



Food and Agriculture Organization  
of the United Nations

# Status of the World's Soil Resources

Main Report

Chapter 16  
Regional Assessment  
of Soil Change in  
Antarctica

© FAO / Giuseppe Bizziari



GLOBAL SOIL  
PARTNERSHIP

itps  
INTERGOVERNMENTAL  
TECHNICAL PANEL ON SOILS



2015  
International  
Year of Soils

# Disclaimer and copyright

## **Recommended citation:**

FAO and ITPS. 2015.

Status of the World's Soil Resources (SWSR) – Main Report.

Food and Agriculture Organization of the United Nations  
and Intergovernmental Technical Panel on Soils, Rome, Italy

The designations employed and the presentation of material in this information product do not imply the expression of any opinion whatsoever on the part of the Food and Agriculture Organization of the United Nations (FAO) concerning the legal or development status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries.

The mention of specific companies or products of manufacturers, whether or not these have been patented, does not imply that these have been endorsed or recommended by FAO in preference to others of a similar nature that are not mentioned.

The views expressed in this information product are those of the author(s)  
and do not necessarily reflect the views or policies of FAO.

ISBN 978-92-5-109004-6

© FAO, 2015

FAO encourages the use, reproduction and dissemination of material in this information product. Except where otherwise indicated, material may be copied, downloaded and printed for private study, research and teaching purposes, or for use in non-commercial products or services, provided that appropriate acknowledgement of FAO as the source and copyright holder is given and that FAO's endorsement of users' views, products or services is not implied in any way.

All requests for translation and adaptation rights, and for resale and other commercial use rights should be made via [www.fao.org/contact-us/licence-request](http://www.fao.org/contact-us/licence-request) or addressed to [copyright@fao.org](mailto:copyright@fao.org).

FAO information products are available on the FAO website [www.fao.org/publications](http://www.fao.org/publications) and can be purchased through [publications-sales@fao.org](mailto:publications-sales@fao.org).

# 16 | Regional Assessment of Soil Change in Antarctica



**Contributing author:** Megan Balks



Antarctica has a total area of  $13.9 \times 10^6$  km<sup>2</sup>, of which 44 890 km<sup>2</sup> (0.32 percent) is ice-free (Fox and Cooper, 1994; British Antarctic Survey, 2005) with potential for soil development. Ice free areas are mainly confined to the Antarctic Peninsula, a few places around the perimeter of the continent and along the Transantarctic Mountains. The largest ice-free area (approximately 5 000 km<sup>2</sup>) is the McMurdo Dry Valleys in the Ross Sea Region.

Mean annual temperatures vary from near 0°C in the moister, marine influenced Antarctic Peninsula to about -20°C in dry, higher altitude inland areas (Campbell and Claridge, 1987). Many soils are formed on mixed tills with some directly formed on bedrock. Organic matter is minimal (< 0.1 percent) in drier, colder inland areas. However, in areas where free moisture occurs, mosses and, on the Antarctic Peninsula, higher plants, may grow and accumulate to form peat soil materials. Ornithogenic materials dominate soils at many coastal locations (e.g. Hofstee *et al.*, 2006). Surface ages in coastal and Antarctic Peninsula regions tend to be predominantly Holocene, exposed by retreat of the Last Glacial Maximum ice. At higher elevations in the McMurdo Dry Valleys, surfaces as old as Mid-Miocene (14 Ma) have been reported (Sugden, Bentley and Cofaigh, 2006) indicating low erosion rates under a stable polar desert climate. Soil microclimates, driven by strong topographic variability, also influence soil properties (Balks *et al.*, 2013).

A wide variety of soils occur in the ice-free areas (Campbell and Claridge, 1987). Gelisols (Soil Survey Staff, 2014) or Cryosols (IUSS Working Group WRB, 2014) are the predominant soils in Antarctica. Cryosols contain permafrost at depth and are overlain by an active layer that thaws during the summer and is frozen in winter. In moister coastal areas the permafrost is ice-cemented and thus 'frozen solid'. However in some inland areas of the Trans-Antarctic Mountains, including the McMurdo Dry Valleys, there is not enough moisture to form ice-cement so soils with temperatures well below 0°C are loose and easily excavated (Bockheim, 1978; Campbell and Claridge, 1987). The soils range from Gelisols (Cryosols) in the Ross Sea Region, through Gelisols and Entisols in coastal East Antarctica, to a mixture of Gelisols, Entisols, Spodosols and Inceptisols in the warmer northern Antarctic Peninsula Region where permafrost is not ubiquitous (Balks *et al.*, 2013). Due to limited weathering in the cold climate, many Antarctic soils are dominantly gravelly sands. Where vegetation is absent, a protective desert pavement usually forms at the soil surface. The focus for studies on Antarctic soils is not on their potential for food production, but rather on their genesis, diversity, and vulnerability to impacts of human activity.

## 16.2 | Pressures/threats for the Antarctic soil environment

---

Most of the human activities in Antarctica, including historic huts, modern research stations, and tourist visits, are concentrated in the relatively accessible, small, ice-free areas, on the coast, particularly in the Ross Sea region and Antarctic Peninsula (O'Neill *et al.*, in press).

Antarctica was first recorded by three whaling ships in 1820 leading to regular whaling visits and the Ross expedition of 1839-1940. The 'heroic era' of exploration (1895-1917) included expeditions such as those of Borchgrevink, Scott, Shackleton, Mawson and Amundsen. Since the International Geophysical Year (1957-1958), greatly increased human activity has occurred with over 70 scientific research bases established, mainly around the Antarctic coast. Ship-based Antarctic tourism has become popular with 46 000 tourists reported in the 2007/08 summer and 27 700 in the 2013-2014 season (IAATO, 2014).



Legacies of human occupation are scattered at isolated sites across Antarctica, particularly in areas close to the major research stations and semi-permanent field camps (Campbell, Balks and Claridge, 1993; Kennicutt *et al.*, 2010; Tin *et al.*, 2009). Impacts have included physical disturbance as a result of construction activities, geotechnical studies, and roading (Campbell, Balks and Claridge, 1993; Campbell, Claridge and Balks, 1994; Harris, 1998; Kennicutt *et al.*, 2010; Kiernan and McConnell, 2001); local pollution from hydrocarbon spills (Aislabie *et al.*, 2004; Kim, Kennicutt II and Qian, 2006; Klein *et al.*, 2012) and from waste disposal (Claridge *et al.*, 1995; Snape, Morris and Cole, 2001; Santos *et al.*, 2005; Sheppard, Claridge and Campbell, 2000); introduction of alien species (Frenot *et al.*, 2005; Chown *et al.*, 2012; Cowan *et al.*, 2011); and disturbance to soil biological communities (de Villiers, 2008; Harris, 1998; Naveen, 1996; Tin *et al.* 2009 and references therein). The amount of contaminated soil and waste has been estimated at 1–10 million m<sup>3</sup> (Snape, Morris and Cole, 2001). The presence of persistent organochlorine pollutants in Antarctica has been attributed to long-range atmospheric transport from lower latitudes (Bargagli, 2008).

Antarctic soils are easily disturbed and natural recovery rates are slow due to low temperatures and often a lack of liquid moisture (Campbell, Balks and Claridge, 1993, 1998a; Campbell *et al.*, 1998b; Kiernan and McConnell, 2001; Waterhouse, 2001). Where physical disturbance removes the protective 'active layer' the underlying permafrost will melt with resulting land surface subsidence and, in drier regions, accumulation of salt at the soil surface (Campbell, Claridge and Balks, 1994; Waterhouse, 2001). Campbell and Claridge (1975, 1987) recognized that older, more weathered desert pavements and associated soils were the most vulnerable to physical human disturbance. However disturbances on active surfaces, such as gravel beach deposits, aeolian sand dunes and areas where melt-water flows, have the capacity to recover (visually) relatively quickly (McLeod, 2012; O'Neill, Balks and López-Martínez, 2012b, 2013; O'Neill *et al.*, 2012a).

Fuel spills are the most common source of soil contamination and have the potential to cause the greatest environmental harm in and around the continent (Aislabie *et al.*, 2004). Hydrocarbon fuel spills have been shown to persist in the environment for decades, with fuel perching on top of ice-cemented permafrost (Balks *et al.*, 2002). When spilled on Antarctic soils, possible fates of the hydrocarbons include dispersion, evaporation, and biodegradation. Hydrocarbon degrading microbes are present in the Antarctic environment but within the Ross Sea region their effectiveness is limited by moisture and nutrient (N and P) availability (Aislabie *et al.*, 2004, 2012). Hydrocarbon spills on Antarctic soils can enrich hydrocarbon-degrading bacteria within the indigenous microbial community (Aislabie *et al.*, 2004, 2012; Delille *et al.* 2000).

Elevated levels of metal concentrations have been reported at base sites especially in areas used for waste disposal or affected by emissions from incinerators or fuel spills (Claridge *et al.* 1995; Sheppard, Claridge and Campbell, 2000; Webster *et al.*, 2003; Santos *et al.*, 2005; Stark *et al.* 2008; Guerra *et al.*, 2011). Particularly high metal levels have been reported at Hope Bay on the Antarctic Peninsula (Guerra *et al.*, 2011) and at the Thala Valley landfill at Casey Station, East Antarctica (Stark *et al.*, 2008). Elevated levels of methyl lead have been detected in soil from a former fuel storage site at Scott Base (Aislabie *et al.*, 2004).

Surface trampling has been shown to impact on soil nematode abundances in the McMurdo Dry Valleys (Ayres *et al.*, 2008) and on arthropod abundance on the Antarctic Peninsula (Tejedo *et al.* 2005, 2009). Potential for introduction of invasive plant, insect, and microbial biota is gaining attention (Cowan *et al.*, 2011; Chown *et al.*, 2012; Greenslade and Convey, 2012).



All activities in Antarctica are regulated through the national administrative and legal structures of the countries active in the region, underpinned by the international legal obligations resulting from the Antarctic Treaty System. The Protocol on Environmental Protection to the Antarctic Treaty (the Madrid Protocol) was signed in 1991 and designates Antarctica as 'a natural reserve devoted to peace and science'. The Madrid Protocol mandates the protection of Antarctic wilderness and aesthetic values and requires that before any activity is undertaken the possible environmental impacts are assessed. Since the ratification of the Madrid Protocol in 1991 environmental awareness has increased and the standard of prevention of human impacts undertaken by many of the Antarctic programmes, such as those operating in the McMurdo Dry Valleys, is now more stringent than environmental management standards in most, if not all, other regions of the planet (O'Neill *et al.*, in press).

The ice-free areas visited by humans are small, relative to the Antarctic continent as a whole, and impacts occur as isolated pockets amongst largely pristine Antarctic wilderness (O'Neill *et al.*, in press). The most intense and long-lasting visible impacts occur around the current and former research bases, and are often remnants of activities in the 1950s-1970s prior to the Madrid Protocol (Campbell and Claridge, 1987; Webster *et al.*, 2003; Bargagli, 2008; Kennicutt *et al.*, 2010; O'Neill, 2013). Since the 1980s environmental accountability, management and awareness have increased, and the environmental footprints of stations such as Scott Base and McMurdo Station on Ross Island have remained static or decreased (Kennicutt *et al.*, 2010). For example, there are mechanisms in place to prevent spills, remove wastes, phase out incineration, limit soil disturbance, and protect sites of particular cultural or environmental significance. These mechanisms are proving effective at preventing further damage to Antarctic soils.

## References

- Aislabie, J.M., Balks, M.R., Foght, J.M. & Waterhouse, E.J. 2004. Hydrocarbon spills on Antarctic soils: effects and management. *Environmental Science and Technology*, 38: 1265–1274.
- Aislabie, J.M., Ryburn, J., Gutierrez-Zamora, M-L., Rhodes, P., Hunter, D., Sarmah, A.K., Barker, G.M. & Farrell, R.L. 2012. Hexadecane mineralization activity in hydrocarbon-contaminated soils of Ross Sea region Antarctica may require nutrients and inoculation. *Soil Biology & Biochemistry*, 45: 49–60.
- Ayres, E., Nkem, J.N., Wall, D.H., Adams, B.J., Barnett, J.E., Broos, E.J., Parsons, A.N., Powers, L.E., Simmons, B.L. & Virginia, R.A. 2008. Effects on human trampling on populations of soil fauna in the McMurdo Dry Valleys, Antarctica. *Conservation Biology*, 22: 1544–1551.
- Balks, M.R., López-Martínez, J., Goryachkin, S.V., Mergelov, N.S., Schaefer, C.E.G.R., Simas, F.N.B., Almond, P.C., Claridge, G.G.C., Mcleod, M. & Scarrow, J. 2013. Windows on Antarctic soil-landscape relationships: comparison across selected regions of Antarctica. *Geological Society, London, Special Publications*, 381: 397–410. doi: 10.1144/SP381.9
- Balks, M.R., Paetzold, R.F., Kimble, J.M., Aislabie, J. & Campbell, I.B. 2002: Effects of hydrocarbon spills on the temperature and moisture regimes of Cryosols in the Ross Sea region, Antarctica. *Antarctic Science*, 14: 319–326.
- Bargagli, R. 2008. Environmental contamination in Antarctic ecosystems. *Science of the Total Environment*, 400: 212–226. DOI: 10.1016/j.scitotenv.2008.06.062



**Bockheim, J.G.** 1978. Relative age and origin of soils of the eastern Wright Valley, Antarctica. *Soil Science*, 128: 142–152.

**British Antarctic Survey.** 2005. *Antarctic Factsheet Geographical Statistics*. UK, Cambridge, British Antarctic Survey. 4 pp. (available at [http://www.antarctica.ac.uk/about\\_antarctica/teacher\\_resources/resources/factsheets/factsheet\\_geostats\\_screen.pdf](http://www.antarctica.ac.uk/about_antarctica/teacher_resources/resources/factsheets/factsheet_geostats_screen.pdf))

**Campbell, I.B. & Claridge, G.G.C.** 1975. Morphology and age relationships of Antarctic soils. *R. Soc. N. Z. Bull.*, 13: 83–88.

**Campbell, I.B. & Claridge, G.G.C.** 1987. *Antarctica: soils, weathering processes and environment*. USA, New York, Elsevier Science Publishers B.V. 368 pp.

**Campbell, I.B., Balks, M.R. & Claridge, G.G.C.** 1993. A simple visual technique for estimating the impact of fieldwork on the terrestrial environment in ice-free areas of Antarctica. *Polar Record*, 29: 321–328.

**Campbell, I.B., Claridge, G.G.C. & Balks, M.R.** 1994. The effects of human activities on moisture content of soils and underlying permafrost from the McMurdo Sound region, Antarctica. *Antarctic Science*, 6: 307–314.

**Campbell, I.B., Claridge, G.G.C. & Balks, M.R.** 1998a. Short- and long-term impacts of human disturbances on snow-free surfaces in Antarctica. *Polar Record*, 34(188): 15–24.

**Campbell, I.B., Claridge, G.G.C., Campbell, D.I. & Balks, M.R.** 1998b. Soil temperature and moisture properties of Cryosols of the Antarctic Cold Desert. *Eurasian Soil Science*, 31: 600–604.

**Chown, S.L., Huiskes, A.H.L., Gremmen, N.J.M., Lee, J.E., Terauds, A., Crosbie, K., Frenot, Y., Hughes, K.A., Imura, S., Kieffer, K., Lebouvier, M., Raymond, B., Tsujimoto, M., Ware, C., Van de Vijver, B. & Bergstrom, D.M.** 2012. Continent-wide risk assessment for the establishment of nonindigenous species in Antarctica. *Proceedings of the National Academy of Sciences*, 109(13): 4938–4943.

**Claridge, G.G.C., Campbell, I.B., Powell, H.K.J., Amin, Z.H. & Balks, M.R.** 1995. Heavy metal contamination in some soils of the McMurdo Sound region, Antarctica. *Antarct. Sci.*, 7: 9–14.

**Cowan, D.A., Chown, S.L., Convey, P., Tuffin, M., Hughes, K., Pointing, S. & Vincent, W.F.** 2011. Non-indigenous microorganisms in the Antarctic: assessing the risks. *Trends in Microbiology*, 19: 540–548.

**De Villiers, M.** 2008. Review of recent research into the effects of human disturbance on wildlife in the Antarctic and sub-Antarctic region. In *Human disturbance to wildlife in the broader Antarctic region: a review of findings*. Working Paper 12 for XXXI Antarctic Treaty Consultative Meeting, Kiev, Ukraine, 2–13 June 2008.

**Delille, D.** 2000. Response of Antarctic soil bacterial assemblages to contamination by diesel fuel and crude oil. *Microbial Ecology*, 40: 159–168.

**Fox, A.J. & Cooper, P.R.** 1994. Measured properties of the Antarctic Ice Sheet derived from the SCAR digital database. *Polar Record*, 30: 201–206.

**Frenot, Y., Chown, S.L., Whinam, J., Selkirk, P.M., Convey, P., Skotnicki, M. & Bergstrom D.M.** 2005. Biological invasions in the Antarctic: Extent, impacts and implications. *Biological Reviews*, 80: 45–72.

**Greenslade, P. & Convey, P.** 2012. Exotic Collembola on subantarctic islands: Pathways, origins and Biology. *Biological Invasions*, 14: 405–417.

**Guerra, M.B.B., Schaefer, C.E.G.R., de Freitas Rosa, P., Simas, F.N.B., Pereira, T.T.C. & Pereira-Filho, E.R.** 2011. Heavy metal contamination in century-old manmade technosols of Hope Bay, Antarctic Peninsula. *Water, Air and Soil Pollution*, 222: 91–102.

**Harris, C.M.** 1998. Science and environmental management in the McMurdo Dry Valleys, Antarctica. In J. Prisco, ed. *Ecosystem Processes in a Polar Desert: the McMurdo Dry Valleys, Antarctica*. Antarctic Research Series 72. Washington, DC, American Geophysical Union.

**Hofstee, E.H., Balks, M.R., Petchey, F. & Campbell, D.I.** 2006. Soils of Seabee Hook, Cape Hallett, Northern Victoria Land, Antarctica. *Antarctic Science*, 18: 473–486.



**IAATO.** 2014. *Tourism statistics*. International Association of Antarctic Tour Operators. (available at <http://iaato.org/tourism-statistics>)

**IUSS Working Group WRB.** 2014. *World Reference Base for soil resources 2014. International soil classification system for naming soils and creating legends for soil maps*. World Soil Resources Reports No. 106. Rome. FAO.

**Kennicutt, M.C., Klein, A., Montagna, P., Sweet, S., Wade, T., Palmer, T. & Denoux, G.** 2010. Temporal and spatial patterns of anthropogenic disturbance at McMurdo Station, Antarctica. *Environmental Research Letters*, 5: 1–10.

**Kiernan, K. & McConnell, A.** 2001. Land surface rehabilitation research in Antarctica. *Proceedings of the Linnean Society of New South Wales*, 123: 101–118.

**Kim, M., Kennicutt II, M.C. & Qian, Y.** 2006. Molecular and stable carbon isotopic characterization of PAH contaminants at McMurdo Station, Antarctica. *Marine Pollution Bulletin*, 52: 1585–1590.

**Klein, A.G., Sweet, S.T., Wade, T.L., Sericano, J.L. & Kennicutt II, M.C.** 2012. Spatial patterns of total petroleum hydrocarbons in the terrestrial environment at McMurdo Station, Antarctica. *Antarctic Science*, 24: 450–466.

**McLeod, M.** 2012. *Soil and Permafrost Distribution, Soil Characterisation and Soil Vulnerability to Human Foot Trampling, Wright Valley, Antarctica*. New Zealand, University of Waikato. 219 pp. (Ph.D. Thesis)

**Naveen, R.** 1996. Human activity and disturbance: building an Antarctic site inventory. In R. Ross, E. Hofman, & L. Quetin, eds. *Foundations for ecosystem research in the Western Antarctic Peninsula region*, pp. 389–400. Washington, DC, American Geophysical Union.

**O'Neill, T.A.** 2013. *Soil physical impacts and recovery rates following human-induced disturbances in the Ross Sea region of Antarctica*. New Zealand, University of Waikato. 369 pp. (Ph.D. Thesis)

**O'Neill, T.A., Aislabie, J. & Balks, M.R.** (in press). Human impacts on Antarctic Soils. In J.G. Bockheim, ed. *Soils of Antarctica*. Dordrecht, Springer Publishers.

**O'Neill, T.A., Balks, M.R., López-Martínez, J. & McWhirter, J.** 2012a. A method for assessing the physical recovery of Antarctic desert pavements following human-induced disturbances: a case study in the Ross Sea region of Antarctica. *Journal of Environmental Management*, 112: 415–428.

**O'Neill, T.A., Balks, M.R. & López-Martínez, J.** 2012b. The effectiveness of Environmental Impact Assessments on visitor activity in the Ross Sea Region of Antarctica. In L. Lundmark, R. Lemelin, & D. Müller, eds. *Issues in Polar Tourism: Communities, Environments, Politics*. Berlin–Heidelberg–New York, Springer.

**O'Neill, T.A., Balks, M.R. & López-Martínez, J.** 2013. Soil Surface Recovery from Vehicle and Foot Traffic in the Ross Sea region of Antarctica. *Antarctic Science*, 25: 514–530.

**Santos, I.R., Silva, E.V., Schaefer, C.E., Albuquerque, M.R. & Campos, L.S.** 2005. Heavy metal contamination in coastal sediments and soils near the Brazilian Antarctic Station, King George Island. *Marine Pollution Bulletin*, 50: 185–194.

**Sheppard, D.S., Claridge, G.G.C. & Campbell, I.B.** 2000. Metal contamination of soils at Scott Base, Antarctica. *Applied Geochemistry*, 15: 513–530.

**Snape, I., Morris, C.E. & Cole, C.M.** 2001. The use of permeable reactive barriers to control contaminant dispersal during site remediation in Antarctica. *Cold Regions Science and Technology*, 32: 157–174.

**Soil Survey Staff.** 2014. *Keys to Soil Taxonomy, 12<sup>th</sup> ed.* Washington, DC, USDA–Natural Resources Conservation Service.

**Stark, S.C., Snape, I., Graham, N.J., Brennan, J.C. & Gore, D.B.** 2008. Assessment of metal contamination using X-ray fluorescence spectrometry and the toxicity characteristic leaching procedure (TCLP) during remediation of a waste disposal site in Antarctica. *Journal of Environmental Monitoring*, 10: 60–70.



**Sugden, D.E., Bentley, M.J. & Cofaigh, C.O.** 2006. Geological and geomorphological insights into Antarctic ice sheet evolution. *Philosophical Transactions of the Royal Society*, 364: 1607–1625. doi:10.1098/rsta.2006.1791

**Tejedo, P., Justel, A., Benayas, J., Rico, E., Convey, P. & Quesada, A.** 2009. Soil trampling in an Antarctic Specially Protected Area: tools to assess levels of human impact. *Antarctic Science*, 21: 229–236.

**Tejedo, P., Justel, A., Rico, E., Benayas, J. & Quesada, A.** 2005. Measuring impacts on soils by human activity in an Antarctic Specially Protected Area. *Terra Antarctica*, 12: 57–62.

**Tin, T., Fleming, L., Hughes, K.A., Ainsley, D.G., Convey, P., Moreno, C.A., Pfeiffer, S., Scott, J. & Snape, I.** 2009. Review: Impacts of local human activities on the Antarctic environment. *Antarctic Science*, 21: 3–33.

**Waterhouse, E.J. (ed).** 2001. *Ross Sea Region 2001: a State of the Environment Report for the Ross Sea Region of Antarctica*. New Zealand, Christchurch, New Zealand Antarctic Institute.

**Webster, J., Webster, K., Nelson, P. & Waterhouse, E.** 2003. The behaviour of residual contaminants at a former station site, Antarctica. *Environmental Pollution*, 123: 163–179.



