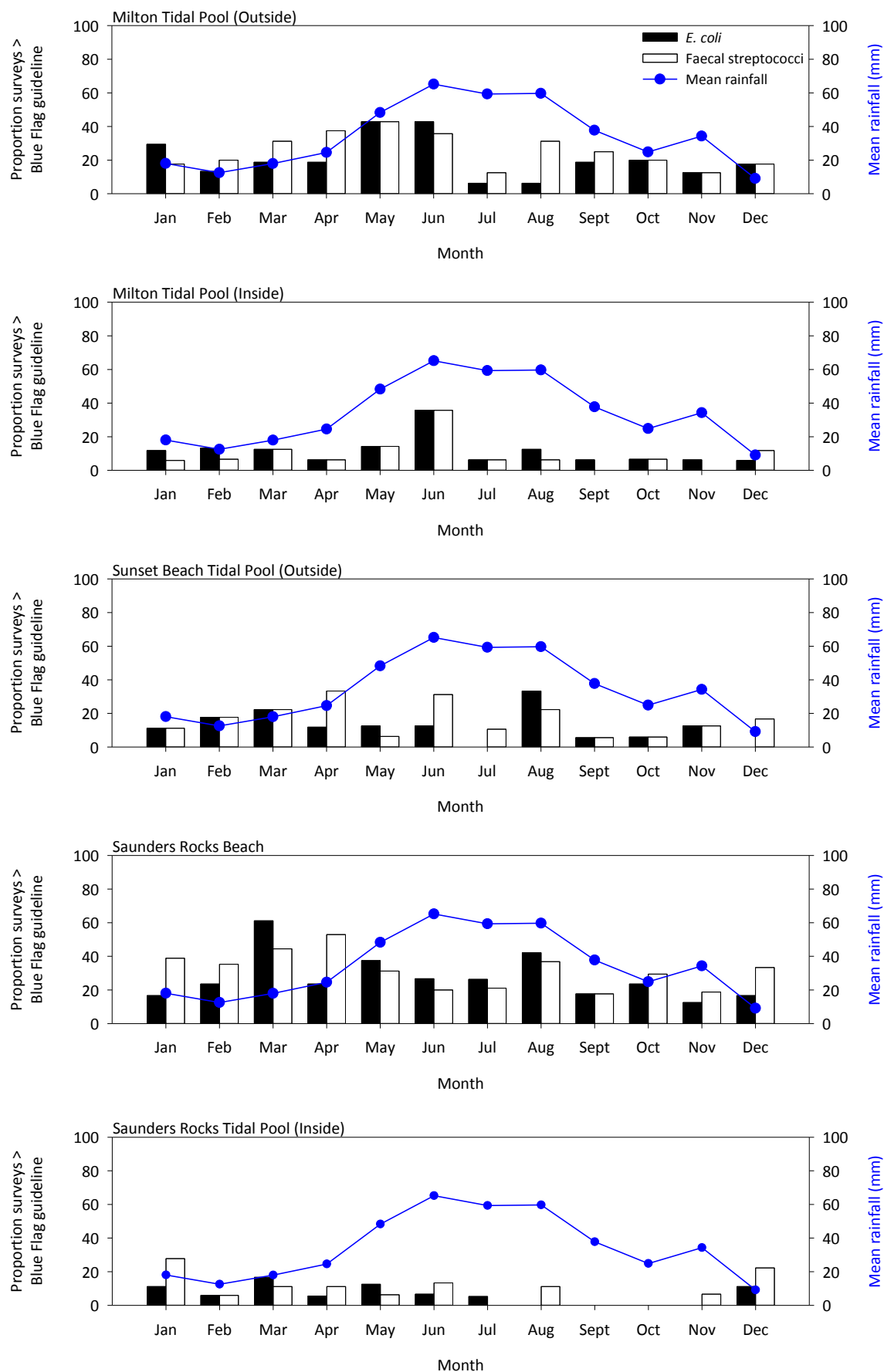


Figure 4.45 continued. Proportion of surveys in months of the year that *E. coli* and faecal streptococci bacteria colony forming unit counts in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 2008 - 2015 exceeded the Blue Flag guideline. Average rainfall for each month for the period 1 January 2008 to 31 December 2015, as recorded at the Cape Point weather station, is included.

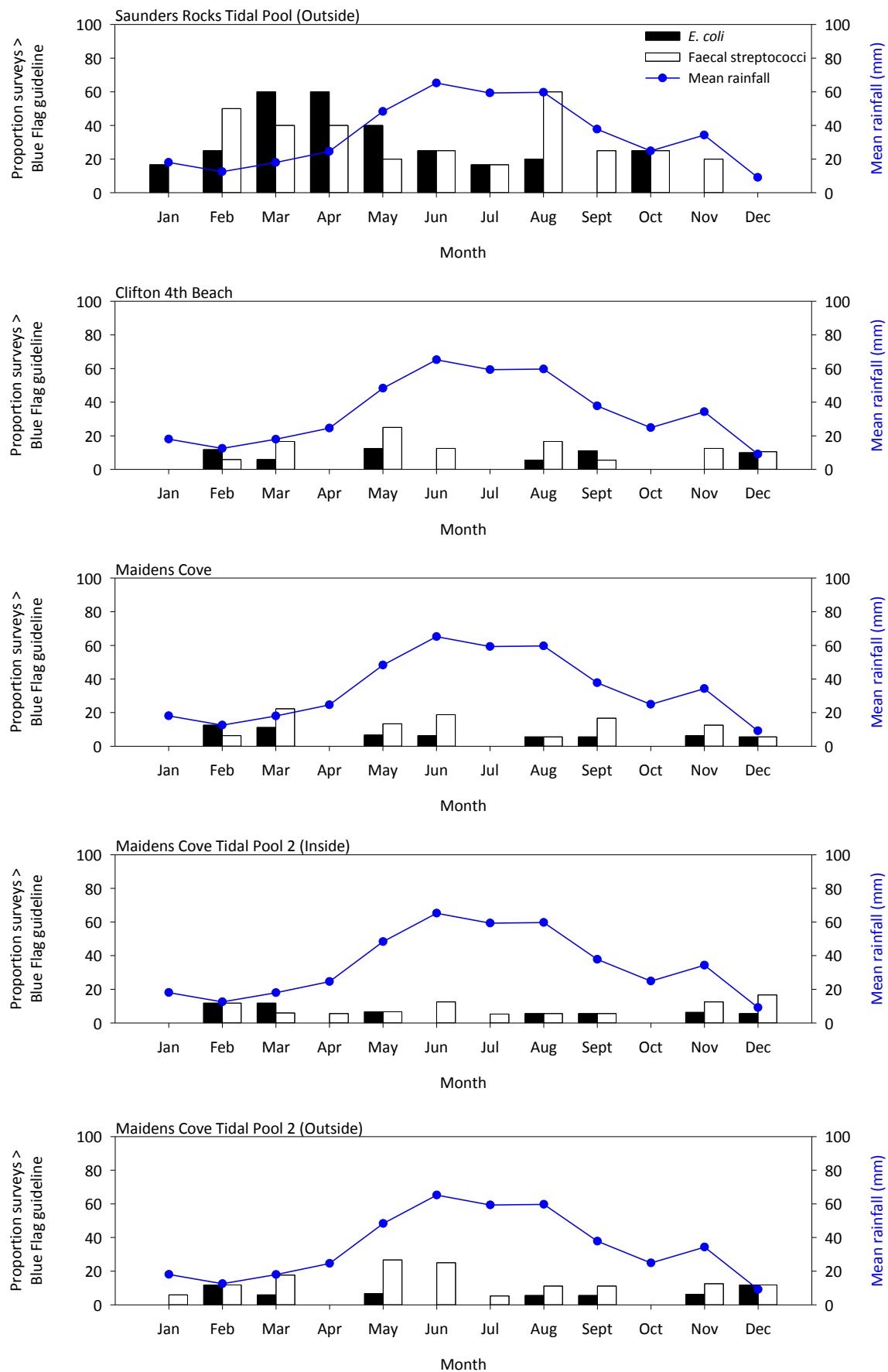


Figure 4.45 continued. Proportion of surveys in months of the year that *E. coli* and faecal streptococci bacteria colony forming unit counts in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 2008 - 2015 exceeded the Blue Flag guideline. Average rainfall for each month for the period 1 January 2008 to 31 December 2015, as recorded at the Cape Point weather station, is included.

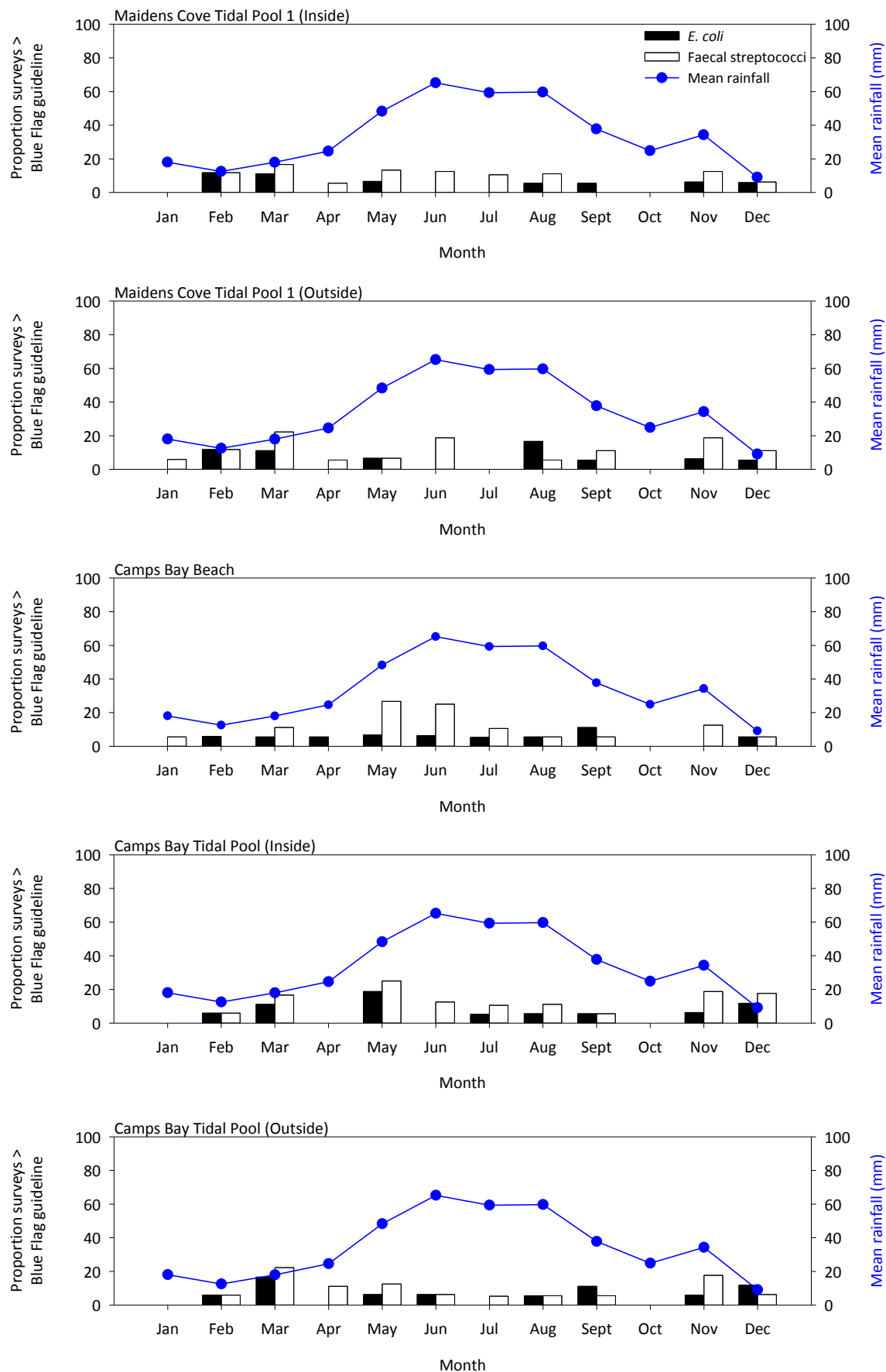


Figure 4.45 continued. Proportion of surveys in months of the year that *E. coli* and faecal streptococci bacteria colony forming unit counts in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 2008 - 2015 exceeded the Blue Flag guideline. Average rainfall for each month for the period 1 January 2008 to 31 December 2015, as recorded at the Cape Point weather station, is included.

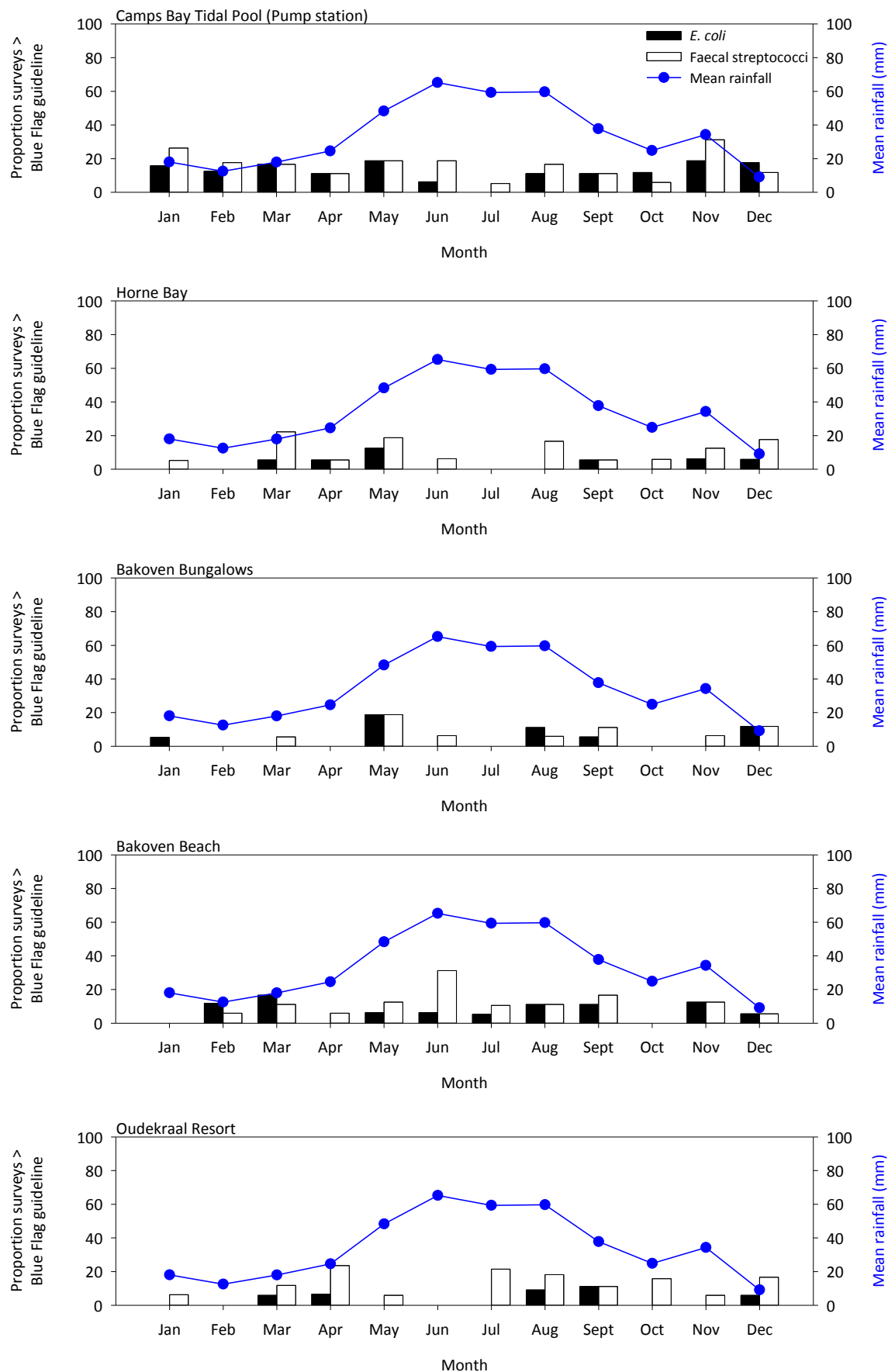


Figure 4.45 continued. Proportion of surveys in months of the year that *E. coli* and faecal streptococci bacteria colony forming unit counts in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 2008 - 2015 exceeded the Blue Flag guideline. Average rainfall for each month for the period 1 January 2008 to 31 December 2015, as recorded at the Cape Point weather station, is included.

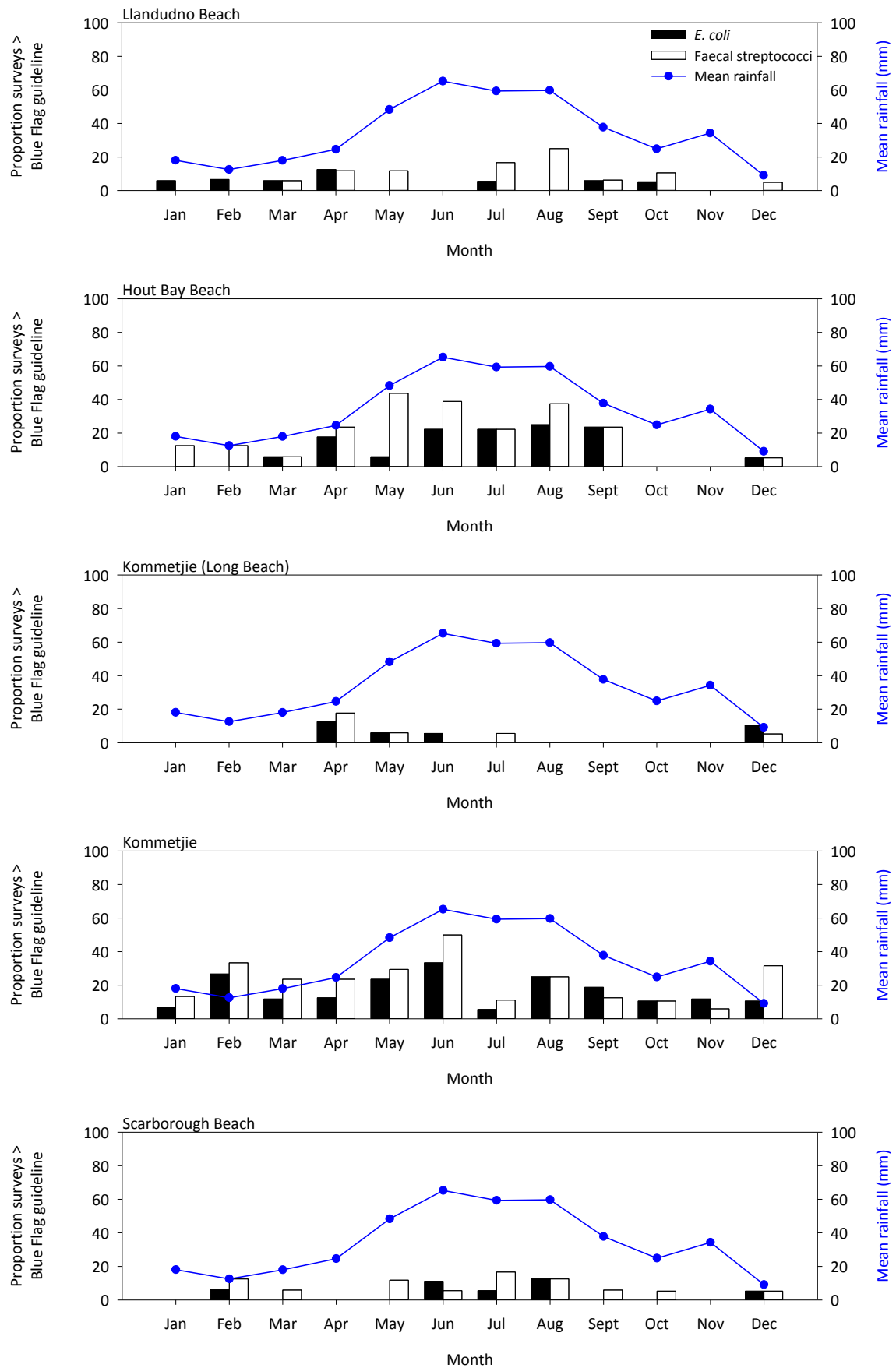


Figure 4.45 continued. Proportion of surveys in months of the year that *E. coli* and faecal streptococci bacteria colony forming unit counts in seawater samples collected along the Table Bay and Cape Peninsula shoreline between 2008 - 2015 exceeded the Blue Flag guideline. Average rainfall for each month for the period 1 January 2008 to 31 December 2015, as recorded at the Cape Point weather station, is included.

on days other than the two or three survey days in a month, if they do not extrapolation of the results will lead to a significant over or underestimate of (non-)compliance. For example, consider two surveys in a 30 day month and that in one survey the *E. coli* colony forming unit count exceeds the Blue Flag guideline (*i.e.* exceedance in 50% of the surveys). Consider further that this is the only day in the month the *E. coli* colony forming unit count exceeds the guideline. Extrapolating the results to days outside the survey dates provides an estimate of about 15 days in the month when the guideline is exceeded, which is not the case. This may lead to public consternation when this is not warranted. Conversely, the results may underestimate the number of days when there is a risk to public health. Further research is required to understand the frequency of Blue Flag (or any other) guideline exceedance at popular bathing beaches in Cape Town through intense spatial and temporal (daily) monitoring. This should include the concurrent analysis of pathogenic microorganisms in seawater samples collected from the shoreline to determine the nature of the relationship between these microorganisms, and through this the utility of using faecal indicator bacteria as an indicator of the presence of pathogenic microorganisms.

The Camps Bay area has been the focus of considerable interest in the media in the context of effluent discharge. The presumption appears to be that effluent discharged through the Camps Bay outfall is trapped in the bay and poses a persistent risk to the health of recreational users of shoreline and nearshore waters. The City of Cape Town faecal indicator bacteria monitoring results cannot be used to refute the contention that effluent-derived constituents are persistently reaching the shoreline due to uncertainties on their actual source, but if this is the case the results suggest this is not posing a persistent risk to human health. Thus, colony forming unit counts for *E. coli* at six sites between Maidens Cove and Camps Bay beach (Figures 4.42 and 4.43) exceeded the Blue Flag guideline in 9 - 10 (or 4.4 - 5.3%) of the 205 - 208 surveys at these sites for the period 2008 - 2015, while colony forming unit counts for faecal streptococci exceeded the guideline in 16 - 23 (or 7.8 - 11.2%) of the surveys. This is amongst the lowest exceedance of Blue Flag guidelines for any site. If more

conservative (halved) 'guidelines' of 125 and 50 colony forming unit counts for *E. coli* and faecal streptococci respectively are considered then the incidence of exceedance increases to 10 - 16 and 24 - 41 surveys respectively.

The above discussion on Blue Flag guideline exceedance does not consider the magnitude of exceedance. In other words, colony forming unit counts of 251 and 5 000 for *E. coli* are both scored an exceedance of the guideline (250 colony forming units), but the number of these bacteria in the samples and hence the potential human health risk is clearly different. Trends in the number of exceedances of guidelines and the associated colony forming unit counts are not analysed here in detail, but the distribution of colony forming unit counts for *E. coli* and faecal streptococci for the period 2008 - 2015 is provided in Figure 4.44. At most sites the majority of colony forming unit counts fall in the range $<2 \times 10^1$ - 2.5×10^1 . However, at all sites high colony forming unit counts were evident in some surveys (high arbitrarily defined here as >500 for *E. coli* and >250 for faecal streptococci). Thus, *E. coli* and faecal streptococci exceeded 500 and 250 colony forming units in 40 and 25% of the surveys at Lagoon Beach respectively for the period 2008 - 2015. In the Clifton 4th Beach to Camps Bay Beach area, in contrast, ≤ 7 and $\leq 10\%$ of colony forming unit counts for these bacteria exceeded 500 or 250 colony forming unit counts respectively for the same period. In 68 - 82% of the surveys, *E. coli* and faecal streptococci colony forming counts were ≤ 25 . The highest incidence for *E. coli* and faecal streptococci colony forming unit counts being ≤ 25 (82 and 80% of surveys respectively) was at the Maidens Cove site, about 600 m from the Camps Bay outfall diffuser section (although the nearest shoreline is about 520 m from the diffuser section), while the lowest incidence (69 and 68% of surveys respectively) was for Camps Bay Beach. *E. coli* and/or faecal streptococci colony forming unit counts in 1 - 3% of surveys fell within the range $1\,000 - 10\,000$. If surveys where *E. coli* colony forming unit counts exceeded 250 or faecal streptococci colony forming unit counts exceeded 100 are taken as clear incidences of effluent reaching the shoreline in the Camps Bay area rather than a stormwater impact then this occurred on 4 - 7% of surveys. This does not mean effluent-derived

constituents are not reaching the shoreline more frequently but that it is impossible to discriminate such incidences compared to sites unlikely to be influenced by effluent discharge. For example, faecal streptococci exceeded 100 colony forming unit counts on 5% of surveys at Oudekraal Resort, Llandudno and Scarborough Beach, which are about 4.8, 7.2 and 27.6 km respectively as the crow flies to the south-southwest of the Camps Bay beach site. These similarities make it difficult to attribute shoreline water impairment to effluent discharge.

The above estimation of the frequency of faecal indicator bacteria colony forming unit count exceedance of Blue Flag guidelines also does not consider seasonality. In other words, the number of surveys where guidelines are exceeded could theoretically occur over a period of a few months or be spread more or less evenly across months of the year. Figure 4.45 provides the cumulative proportion of surveys within each month for the period 2008 - 2015 in which *E. coli* and faecal streptococci colony forming unit counts exceeded Blue Flag guidelines. There was usually no marked seasonality in exceedance apart from some sites, such as Lagoon Beach, where exceedance increased progressively from January through to June and July and then decreased progressively to December. This said, at numerous sites the most frequent exceedances were usually for one or more of the months May, June, July and August. This probably reflects, at least in part, the influence of rainfall on river flow in the case of Lagoon Beach (Diep River, and possibly also Salt River) and Hout Bay beach (Disa River), and stormwater runoff at other sites considering the highest average rainfall in the Cape Town area is for these months (*i.e.* late autumn and winter). This said, the predominance of north-westerly winds in winter could also be advecting effluent-derived faecal indicator bacteria onshore.

Regardless of the approach used to analyse the data the incidence of *E. coli* and faecal streptococci bacteria exceeding Blue Flag guidelines or any other target at sites in the Camps Bay area was amongst the lowest. Nevertheless, there were days when full contact recreation at Camps Bay Beach posed a risk to the health of vulnerable segments of the population (*e.g.* those with a compromised immune

system). Unfortunately, this situation is not unique to the Camps Bay area, to the City of Cape Town, nor to other cities in South Africa, but is a challenge faced by coastal cities in most parts of the world to varying degrees.

4.3.3. Seawater Toxicity

Toxicity testing of seawater is usually performed to assess the possible risk to the ecology of the receiving environment through potential acute or chronic impacts to biota. A total of 175 surface seawater samples were tested for toxicity to sea urchin gametes. A single sample was identified as toxic, namely that collected at Site HB6 about 60 m from the Hout Bay outfall terminus in the July 2016 survey. The toxicity was, however, mild, with the average fertilisation success 2.5% lower than that for the control treatment. Faecal indicator bacteria colony forming unit counts in this sample were high (3 900 for *E. coli* and 760 for faecal streptococci), suggesting the toxicity was linked to diluted effluent in the water column. This said, faecal indicator bacteria colony forming unit counts in surface seawater samples collected near the Hout Bay outfall in another survey and in several surveys for the Green Point and Camps Bay outfalls were as high or higher than counts for the sample that was mildly toxic, yet these samples presented no toxicity to sea urchin gametes. The absence of toxicity for other samples where effluent was clearly present at the sea surface suggests toxicants in the effluent had been sufficiently diluted to render it not acutely toxic to sea urchin gametes. This indirectly suggests, on these survey dates at least, that dilution of the effluent in the marine receiving environments exceeded the number of dilutions required (*i.e.* Minimum Acceptable Toxicant Dilution) to render the effluent non-toxic to sea urchin gametes in the laboratory.

4.4. Conclusions

The analysis of faecal indicator bacteria in surface seawater samples collected in the greater vicinity of the Green Point, Camps Bay and Hout Bay outfalls between January and December 2016 provides evidence that effluent reached the sea surface near the diffuser section of each outfall in several surveys. Effluent reached the sea surface more often at the Green Point outfall (six of 12 surveys)

compared to the Camps Bay and Hout Bay outfalls (three and two of 12 surveys respectively). In surveys when faecal indicator bacteria colony forming unit counts at the sea surface could clearly be linked to effluent discharge, the counts were high enough to suggest pathogenic organism in the seawater posed a risk to the health of humans if exposed. That effluent periodically reached the sea surface near each outfall was not surprising as these events have been captured photographically by members of the public and published in the media, and are evident in satellite images provided in Google Earth. Outfall design cannot rule out the likelihood of effluent reaching the sea surface under calm sea states.

Faecal indicator bacteria colony forming unit counts at the sea surface decreased sharply with distance from the outfall diffuser sections. Thus, counts could usually not be distinguished from 'background' counts within about 300 m of the outfall diffuser sections with the exception of some surveys for the Green Point outfall. This undoubtedly reflects the rapid dilution and dispersion of effluent. In one survey, however, faecal indicator bacteria probably derived from effluent were detected at a high colony forming count at a site situated about 1 200 m from the Green Point outfall diffuser section.

There was no clear evidence that effluent was reaching the shoreline in surface waters apart possibly from one survey for the Green Point outfall and one survey for the Hout Bay outfall. It is not possible, however, to determine if the bacteria evident in nearshore waters in these surveys were derived from effluent or stormwater runoff, or both. This is because the surveys were preceded by periods of rainfall, and stormwater runoff is known to be a significant vector for the introduction of faecal indicator bacteria to coastal marine waters in urban areas.

The analysis of long-term trends in faecal indicator bacteria colony forming unit counts in seawater samples collected at 40 shoreline sites in Table Bay and on the Atlantic seaboard of the Cape Peninsula revealed that colony forming unit counts of *E. coli* and faecal streptococci exceeded guidelines for the Blue Flag programme at all sites. The frequency of

exceedance differed markedly between sites. Although the results of the analyses cannot be used to identify sources of the bacteria, there was no clear evidence that effluent discharged through the Green Point, Camps Bay and Hout Bay outfalls was persistently resulting in microbiological impairment of shoreline water. It is, however, not impossible that effluent-derived constituents are reaching the shoreline under favourable wind and sea states, even if only periodically and in a much diluted form. Regardless of the source, faecal indicator bacteria colony forming unit counts in shoreline waters at most sites are periodically high enough to suggest a risk to human health through exposure to co-occurring pathogenic microorganisms.

The toxicity testing of 175 seawater samples collected at the sea surface in the greater vicinity of the Green Point, Camps Bay and Hout Bay outfalls revealed a single incidence of toxicity to sea urchin gametes. This incidence was for a seawater sample collected in the immediate vicinity of the Hout Bay outfall diffuser section. Since some of the seawater samples tested for toxicity were collected in the effluent plume at the sea surface the virtual absence of toxicity suggests there was little likelihood the effluent was acutely toxic to marine organisms beyond the margin of the zone of initial dilution. This agrees with the results of mass balance modelling for most effluent constituents, as discussed in Chapter 2.

While the toxicity testing of surface seawater samples using sea urchin gametes suggests little likelihood of acute toxic effects beyond the zone of initial dilution, this type of toxicity testing does not account for possible chronic toxic effects posed by effluent constituents beyond this zone. Toxicity testing also does not address the possible effect of nutrient enrichment (eutrophication) as a result of effluent discharge on ecological processes or possible toxic effects to marine organisms as a result of persistent exposure to low (non-lethal) concentrations of chemicals that have a high bioaccumulation and biomagnification potential.

A limitation of the surveys discussed in this chapter is that no indicators of water quality apart from faecal indicator bacteria and toxicity were analysed, and then only for surface seawater samples. As

stated previously, it was recognised at the outset that water quality beyond the zone of initial dilution is, at least periodically, not compliant with South African Water Quality Guidelines for Coastal Marine Waters (DWAF, 1995). This conclusion was based on effluent reaching the surface near the Green Point outfall being visible in satellite images provided in Google Earth beyond the area that can reasonably be considered to encompass the zone of initial dilution. At the least this probably represents (periodic) non-compliance with South African Water Quality Guidelines for Coastal Marine Waters that state that objectionable matter should not be evident at the sea surface and total suspended solids concentrations should not exceed the ambient concentration by more than 10%. Comprehensive water quality monitoring was not, however, considered for this survey since in the absence of a detailed understanding on the dispersion of effluent in the marine receiving environments through numerical modelling or based on real time current data such monitoring may be a 'hit and miss' affair if the effluent is not visible at the sea surface. The need for more comprehensive water quality monitoring near the points of effluent discharge is acknowledged and should be included in future surveys.

The usual approach to locating effluent plumes, and for determining compliance with water quality targets at the margin of the zone of initial dilution is to cast instruments that measure water quality *in situ* and to collect water samples for analysis in the laboratory at predefined positions and depths in the marine receiving environment. However, the temporal resolution of this type of monitoring (in South Africa, usually annually) is inadequate to capture the variability in plume location and concentration over time scales of interest, namely hours to days. This type of monitoring also does not provide information in the minimum initial dilution for an outfall. Numerical modelling provides a

powerful tool for simulating the dilution, dispersion and fate of effluent discharged through an outfall and for establishing the minimum initial dilution. It is, therefore, recommended that the dispersion and fate of effluent discharged through the Cape Town outfalls be simulated through numerical modelling. The modelling should:

- a. Estimate the minimum initial dilution, dispersion and concentration of effluent constituents in both the near- and farfield under oceanographic conditions representative of the receiving environments (including seasonal differences).
- b. Estimate the minimum dilution at the margin of the mixing zone for each outfall, as determined following the approach recommended by the Department of Environmental Affairs based on the number of diffusers for each outfall (see Chapters 1 and 2).
- c. Estimate the likelihood of effluent constituents, particularly faecal indicator bacteria, reaching the shoreline and the frequency and duration of these events.
- d. Simulate effluent dilution and dispersion for extended outfall scenarios.
- e. Simulate effluent dilution and dispersion under increased effluent flows for each outfall, including extended outfall scenarios.

Studies in many parts of the world have revealed that stormwater is a significant source of faecal indicator bacteria, viruses and other pathogenic microorganisms (and indeed other contaminants) to coastal waters. It is further recommended, therefore, that the City of Cape Town investigate the degree to which sewage is entering the stormwater reticulation system through illicit or incorrect connections and degraded sewers. Strategies to reduce the ingress of contaminants to stormwater reticulation systems from road and paved surfaces should also be investigated and implemented where possible and feasible, such as the use of vegetated swales and pervious paving.