Fire and sediment in an upland stream in Hong Kong

MERVYN. R. PEART[1], LINCOLN FOK[2] & RONALD. D. HILL[3]

1 *Department of Geography, University of Hong Kong, Hong Kong*
mrpeart@hku.hk
2 *Department of Science and Environmental Studies, Hong Kong Institute of Education, Hong Kong*
3 *Department of Ecology and Biodiversity, University of Hong Kong, Hong Kong*

Abstract Hill fires are common in Hong Kong. In February 2007, a hill fire burnt an area of around 1 km^2 on the hillslopes of Tai To Yan providing the opportunity to examine the effects of fire. Descriptive statistics in the form of the 25th, 50th and 75th percentiles show an increase in storm-period suspended sediment concentration compared to the year preceding the fire (2006). Similar results were observed for a fire in December 2004. Storm-period suspended sediment data for the years 2008–2011 show evidence of a return to pre-fire levels. Regular weekly sampling for suspended sediment for the years 2006 to 2010 indicates that fire resulted in an increase in the dry season median value in 2007 compared to that in 2006, the year preceding the burn. Weekly sampling has been undertaken during 2006 to 2010 for chlorophyll-a in the stream water, and the results are elaborated upon in terms of the impact of fire on water quality.

Key words fire; suspended sediment; chlorophyll-*a*; statistical comparison

INTRODUCTION

In Hong Kong, wildfire is referred to as hill fire. Marafa & Chau (1999) have observed that half of the area within Hong Kong country-park boundaries (442 km^2) has been burnt at least once in the last 12 years, whilst Owen & Shaw (2007) suggest that about 5% of the land area is burnt annually. Over a 10-year period from 2001/2 to 2009/10, the Agriculture, Fisheries and Conservation Department reported 551 hill fires within or threatening Hong Kong Country Parks, whilst the Fire Services Department attended 1295 and 819 vegetation fires in 2009 and 2010, respectively. The existence of grassland and shrubland on the hillslopes of Hong Kong provides the fuel for wildfires, and these are the types of vegetation most commonly affected (Chan, 2005). Chan (2005) also noted that hill fires tended to be more frequent on slopes with an easterly to southerly aspect, which gave a longer exposure to sunlight thereby promoting drier fuel, often grass, for ignition. The study by Chan (2005) revealed that the elevations with the highest fire frequency were 190–380 m PD. Generally speaking, hill fire is not natural in Hong Kong (Chan, 2005) and most fires result from human activity. Both Chau & Corlett (1994) and Chan (2005) attest to the seasonality of hill fire occurrence in Hong Kong; they are typically associated with the dry season (October to April). The high rainfall and higher humidity levels in summer do not promote the ignition and spread of hill fires, whilst Chan (2005) suggests that the comparatively low relative humidity in the dry season may be an important control. The two hill fires that were included in this study occurred in December 2004 and January 2007, coinciding with the dry season.

Hill fires have been demonstrated to affect soil erodibility in Hong Kong (Ternan & Neller, 1999) whilst Vohora & Donoghue (2004) indicate a causal linkage to slope degradation, including landslides. Peart *et al.* (2009) have identified that hill fire impacts upon soil erosion and suspended sediment transport in Hong Kong. A recent hill fire in early February 2007, in a small upland catchment, of which 80% burned, afforded a further opportunity to examine the effects of fire upon sediment production in Hong Kong and the observations are presented in this paper.

STUDY AREA AND METHODS

Hong Kong has a subtropical climate with a hot, wet summer and cool, dry winter. Climatological data for 1971–2000 give an annual average rainfall of 2383 mm, of which more than 80% occurred in the months of April to September. Mean annual air temperature is 23.1°C, with

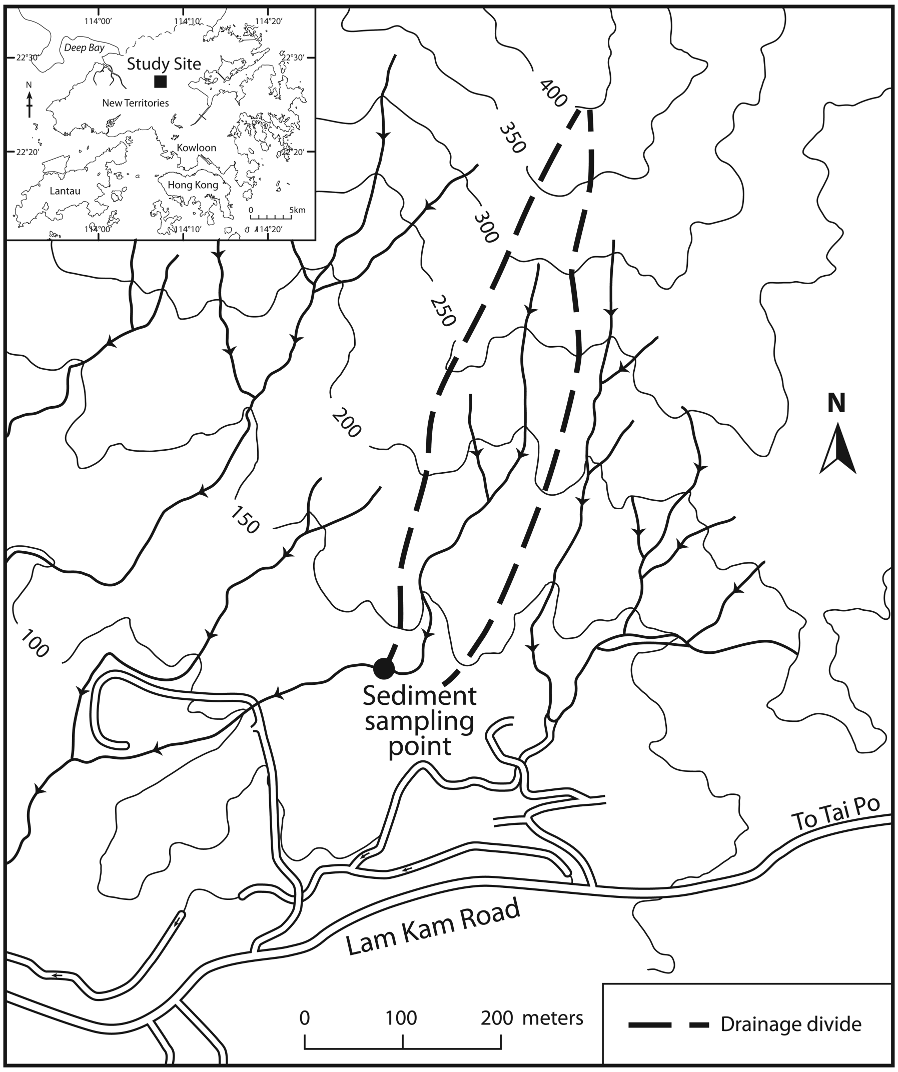

Fig. 1 Location of the study area.

monthly mean air temperatures ranging from 16.1°C to 28.7°C. Mean annual relative humidity for 1971–2000 is 78% and ranges from 69% in December to 84% in May. The topography of Hong Kong may be described as rugged, with altitudes ranging up to 957 m PD on the highest peak of Tai Mo Shan. Where the soil is poor or frequently affected by fire hillslopes may be covered by grass, but in other areas shrubs may dominate. Some woodland and plantations are observed on hillslopes. About 40% of the land area is designated under the Country Parks Ordinance.

The study area (Fig. 1), located on the slopes of Tai To Yan in the Northwest New Territories, has a vegetation cover predominantly comprising grass, fern and shrubland (Hill *et al.*, 2004), which is typical of Hong Kong (Dudgeon & Corlett, 2004). Fires have occurred in the area with burns recorded in 1988, 1990, 1992, 1995, 1998, 2004 and 2007, and Chan (2005) also confirms that the area is susceptible to fire. The occurrence of fire has influenced vegetation development in the area and is reflected in the dominance of grass, fern and low shrubland. The geology consists of volcanic tuffs with some siltstone/sandstone interbeds and granodiorite. Colluvium is widespread on the lower slopes. Small-scale landsliding occurred in the upper source area of the drainage system in 2001 and 2003, triggered by rainfall. For the period 1999–2010, mean annual rainfall at the nearby Kadoorie Farm and Botanic Garden gave an average annual rainfall of 2772.9 mm, with considerable inter-annual variation.

Suspended sediment production has been monitored in this small upland headwater catchment (0.052 km^2), which is located in the Kam Tin drainage basin. The outlet of this small basin is around 120 m PD, whilst the highest point is around 380 m PD. The average slope gradient is 30°, with some areas being over 50°, which compares with between 15 and 60° for 66% of Hong Kong slopes (Styles & Hansen, 1989). Suspended sediment sampling began in this drainage basin from 1993, with typical sample volumes being 400–500 ml. Manual sampling, from the centre of the <1-m wide channel, and an ISCO model 2700 automatic sampler, were used to collect samples under a range of streamflow conditions and stage-levels throughout any given year. The sampling strategy has included periods of regular-interval weekly sampling. Upon return to the laboratory, the suspended sediment was separated by filtration using pre-weighed GF/C filter papers and suspended sediment concentration determined by oven drying (at 103–105°C) to a constant weight. For determination of chlorophyll-a, sampling was undertaken on a regular weekly schedule. Water samples were collected, transferred to the laboratory and filtered as soon as possible through a GF/C filter paper. Acetone was used to extract the chlorophyll and a spectrophotometer measured extinction at 665 nm. The method is based upon Golterman (1970) and Lorenzen (1967). For both suspended sediment and chlorophyll-a, the non-parametric Wilcoxon rank-sum test, which avoids the assumptions regarding data associated with parametric tests, has been used to compare the data and the 95% significance level adopted. The tests were done using the R-project statistical package.

RESULTS

The summary descriptive statistics of the storm period suspended sediment concentration data (2004–2011) for the study basin are presented in Table 1. From Table 1, it can be seen that the two years in which the basin was affected by fire, namely 2005 and 2007, exhibited an increase in suspended sediment for the percentile values compared to the preceding and non-fire years of 2004 and 2006, respectively. Moreover, there is a statistical difference at the 95% significance level between 2004 *vs* 2005 and 2006 *vs* 2007, suggesting that fire raised suspended sediment in the stream compared to the preceding years. The respective increases in medians are 8.3 and 3.0 mg/L, which equate to 148% and 16%. Comparison of 2007 with 2008 median values in Table 1 reveals that 2008 is higher compared to 2007 by 7.3 mg/L, and that there is no statistically significant difference between the two data sets at the 95% level, suggesting that suspended sediment levels remained high in 2008 over 12 months after the fire of January 2007. Aggregation of the years 2008, 2009, 2010 and 2011 gives a median value of 16.8 mg/L, lower than the 21.7 mg/L observed

Table 1 Storm period suspended sediment statistics (mg/L).

Year	Percentiles: 25	50	75	Sample size
2004	2.7	5.6	10	77
2005*	5.7	13.9	34.5	196
2006	9.8	18.7	41.8	229
2007*	11.3	21.7	61.8	173
2008	12.5	29	67.5	128
2009	3.7	8.9	18.3	164
2010	16.7	36	92.4	73
2011	5.7	12.9	30.1	89
2005 + 2007*	8.5	17.8	46.3	369
2004 + 2006	6.6	13.8	37.2	306
2006 + 2008	10.2	22.6	50.2	357
2008, 2009, 2010 + 2011	6.5	16.8	43.7	454

* fire affected

Table 2 Weekly sampling median suspended sediment concentrations (mg/L).

Year	Dry season	Sample size	Wet season	Sample size
2006	3.52	20	5.8	17
2007*	5.74	17**	5.51	21
2008	3.17	22	5.63	24
2009	4.9	18	3.15	18
2010	4.04	25	8.3	24
2009–2010	4.49	106	5.69	104

* fire affected
** no data in January pre-fire

Table 3 Weekly sampling median chlorophyll-a concentrations (μg/L).

Year	Dry season	Sample size	Wet season	Sample size
2006	0.33	20	0.28	17
2007*	0.45	17**	0.38	21
2008	0.19	22	0.33	24
2009	0.16	18	0.22	18
2010	0.23	25	0.22	24
2006–2010	0.24	106	0.24	104

* fire affected
** no data in January pre-fire

for the 2007 fire-affected year. Statistical testing of the 2007 year against the combined 2008–2011 data sets reveals a significant difference at the 95% level. This suggests that suspended sediment concentrations are gradually declining to below post-2007 levels.

Regular weekly sampling of suspended sediment has been undertaken in the drainage basin, and at the same time bulk water samples were collected for chlorophyll-a determination. The results from the regular sampling programme for suspended sediment and chlorophyll-a are presented in Tables 2 and 3, respectively. In terms of suspended sediment, the annual median suspended sediment concentrations for the years 2006–2010 range from 3.17 to 5.74, and 3.15 to 8.30 mg/L, respectively, for the dry and wet seasons. The fire year of 2007 does have the highest dry season median value, and at 5.74 mg/L the concentration is 2.2 mg/L, or 63%, higher than the 2006 value of 3.52 mg/L. The fire impacted dry season data for 2007 are significantly different at the 95% level from the dry season data of 2006, 2009 and 2010, but not 2008. It should be noted that the concentrations are very low and are also much smaller than for the equivalent storm period median values during corresponding years. Comparison of the wet season data for the regular interval sampling is complicated by the occurrence of storm events.

Regarding chlorophyll-a, Table 3 reveals that the dry season samples for 2007 exhibited the highest median, with a value of 0.45 μg/L. However, the variation across the years is small. Statistical testing reveals no significant difference at the 95% level between 2006 *vs* 2007, and 2007 *vs* 2006, 2008, 2009 and 2010. The wet season data also reveals limited inter-annual variation in chlorophyll-a, and there is no statistically significant difference at the 95% significance level between 2007 and other years. In general, the concentrations for chlorophyll-a are low and for the 2006–2010 data, the median dry and wet season chlorophyll-a values are 0.24 and 0.24 μg/L, respectively. Regarding chlorophyll-a, the fire of January 2007 did therefore not result in great change on the basis of the data assembled using regular weekly sampling.

DISCUSSION

As noted above, the data in Table 1 suggest that in the year immediately following fires, namely 2005 and 2007, the median storm period suspended sediment concentration was higher than in the preceding year: hill fire results in an increase in storm period sediment concentrations. Data for two other fire years in the same basin, namely 1996 and 1998, show the same pattern with median storm-period suspended sediment concentrations being 5.3 and 2.3 mg/L higher, respectively, than in the year preceding the fire; these are equivalent to 88% and 24% increases. The two hill fire events of December 2004 and February 2007 provide evidence that the burning of vegetation can result in enhanced suspended sediment concentrations. An increase in suspended sediment concentrations following fire has been reported by previous work, including, amongst others, Veenhuis & Bowman (2002) and Malmon *et al.* (2007). Table 1 shows that the annual median suspended sediment concentrations for the years 2006 and 2008 were greater than the fire impacted years of 2005 and 2007, respectively. This suggests that the impact from the fires of December 2004 and February 2007 on the storm-period suspended sediment may extend beyond the first 12 months following a burn. This finding is in contrast to data reported by Peart *et al.* (2009) for earlier fire events in the study drainage basin. The prolongation of the effects of fire upon suspended sediment concentrations may be due to climate, as 2006 and 2008 were comparatively wet with annual rainfall totals at the adjacent Kadoorie Farm and Botanic Gardens of 3256.5 mm and 3483.7 mm, respectively. In addition, Kunze & Stednick (2006) have shown that sediment storage can affect post-fire sediment production. It should also be noted that there is a statistically-significant difference between 2007 and the combined 2008, 2009, 2010 and 2011 data sets indicating a decline in storm-period sediment concentrations over the longer term after the February 2007 fire. Bearing in mind any limitations of the sampling strategy, evidence of a change in sediment concentrations following a hill fire in an upland catchment has been presented. However, it should be noted that the response of suspended sediment to fire may be complicated by, for example, sediment delivery and storage (Kunz & Stednick, 2006; Shakesby & Doerr, 2006), the type and sequence of storm events, both pre- and post- fire (Desilets *et al.*, 2007; Smith *et al.*, 2010) and, the extent and severity of the burn (Rhoades *et al.*, 2011).

Evidence of an increase in storm period suspended sediment concentrations following hill fire has been presented. However, the median values and 75th percentile values presented in Table 1 show that the concentrations are comparatively low. This may reflect vegetative cover regeneration. For example, for the fire of December 2004, which affected sediment production in 2005, vegetation cover on three monitoring plots had reached 88%, 79% and 70% by November 2005 and, at one other plot, 99% by August 2005. For the fire of February 2007, data from two monitoring plots reveal live vegetation coverage of 25% and 33% by 11 April 2007, 65% and 71% by 24 May 2007, and 98% and 97% by 28 August 2007. A further contributing factor may be that during the hill fire of January 2007, soil moisture associated with the drainage system prevented ignition and burning of vegetation in some of the riparian zone. This riparian vegetation may have acted as a filter, reducing sediment delivery to the basin outlet.

The study basin stream is part of the Kam Tin drainage basin, which is one of the largest in Hong Kong. As part of the Hong Kong Governments attempts to improve water quality in surface waters, a series of Water Quality Objectives have been introduced. For the Kam Tin drainage basin, the suspended sediment Water Quality Objective is a median value of <20 mg/L based upon monthly sampling. Table 1 reveals that for the eight years of data, only three (2007, 2008 and 2010) have median values that exceeded 20 mg/L. Moreover, for the eight years of data presented in Table 1, the highest 75th percentile was only 92.4 mg/L, which is low. For example, in comparison Peart (1997) reports a storm period sampling 75th percentile value of 954 mg/L for 346 samples, for the period 1991–1995 in the nearby Lam Tsuen River, which during 1991 and 1992 was impacted by roadwork's. The low values for the 75th percentiles observed in this study basin are evidence of the protective effect of vegetation that has previously been demonstrated by Lam (1978) in a study of three small catchments at Tai Lam Chung, also in the New Territories of Hong Kong.

The concentrations of chlorophyll-a in streams and rivers may be influenced by physical, chemical and biological factors and processes (Neal *et al.*, 2006). If the occurrence of fire in the basin had resulted in a large change in any of the factors controlling chlorophyll-a concentrations, then it might be expected that 2007 would have distinctive levels of chlorophyll-a. For example, the burn of 2007 could have reduced the shade afforded to the stream channel by riparian vegetation allowing more sunlight and thereby stimulating primary production of aquatic algae. Light availability is an important driver of primary production in tropical streams and rivers and green algae require much higher light intensities compared to diatoms or cyanobacteria (Davies *et al.*, 2008). Indeed, Dudgeon (1988) has shown that for Hong Kong streams, the lowest standing stock of periphyton occurred in shaded streams. A further control on light availability is suspended matter (Lewis, 2008). Table 2 illustrates that regular weekly sampling reveals no great difference in suspended sediment concentrations for the year affected by the hill fire, 2007, compared to the years of 2006, 2008, 2009, 2010 and 2011 and, furthermore, Table 1 indicates that whilst fire may result in higher median values of storm-period suspended sediment compared to the preceding year, the increases were 8.3 and 3.0 mg/L, respectively, for the fire years of 2005 and 2007. These values are too low to result in a change in light availability (Lewis, 2008). Ganf & Rea (2007) reported that the Queensland Water Quality Guidelines for the wet tropics recommend that chlorophyll-a concentrations for rivers should be <3 μg/L. The annual median values presented in Table 3 are well below this value and for the years 2006, 2007, 2008, 2009 and 2010, only zero, four, three, zero and two recorded values were greater than 3 μg /L, respectively.

In terms of comparison, Zhang *et al.* (2011) reported values for chlorophyll-a in the Pearl River Estuary of from around 0.83 to 11.77 μg/L, with the observed values in the study catchment being similar to the lower values reported by Zhang *et al.* (2011). Table 3 suggests that fire has not impacted the chlorophyll-a content of water in the study stream as 2007 is similar to the other years for which chlorophyll-a data are available.

CONCLUSION

Based upon observations in a small upland drainage basin in Hong Kong and bearing in mind any limitations of the sampling strategy, hill fire may result in an increase in storm-period suspended sediment concentrations. Data for 2008, 2009, 2010 and 2011 suggest a gradual decline of storm-period sediment concentrations to pre-fire levels. Regular weekly sampling suggests an increase in dry season sediment concentrations (which reflect low-flow conditions) in the fire affected year of 2007, compared to the dry season of the preceding year, but the suspended sediment concentrations are in general low. Chlorophyll-a values in runoff from the basin appear not to have changed post-fire.

Acknowledgements Funding from the Hui-Oi-Chow Trust Fund is gratefully acknowledged.

REFERENCES

Chan, Wu-wah (2005) A feasibility study of hill fire management in Hong Kong Country Parks using GIS analysis. MSc Dissertation, Environmental Management, University of Hong Kong, 85 pp.

Chau, K. C. L. & Corlett, R. T. (1994) Fire and weather in Hong Kong. In: *Proceedings 12th Conference on Fire and Forest Meteorology* (October 1993, Georgia, USA), 442–452. Society of American Foresters.

Davies, P. M., Bunn, S. E. & Hamilton, K. (2008) Primary production in tropical streams and rivers. In: *Tropical Stream Ecology* (ed. by D. Dudgeon), 23–42. Elsevier, Amsterdam.

Desilets, S. L. E., Nijssen, B., Ekwurzel, B. & Ferré, Ty, P. A. (2007) Post-wildfire changes in suspended sediment rating curves: Sabino Canyon, Arizona. *Hydrol. Processes* 21, 1413–1423.

Dudgeon, D. (1988) The influence of riparian vegetation on macro invertebrate community structure in four Hong Kong streams. *J. Zool. Lond*. 216, 609–627.

Dudgeon, D. & Corlett, R. (2004) *The Ecology and Biodiversity of Hong Kong*. Friends of the Country Parks and Joint Publishing, Hong Kong, 336 pp.

Ganf, G. G. & Rea, N. (2007) Potential for algal blooms in tropical rivers of the Northern Territory, Australia. *Marine and Freshwater Research* 58, 315–326.

Golterman, H. L. (1970) *Methods for Analysis of Fresh Waters*. IBP Handbook no. 8. Blackwell Scientific, Oxford.

Hill, R. D., Peart, M. R. & Guan, D.-S, (2004) The effects of annual harvesting on the subsequent phytomass and species composition of grassland and fernland: a Hong Kong case, Singapore *J. Tropical Geogr*. 25(1), 77–91.

Kunz, M. D. & Stednick, J. D. (2006) Streamflow and suspended sediment yield following the 2000 Bobcat fire, Colorado. *Hydrol. Processes* 20, 1661–1681.

Lewis, Jr, W. M. (2008) Physical and chemical features of tropical flowing waters. In: *Tropical Stream Ecology* (ed. by D. Dudgeon), 1–21. Elsevier, Amsterdam.

Lam, K. C. (1978) Soil erosion, suspended sediment and solute production in three Hong Kong catchments. *J. Tropical Geog.* 47, 51–62.

Lorenzen, C. J. (1967) Determination of chlorophyll and pheo-pigments: spectrophotometric equations. *Limn. and Oceanogr.* 12, 342–346.

Malmon, D. V., Reneau, S. L., Katzman, D., Lavine, A & Lyman, J. (2007) Suspended sediment transport in an ephemeral stream following wildfire. *J. Geophys. Res.* 112. doi: 0.1029/2005 FJ000459, 2007.

Marafa, L. M. & Chow, K. C. (1999) Effect of hill fire on upland soil in Hong Kong. *Forest Ecology & Manage.* 120, 97–104.

Neal, C., Hilton, J., Wade, A. J., Neal, M. & Wickham, H. (2006) Chlorophyll-a in the rivers of eastern England. *Sci. Total Environ.* 365, 84–104.

Owen, B. & Shaw (2007) *Hong Kong Landscapes: Shaping the Barren Rock*. Hong Kong University Press. 253 pp.

Peart. M. R. (1998) Human impact upon sediment in rivers: some examples from Hong Kong. In: *Human Impact on Erosion and Sedimentation* (ed. by D. E. Walling & J.-L. Probst), 111–118. IAHS Publ. 245. IAHS Press, Wallingford, UK.

Peart, M. R., Hill, R. D. & Fok, L. (2009) Environmental change, hillslope erosion and suspended sediment: some observations from Hong Kong. *Catena* 79, 198–204.

Rhoades, C. C., Entwistle, D. & Butler, D. (2011) The influence of wildfire extent and severity on streamwater chemistry, sediment and temperature following the Hayman fire, Colorado. *Int. J. Wildland Fire* 20, 430–442.

Shakesby, R. A. & Doerr, S. H. (2006) Wildfire as a hydrological and geomorphological agent. *Earth-Science Revs* 74, 269–307.

Smith, H. G., Sheridan, G. J., Lane, P. N. J. & Sherwin, C. B. (2010) Paired *Eucalyptus* forest catchment study of prescribed fire effects on suspended sediment and nutrient exports in south-eastern Australia. *Int. J. Wildland Fire* 19(5), 624–636.

Styles, K. A. & Hansen, A. (1989) *Geotechnical Areas Studies Programme Territory of Hong Kong*. Geotechnical Control Office, Civil Engineering Services Department. Hong Kong GASP Report XII. 345 pp.

Ternan, J. L. & Neller, R. (1999) The erodibility of soils beneath wildfire prone grasslands in the humid tropics, Hong Kong. *Catena* 36, 49–64.

Veenhuis, J. E. & Bowman, P. R. (2002) Effects of wildfire on the hydrology of Frijoles and Capulin canyons in and near Bandelier National Monument, New Mexico. *USGS Fact Sheet*, *141-02. 4P*.

Vohora, U. K. & Donoghue, S. L. (2004) Application of remote sensing data to landslide mapping in Hong Kong. In: *Geo-Imagery Bridging Continents* (Proc. ISPRS Congress, July 2004 Istanbul, Turkey), vol. XXXV, part B5, 489–493.

Yuanzhi Zhang, Hui Lin, Chuqun Chen, Liding Chen, Bing Zhang & Gitelson, A. A. (2011) Estimation of Chlorophyll-a concentration in estuarine waters: case study of the Pearl River estuary, South China Sea. *Environ. Res.* 6(2), doi:10.1.1088/1748-9326/6/2/024016.