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Ecological research and conservation management in the Cape Floristic Region between 1945 and 2015: History, current understanding and future challenges

Brian W. van Wilgen[1*], Jane Carruthers[2], Richard M. Cowling[3], Karen J. Esler[4], Aurelia T. Forsyth[5], Mirijam Gaertner[1,6], M. Timm Hoffman[7], Frederick J. Kruger[8,9], Guy F. Midgley[10], Guy Palmer[5], Genevieve Q. K. Pence[11], Domitilla C. Raimondo[12], David M. Richardson[1], Nicola J. van Wilgen[1,13] & John R.U. Wilson[1,14]

[1]Centre for Invasion Biology, Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa; [2]Department of History, University of South Africa, PO Box 392, Unisa, 0003, South Africa; [3]Department of Botany, Nelson Mandela Metropolitan University, PO Box 7700, Port Elizabeth, 6031, South Africa; [4]Centre for Invasion Biology, Department of Conservation Ecology and Entomology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa; [5]CapeNature, Private Bag X5014, Stellenbosch, 7599, South Africa; [6]City of Cape Town, Invasive Species Unit, Postnet Suite 80, Private Bag X26, Tokai, 7966, South Africa; [7]Plant Conservation Unit, Department of Biological Sciences, University of Cape Town, P/Bag X3, Rondebosch, 7701, South Africa; [8]Centre for Environmental Management, University of the Free State, PO Box 33, Skukuza, 1350, South Africa; [9]Organization for Tropical Studies, PO Box 33, Skukuza, 1350, South Africa; [10]Department of Botany and Zoology, Stellenbosch University, Private Bag X1, Matieland, 7602, South Africa; [11]CapeNature, Private Bag X7, Claremont, 7735, South Africa; [12]South African National Biodiversity Institute, Private Bag X101, Pretoria 0001, South Africa; [13]Centre for Invasion Biology, Cape Research Centre, South African National Parks, PO Box 216, Steenberg, 7947, South Africa; [14]South African National Biodiversity Institute, Kirstenbosch Research Centre, Cape Town, South Africa
**Author for correspondence E-mail: bvanwilgen@sun.ac.za*

In 1945, the Royal Society of South Africa published a wide-ranging report, prepared by a committee led by Dr C.L. Wicht, dealing with the preservation of the globally unique and highly diverse vegetation of the south-western Cape. The publication of the Wicht Committee's report signalled the initiation of a research programme aimed at understanding, and ultimately protecting, the unique and diverse ecosystems of the Cape Floristic Region. This programme has continued for over 70 years, and it constitutes the longest history of concerted scientific endeavour aimed at the conservation of an entire region and its constituent biota. This monograph has been prepared to mark the 70th anniversary of the Wicht Committee report. It provides a detailed overview of the circumstances that led up to the Wicht Committee's report, and the historical context within which it was written. It traces the development of new and substantial scientific understanding over the past 70 years, particularly with regard to catchment hydrology, fire ecology, invasive alien plant ecology, the harvesting of plant material and conservation planning. The Wicht Committee's report also made recommendations about ecosystem management, particularly with regard to the use of fire and the control of invasive alien plants, as well as for the establishment of protected areas. Subsequently, a combination of changing conservation philosophies and scientific conservation planning led to the creation and expansion of a network of protected areas that now covers nearly 19% of the Cape Floristic Region. We also review aspects of climate change, most of which could not have been foreseen by the Wicht Committee. We conclude that those responsible for the conservation of these ecosystems will face many challenges in the 21st century. These will include finding ways for effectively managing invasive alien plants and fires, as foreseen by the Wicht Committee. While the protected area network has expanded beyond the modest targets proposed by the Wicht Committee, funding has not kept pace with this expansion, with consequences for the ability to effectively manage protected areas. The research environment has also shifted away from long-term research conducted by scientists embedded in management agencies, to short-term studies conducted largely by academic institutions. This has removed a significant benefit that was gained from the long-term partnership between research and management that characterised the *modis operandus* of the Department of Forestry. Growing levels of illegal resource use and a changing global climate also pose new challenges that were not foreseen by the Wicht Committee.

Keywords: conservation planning; fire; fynbos; global change; invasive alien plants; protected areas; red-listed species; resource use; threats

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TABLE OF CONTENTS

INTRODUCTION

Biodiversity conservation is facing, and will continue to face, significant and escalating challenges in the 21st century, as the cumulative effects of the Anthropocene Epoch play out across the globe. Our ability to address these challenges will be strongly influenced by the degree to which ecological understanding was developed in the 20th century, and how this understanding can be brought to bear on socio-economic development imperatives of the new millennium. Conservation of what today are known as "biodiversity hotspots" places unusual demands on the institutions and organisations to which the responsibility for this conservation falls. More than 20 such hotspots have been delineated around the world (Myers *et al*., 2000). Of these, the Cape Fynbos, or more precisely the ecosystems within the boundaries of the Cape Floristic Region (CFR), has the longest history of science and policy for conservation. In this monograph, we outline how this history began, how it unfolded, and what implications it has for those who will be tasked with the conservation of the CFR in future.

This history began in 1943, when nature conservation issues became increasingly apparent in the CFR, but elicited divergent opinions about their urgency, and the potential ways to address them. John S. Henkel, an elected Fellow of the Royal Society of South Africa (RSSAf), prompted by an extreme wildfire in the south-western Cape Province and his analysis of the same problem in the Cederberg, submitted in his 1943 memorandum to the Society, that "The prevalence of fires in the vegetation of the mountains of the South-Western districts calls for a re-study of the problem of the preservation and maintenance of the indigenous flora". In keeping with its tradition of promoting science in service of society, the RSSAf responded by instituting a committee to address the issues that Henkel raised. This ultimately led to the publication of a committee report authored by Christiaan L. Wicht in 1945. This report (*Preservation of the Vegetation of the South Western Cape*, Wicht, 1945) was the first multidisciplinary attempt to assess the problems facing conservation in the CFR, and it laid the foundation for the thinking behind many of today's conservation interventions and practices.

The Wicht Committee's influential report was part of a historic dialectical process addressing the social, ecological and political trade-offs between options for managing water resources, catchment ecosystems and planted forests in South Africa. It built on contemporary ideas among scientists of the ecosystem and how such thinking could shape a view on the protection of the fynbos, while confronting emerging environmental issues (invasive plants) and policy dissent (fire management). At the centre of this debate was an energetic body of educated and argumentative foresters, botanists and engineers. It was the dissent among them, with the common purpose of finding some optimum among competing development options regarding water, forests and catchments, that opened the way to a fertile field of research that continued for several decades and informed central elements of South Africa's public policy. Arguably, however, the Wicht Committee's report took its character from the fact that among those working on the report were two, Henkel and Wicht, whose ideas had been formed and tempered not only by the science of the day, but also by their testing experiences in the management of fynbos landscapes, as well as in the vigorous debates of public policy forums.

The Wicht Committee's report focused on biodiversity conservation and biodiversity science, and was ahead of its time as these are relatively new fields even today. Moreover, while national parks and protected and conserved forests – National Forests, Crown Forests, or State Forests – have existed as statutory entities now for over 150 years (e.g. Barton, 2001), and in South Africa for over 100 years, organised conservation of an entire biome, or its constituent biota, does not have such a deep history. We contend that the history of such efforts in the CFR goes back further than in any other biome or region worldwide, and further that this history began with the Wicht Committee's report in 1945.

The ecological scope of the Wicht Committee's report coincides broadly with the boundaries of what today is defined as Mountain Fynbos. In this monograph, the scope of our analysis is the CFR, coincident in broad terms with the Fynbos Biome, but including elements of the succulent Karoo. The concept of *biome* did not exist at the time of the Wicht Committee's work, though the vegetation map of John Bews (Bews, 1916), and the biotic formations proposed by John Phillips (Phillips, 1931) anticipated the emergence of this ecological classification, while Wicht himself employed the equivalent idea of the biogeocoenose in his ecological thinking. We have framed the analysis in this monograph as a history of science and conservation of the broader CFR, extending beyond the original, narrower idea.

The Wicht Committee's report provides a perspective of an uncertain future that can now be reflected upon with hindsight. It offers an opportunity to consider the range of futures we face compared to the imagined futures faced by others before us. With the benefit of hindsight, we can examine the assessments of problems, and prognoses for their solution, made by a committee that in many ways was addressing scientific fields that were in their infancy, both in the Cape and globally. We can trace the scientific developments that informed the development of policy, and the evolution of institutional arrangements to implement policy. It is also interesting to identify the aspects of the Wicht Committee's assessments that proved to be accurate, as well as those that either did not turn out as expected, or where unforeseen issues have arisen. As in 1945, our account has been drawn up by a "committee" in the face of an uncertain future, as there will doubtless be further unexpected events that dramatically alter the course of conservation in the region. The circumstances, events and activities that led to outcomes not predicted or foreseen by the Wicht Committee should serve as lessons for our own assessments of the future.

This monograph is in six parts, which deal with (1) the historical context that led to the formation of the Wicht Committee and shaped its terms of reference; (2) the history of scientific endeavour as it unfolded between 1945 and 2015; (3) a review of the research that led to the development of understanding today, with respect to individual fields of interest; (4) the development of a network of protected areas to underpin conservation in the CFR; (5) the evolution of management practices; and (6) conclusions.

Part 1 starts with a description of the role of the RSSAf as an organisation that was responsive to the pressing issues of the day where scientific input was required. It provides biographical accounts of the five members of the Wicht Committee, and details of the production of their report. It also reviews the competing scientific paradigms of the time under which the Wicht Committee had to operate.

Part 2 provides a history of scientific endeavour, starting with a comprehensive overview of the research programmes run by the then Department of Forestry, emphasising the core role of the Jonkershoek Forestry Research Centre. The science of fynbos ecology, with its genesis in Alexander von Humboldt's ideas about the relationship between forests, mountains and water resources, was conveyed to South Africa by Ludwig von Pappe and John Croumbie Brown (Grove, 1987). This science evolved in concert with the catchment hydrology programme that was initiated at Jonkershoek in 1935, which flourished from 1965 onwards. We review the development of this field as it was shaped and stimulated by the Fynbos Biome Project that began in the late 1970s, an initiative that assembled the work of diverse disciplines from the various research organisations in South Africa into a coherent agenda of work that continued for a decade, bolstered by and fostering international exchange. The programme strengthened and broadened the linkages between science, policy and ecosystem management, now termed 'the science–policy interface'. These linkages were maintained later through the Fynbos Forum.

Part 3 provides detailed accounts of the development of understanding relating to fire ecology, the ecology and impacts of invasive alien plants, and the sustainable harvesting of plant resources (issues that were originally raised by the Wicht Committee). It also addresses recent research into the relatively new issue of climate change, as well as trends in land use. On the ecology of fire, we find that the origin of the ecological view of fire in fynbos originates, formally, in a report on the status and management of the Cederberg, which John Henkel submitted in 1907, after a rigorous investigation in the field. During that investigation, Henkel found evidence that fire was not as harmful as it was purported to be, and it is that experience which underpinned his memorandum to the RSSAf, leading to the Wicht Committee's report nearly four decades later. We also review the development of the new field of invasion science, consequent on the work on the SCOPE programme on the Ecology of Biological Invasions and its reports in the 1980s (Drake *et al.*, 1989; Macdonald *et al.*, 1986). In addition, Part 3 reviews the rise in the significance of projected changes to global climate, as well as concerns about land conversion.

Part 4 deals with protection and conservation, and has a focus on the development of a protected area network that followed the proposals of the Wicht Committee for the establishment of five "National Nature Reserves" in the Cederberg, Hottentots-Holland, Langeberg, Outeniqua and Swartberg ranges. It provides an account of the development of the science of conservation planning, which was used to inform the spatial location of protected areas. This scientific initiative built on opportunities that included the growing recognition of the importance of "biodiversity", and South Africa's transition to a democratic government that led to a host of opportunities for conservation. At the time, the work elevated Cape conservation scientists to the leading edge of systematic conservation planning globally. Data are also presented on the current extent of protected areas, their recognition as World Heritage Sites, and their ongoing expansion through the implementation of stewardship programmes. Finally, the process that led to the comprehensive assessment of the conservation status of all of the CFR's 9383 plant species is described.

Part 5 focuses on the evolution of the management of the four most important processes that impact the ecosystems of the CFR, namely fire, invasive alien plants, the harvesting of plant resources and climate change. Part 5 is closely linked to Part 3 on research and the development of understanding, and links policy changes to shifts in understanding, for example with relation to burning prescriptions that changed in response to new information on the effects of fire. Not all changes to management came about as a result of changes in scientific understanding, and several are directly attributable to changing political circumstances. Thus we describe how public works programmes were initiated to simultaneously address the issues of fire and alien plant management, and to create employment opportunities for the rural poor.

Part 6 returns to the problems that society will face in the 21st century. Despite significant advances in understanding, we arguably face greater uncertainty than at the time of the Wicht Committee in 1945. The rate of social, technological and environmental change has accelerated, and will continue to do so for the foreseeable future. Adapting to this, and ensuring the most favourable environmental outcomes, will demand flexible management in an increasingly bureaucratic and rule-bound environment. Some of the insights in the Wicht Committee's report are still valid today. We conclude by assessing the present-day institutional and organisational landscape within which invasive alien plants and fire are managed, and return to the question of conservation triage originally mooted by the Wicht Committee. This final part therefore addresses the major challenges that will face the next generation of conservation scientists and practitioners as they strive to conserve the unique ecosystems of the CFR.

PART 1: HISTORICAL CONTEXT TO THE WICHT COMMITTEE REPORT

The local promotion of science by the Royal Society of South Africa

The appellation "Royal Society" declares gravitas, excellence and expertise. The nature of the relationship between the Royal Society of South Africa (RSSAf), which received its Charter in 1908, and the Royal Society of London, founded in 1660, is a question frequently asked. Despite having a similar name, however, RSSAf has no formal connection to its more famous namesake. Nevertheless, it is heir to many of its rich traditions and the two societies have many common features. For example, both are entirely independent of government, both are multidisciplinary, and both have very similar organisational and administrative structures. Fellows are elected solely on the basis of scholarly excellence and on their contribution to science.

There is a network of Royal Societies in former British colonies. Although each is firmly rooted in the time and locality of its founding, they share certain characteristics. Principal of these is the link between scientific knowledge and national development. Another is their connection to the rise of the colonial middle class, providing a voice for civil society and encouraging local self-confidence. Notwithstanding this pride in the local, the colonial communities of scientists in Canada, the Australian colonies, New Zealand and South Africa gained status and affirmation by obtaining Royal Charters signifying their equality to similar prestigious institutions in imperial Britain of far longer standing.

The origins of the RSSAf can be traced to the emergence of an intelligentsia in Cape Town in the 1820s. John Fairbairn, a member of the dynamic Literary and Philosophical Society in Newcastle who had immigrated to the Cape Colony, initiated the first intellectual society in Cape Town in 1824, naming it the South African Literary Society. There was, of course, no country called South Africa until 1910, but in the Cape Colony at that time many organisations referred to themselves as "South African". Discovering that Cape Town, with its prevailing social and material culture inherited from the Dutch East India Company and the Batavian Republic, lacked a school, newspaper, bookshop or museum when finally ceded to Britain in 1814, the South African Literary Society took on the task of acquiring and disseminating verifiable knowledge. It supported specialist societies that later came into being, promoted exploration into the interior, and encouraged the foundation of a botanical garden, a museum and a library in Cape Town (Dubow, 2006; Carruthers, 2008).

In time, Fairbairn's original Society transformed into the South African Philosophical Society (1877) and in 1908, shortly before Union, this became the more geographically representative RSSAf with Fellows and Members in the other colonies (after 1910, provinces) (Carruthers, 2008). The Wicht Committee's report in 1945 should be considered as a part of the Royal Society's long public and scientific engagement with issues of importance to the Cape and its high standing in South African scientific endeavour.

It is sometimes assumed that science exists independently from, and operates neutrally in, the surrounding socio-political and economic matrix. Quite the opposite is true. Scientific endeavour relates to the concerns of society at a particular place and time, seeking to remedy or elucidate some of them. In addition, "science" – a problematical English word – is not static and perceptions and practices of science change over time. In *The Structure of Scientific Revolutions* physicist-philosopher Thomas Kuhn (1970) was adamant that any science had to be evaluated within its own time and context. Others have warned against "the use of hindsight as an explanatory tool" (Jardine *et al.*, 1996). It is thus useful to position the Wicht Committee's report in the context of the 1940s in South Africa and the concerns, possibilities and constraints of the period in which it was written as well as to explain the backgrounds, education and careers of the men involved.

Historian of science George Basalla (1967) suggested a three-stage evolution in colonial science that seems relevant for South Africa. In the first phase, visitors from Europe collected specimens taking them back to the metropole from other parts of the globe as part of an imperial process of exploration that involved collection and classification. This was followed by a period of "colonial science" in which locally knowledgeable people began to participate, but in subservient roles. Eventually, according to Basalla, the colony "slowly develops a scientific tradition of its own". In some respects, the Wicht Committee Report can be interpreted within this model. The 1945 Committee comprised expert South African biologists deeply concerned about and committed to studying the flora of the south-western Cape and who worked within a tradition that had, by then, begun to mature separately from Britain, while yet retaining links with it.

Scientific endeavour takes different forms in different regions and countries. Many years ago an editorial in the *Journal of the History of Biology* noted that "Biology, in particular, must be studied in terms of its relationship … with the intellectual currents of its day. It may be examined as well for its interaction with the institutions of the society which spawns it" (Mendelsohn, 1968). In order to achieve this, the history of biology must be locally grounded (Jardine *et al.*, 1996). In 1905, in *Science in South Africa: A handbook and review*, one of the editors, marine biologist John D.F. Gilchrist, noted that "Few countries owe more to science than South Africa … We can point to but an honoured few who in the past have done good original scientific research. But with the recent importation of men of trained scientific capacity, as professors in our colleges, or government experts, and now with a few sons of the soil who have been trained by them, there is evidence of a marked increase in true scientific work, and a hopeful prospect of more" (Flint & Gilchrist, 1905). Similar sentiments came from the Transvaal. In 1908, conveying their disappointment to Colonial Secretary Jan Smuts at the abolition of the post of Professor of Zoology and Botany at the Transvaal Technical Institute, the Johannesburg Field Naturalists' Club declared that "South Africans need to be educated, so that it will not be necessary to import government entomologists and officials … surely persons born and bred in this country … would stand a better chance of successfully dealing with the problems in this country than outsiders whose education and training has been on an alien fauna and flora?" (quoted in Carruthers, 2007).

The advancement of South African scientific endeavour is central to the mission of the RSSAf, and in this regard, the Society's initiation of, and contribution to, interdisciplinary publications, conferences, symposia, colloquia and workshops has influenced the understanding of the natural and intellectual environments of our region. Because of its history, it is a unique scientific institutional structure with two-tier participation, comprising Fellows elected by their peers for outstanding scholarship but also Members who may be students or any interested member of the public. It focuses on many branches of knowledge but, unlike the Akademie vir Wetenskap en Kuns, not the arts or languages. It is also distinct from the older South African Association for the Advancement of Science that was arranged into disciplinary Sections, and even from the current Academy of Science of South Africa by being entirely independent of government. It is thus an extremely flexible body and its multidisciplinary journal, *Transactions of the Royal Society of South Africa*, the successor to the *Transactions of the Philosophical Society of South Africa* (1877–1908), is the oldest scientific journal in the region. From the outset, the *Transactions* has promoted work in special issues and expert reports that unite disciplines on specific topics; the Wicht Committee's report provides a good example.

Finally, while scientists themselves have recorded the chronology of their disciplines and their professional organisations, historians have been slower in their task of explaining and interpreting the role of science in South African politics and society, but this is changing (Box 1).

Box 1. The recent growth of historical perspectives on the role of science in policy and society.

Despite a slow start, the historiography that unpacks aspects of the South African environmental past relating to botany is growing, and there are now several well-researched texts that cover the development of environmental management in the CFR. These studies have covered a variety of topics, and some are listed below. Van Sittert and Pooley have written about the emergence of cultural sensitivity among middle class white Capetonians – the Mountain Club of South Africa in particular – to the Cape flora and scenery in the late 19th and early 20th centuries (van Sittert, 2002, 2003; Pooley, 2010).

The sourcing and introduction of alien trees from Australia, and the subsequent development of forestry practices based on these trees has been covered by Bennett (2011, 2013, 2014), Bennett & Kruger (2013) and Kruger & Bennett (2013).

Showers (2010) and especially Pooley (2014) have contributed important historical dimensions to issues around forestry and fire in changing perceptions of the environmental mechanisms of this vegetation type and its management, as well as to plantation (alien pine-based) forests.

Carruthers (2011) has explored some of the inter-provincial rivalries around botanical politics, and Carruthers and Robin (2010) and Robin and Carruthers (2012) have published on an aspect of the history of taxonomy and nationalism.

Anker (2001) has explored elements of the imperial botanical connection and ideas around ecology, while Beinart (2003) has considered conservationism and veld management among rural white South Africans.

Dubow (2006) has written on South African sciences more broadly, extending his analysis to the physical and applied as well as to the natural sciences.

Members of the Wicht Committee and their report

At its meeting on 1 March 1943 the Council of the RSSAf, under President Alexander Brown, Professor of Applied Mathematics at the University of Cape Town, discussed what was referred to in the minutes as "A letter from Dr Henkel on grass-burning". The Council agreed to obtain the opinion of Professor R.S. Adamson to establish whether the Society should take any action on the document. Entitled "Preservation of Mountain Vegetation of the South-West Districts of the Cape Province", John S. Henkel wrote in the aftermath of serious fires in the Cape mountains that year, highlighting the question of whether the "best methods are being followed in the protection and preservation of mountain vegetation". Advocating a differentiated management regime for the various southern African floras, Henkel recounted his observations over many years as a trained forester in parts of the Cape and in the Natal Drakensberg. His document referred to issues that were worrying foresters, botanists and conservationists of his time – and that remain of concern today – soil erosion, water extraction, alien tree plantations and inappropriate human use of the vegetation. In his conclusion, Henkel made five recommendations. First, that an organisation be established and drawn from persons interested in the protection of indigenous fauna and flora with assistance from "geologists, meteorologists, botanists, ecologists, foresters and agronomists". Second, that maps be compiled to show landscape detail of the country's mountains and valleys; third, that plant covering be mapped on an ecological basis to display zonation; fourth, that fire data be carefully maintained and regeneration be monitored; and fifth, that experimental burning be carried out and the results be used to inform a national policy.

With the authority of age and experience, Henkel was well qualified to write such a document. The eldest son of Carl C.H. Henkel, a German immigrant to the Eastern Cape who became Chief Forest Conservation and Plantation Officer in the Transkei, John S. Henkel (1871–1962) was born in Peddie and worked as an Assistant and then District Forest Officer in Bathurst, King Williams Town, and Stutterheim. After serving in the South African War (1899–1902) he was selected to study forestry at the Royal Indian Engineering College at Cooper's Hill near London. Duly trained, on his return to South Africa he served as a forester in the Eastern Conservancy (Eastern Cape), then the Western Conservancy (Cape Town) and he taught at the short-lived South African School of Forestry in Tokai, Cape Town (Bennett, 2013). He was then sent to the Midlands Conservancy (Knysna) and in 1912 was promoted to the position of Conservator of Forests for the Cape Province. In 1915 he was transferred to Pietermaritzburg as Conservator of Forests for Natal. He left South Africa to found the Forest Service of Southern Rhodesia in 1920 and remained there until his retirement in 1931. He was elected a Fellow of the RSSAf in 1930 and he participated in many other scientific societies and advisory boards. An extremely active writer and researcher with, by 1943, a long career behind him and many years of familiarity with the vegetation of the subcontinent, Henkel was ideally placed to raise the topic of preserving the mountain flora of southern Africa with the Society.

Henkel's paper was read by geologist Dr A.L. (Alex) du Toit at the Society's "Ordinary" (public) meeting in May 1943. It was there agreed to circulate 30 copies of Henkel's report to obtain information so that further discussion could follow. Some 17 detailed replies were received that contributed information and represented, in the Council's view, "a fair sample of enlightened opinion". Henkel himself submitted additional material. The matter came up for discussion on 19 August 1943, and the Council considered that because of its "considerable importance", and the fact that various respondents submitted "views which dispute Henkel's main theme", the issue should be pursued. Council member Dr C.L. Wicht – who had been elected a Fellow of the Society the previous year – proposed that a committee be appointed, while Dr S.H. Skaife thought that a workshop would be preferable. It was finally decided that Wicht would prepare a digest and agenda for a subsequent meeting on the topic. This Wicht did, and after apparently detailed discussion, he was roundly thanked on 16 September 1943 for his summary of Henkel's document and its incorporation of additional material. Wicht then proposed that further opinions be sought and a single report compiled under appropriate headings that would be edited and arranged by a committee. Wicht was quickly appointed convenor of the "Veld-burning sub-committee", which also comprised John S. Henkel, Sydney H. Skaife, Robert S. Adamson and Robert H. Compton (Figure 1).

That the Society was able to give its attention to such a matter during some of the darkest days of World War II is worthy of remark. That very month, Italy capitulated to

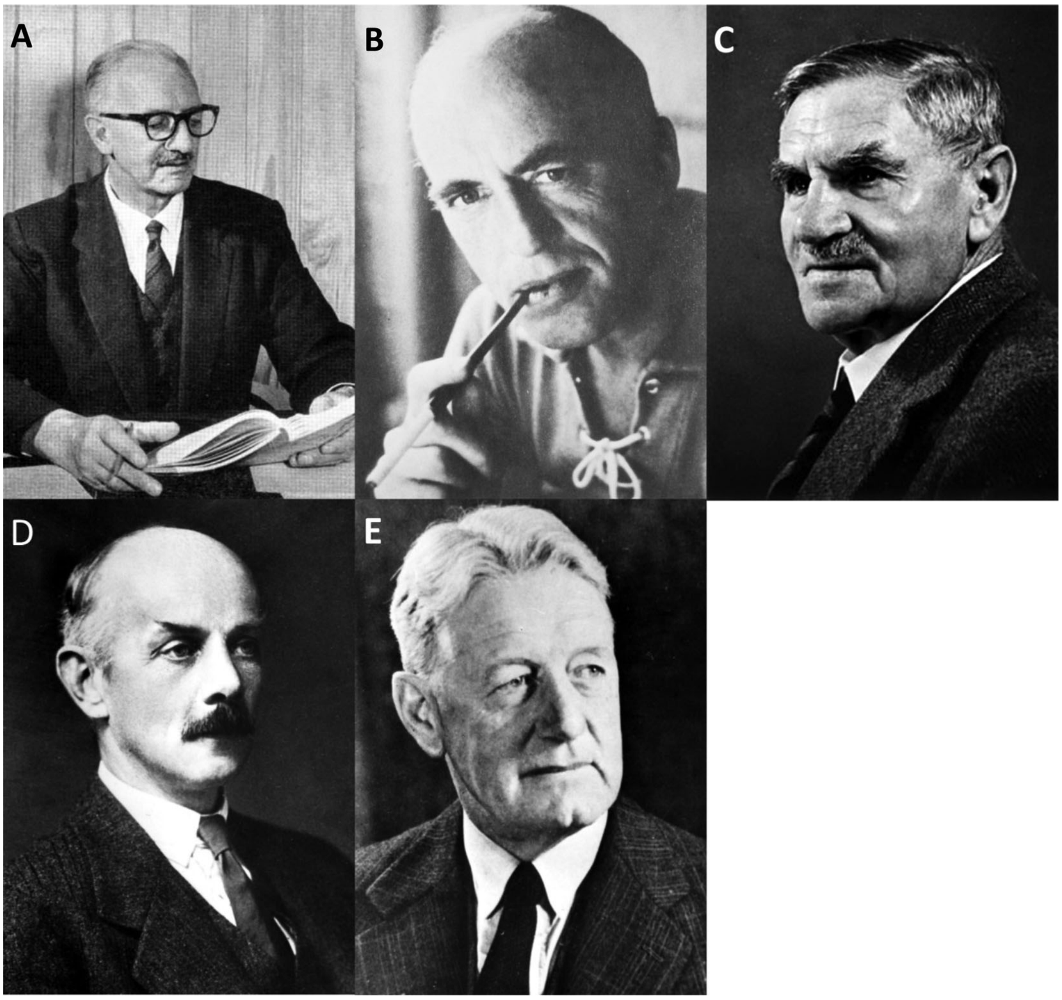


Figure 1. The members of the Wicht Committee. A) Christiaan L. Wicht; B) Sydney H. Skaife; C) John S. Henkel; D) Robert S. Adamson; and E) Robert H. Compton. Photographs courtesy of the Mary Gunn Library, SANBI and Mrs Skaife.

Germany, the war in the Pacific was at its height, and Nazi atrocities against Jews were becoming more widely known. As far as South Africa's internal politics were concerned, a general election had been held just two months earlier, on 17 July 1943. The previous election had been held in 1938. In 1939, Jan Smuts had replaced J.B.M. Hertzog as Prime Minister who left the United Party over the question of South Africa's participation in the war. Smuts, well known for his interest, and indeed expertise, in matters botanical, won an absolute majority in the 1943 election, and it is possible that this might have encouraged the Royal Society's Council. Certainly, as will be recounted below, there were other botanical conservation initiatives during the war that Smuts encouraged at this time. Another factor is that the issue of nature conservation in the post-war world was gaining international traction and in this regard, the Wicht Committee Report took its lead from Britain. After his death in 1923, Rothschild's 1912 Society for the Promotion of Nature Reserves had been taken over by G.F. Herbert Smith. Smith, together with conservation leaders such as Max Nicholson and Julian Huxley, and British Ecological Society (BES) experts Arthur Tansley and Charles Elton, formed a Nature Reserves Committee. One of its publications, *Memorandum No. 3 of the Conference on Nature Preservation in Post War Reconstruction*, is listed in the References of the Wicht Committee Report and clearly had a considerable influence on it. As Wilson (2014) recounts, the Nature Reserves Investigation Committee (NRIC) in Britain that included Tansley, Huxley and others, became involved in post-war land use planning as the devastation of the war on British landscapes, that had necessitated replacing refuges for fauna and flora with airfields and factories, became apparent. In 1943 the NRIC presented a list of proposed nature reserve sites to government and produced a report that these should be managed to maintain their ecology. The template of the Wicht Committee Report does the same, shifting the emphasis off amateur naturalists to a more scientific approach and governance (Wilson, 2014). In discussion around the shape of the post-war world, ideas around an international union for nature protection were also being mooted. Such perspectives may well have influenced the shape and timing of the Royal Society's investigative report.

At the time of the Wicht Committee's report, Henkel was well into his 70s, three other members were in their 50s and probably not eligible for wartime service, while convenor Wicht – then aged 38 – was not eligible for the army as he was blind in one eye as a result of a childhood accident. Convenor of the Committee, Christiaan L. Wicht (1908–1978) was born in the Stellenbosch district close to Jonkershoek, the descendant of a prominent and wealthy Cape Town family of property owners (Bickford-Smith, 1995). Educated at what is now the Paul Roos Gymnasium, and as a youngster keen on exploring the landscape around his home, Wicht was nominated for sponsorship from the Department of Forestry to study silviculture after completing his schooling. Described in the *Dictionary of South African Biography* as a "silviculturalist and hydrologist", he obtained his BSc at Stellenbosch University in 1929 and took his postgraduate degree in 1931 in the Imperial Forestry Institute at the University of Oxford (the successor to the national forest school at the Cooper's Hill College of Engineering, and funded, among other sources, by a number of South African philanthropists) (*Dictionary of South African Biography* 5: 887; Burley, 2009). For financial reasons it was not possible for him to study at the Yale University Forestry School, then the most prestigious of forestry schools, and Wicht continued his studies in Germany at what had been the Royal Saxon Academy of Forestry at Tharandt, near Dresden. Wicht's dissertation for the Dr. Ing. degree, obtained in 1934, dealt with the methodology of tree thinning experiments.

On his return to South Africa in 1934, Wicht joined the Department of Agriculture and Forestry in Pretoria within the Division of Forestry. Forestry was reinstated as a separate Department in October 1945 – two months after the Wicht Committee's report was published. In the year following his return to South Africa (1935) Wicht was posted to the new forestry station at Jonkershoek – his home ground. Named the Jonkershoek Forest Influences Research Station it had been one of the recommendations to the Union Government that emanated from the 1935 Empire Forestry Conference (Union of South Africa, 1952). This was a period during which such initiatives within state departments in South Africa – particularly forestry, agriculture and the railways – had the dual purpose of supplying labour and the upliftment of "poor white" communities, a problem on which a good deal of socio-economic and political attention was devoted during the Depression. Part of Jonkershoek was already a government research site, established in 1896 with encouragement from the Western Districts Game Protection Association for the acclimatisation and propagation of imported fish species, especially trout (Hey, 1977a). It was while posted at Jonkershoek that Wicht worked on the Committee Report. He was transferred to Pretoria in 1947 as Chief of Forest Research but returned to the Cape in 1950 as Professor of Silviculture at Stellenbosch University. Retiring in 1974, he worked as a consultant on various aspects of forestry research. Wicht's reputation rests largely on his important work on the hydrological implications of catchment management (see below), rather than on his compilation of the Wicht Committee's report. A prolific author of both popular and scientific works, he was an inspirational teacher and lecturer who published widely on many aspects of forestry education in which he was involved.

Two other committee members, R.S. Adamson and R.H. Compton, were botanists rather than foresters while the fifth, S.H. Skaife, was an entomologist. Unlike Henkel and Wicht, all three had been born in England and had immigrated to South Africa to take up career positions in Cape Town. Robert S. Adamson (1885–1965) was born in Manchester and studied at the universities of Edinburgh and Oxford. He lectured at Manchester University before being appointed Professor of Botany at the University of Cape Town in 1923, from which he retired in 1950. Adamson soon became an expert on the Cape flora and he contributed many important articles and books on this topic. He was particularly interested in ecological associations and vegetation theory and he was a correspondent and close colleague of Arthur Tansley, with whom he co-authored a paper in the *Journal of Ecology* on "Studies of the vegetation of the English Chalk" (Tansley & Adamson, 1925). An elected Fellow of the RSSAf, Adamson was its President in 1948. Fittingly, as it complements and expands upon the section he authored for the Wicht Committee's report, Adamson's Presidential Address was entitled "Some Geographical Aspects of the Cape Flora" that followed upon his *The Vegetation of South Africa* for the British Empire Vegetation Committee, 1938 (Adamson, 1938, 1948) and his other seminal publications on the plant communities of the south western Cape (Adamson, 1926; Adamson, 1927; Adamson, 1931a, 1931b, 1935). Throughout his life Adamson retained his association with botanical and nature conservation developments in Britain and his input into the Wicht Committee's report is visible in the references to those developments in Britain that appear in that document.

Like Adamson, Robert H. Compton (1886–1979) was an academic botanist. Born in Tewkesbury, he was an outstanding student at Cambridge and remained as a Demonstrator in Botany after completing his MA. He undertook an extensive collecting expedition to New Caledonia before immigrating to South Africa in 1919 to take up the position of Director of the National Botanic Gardens at Kirstenbosch which was linked to the Harold Pearson Chair of Botany at the University of Cape Town. The originator of the *Journal of South African Botany* in 1935, he published a good deal of his research – mostly on taxonomy – in this journal. He was a Fellow of the RSSAf and, like many scientists with Commonwealth connections and previous ties to the Smuts government, he left South Africa after his retirement in 1953.

Sidney H. (Stacey) Skaife can perhaps best be described as a general biologist and specialist entomologist. In the rather disparaging words of zoology Professor A.C. Brown, "Whether Stacey Skaife … was a great scientist is open to debate and opinions differed during his life time; he was, however, a naturalist of considerable repute and a great educator, and surely these attributes justified the award of his Royal Society Fellowship in 1938" (Carruthers, 2014). Like Adamson and Compton, Skaife (1889–1976) had been born in England. His university degree (London) was in the arts, but his passion lay in biology and in 1913 he immigrated to South Africa to become biology teacher at Rondebosch High School. He left teaching to become an agricultural entomologist and obtained his MSc at Natal University College in 1920, and his PhD from the University of Cape Town in 1922 for his work on bean weevils. He returned to the education sector, and between 1921 and 1945 was Inspector of Science in the Cape Department of Education. He was an effective populariser of the biological sciences, writing a number of books on natural history, speaking on the radio and writing for the press. An early conservationist, he was involved in the foundation of the Wild Life Protection Society in 1929 and, as its chairman, he assisted in the proclamation of a number of wildlife reserves and national parks in the 1930s. Active in a number of other societies, committees and commissions, he became President of the RSSAf in 1950.

The five members of the committee began their work, and by the following year – March 1944 – Wicht could report to

Council that a preliminary report had been completed. By March 1945, the report had been finalised and it, and the original notes upon which it was based, had been handed in for filing in the Society's records. At this meeting, Skaife suggested that the title page read "By Dr C.L. Wicht" to draw attention to the work that Wicht had done as convenor and compiler. It was also at this meeting that Council agreed that the final report would be read at the "Anniversary" (public) Meeting of the Society and that eminent persons, such as the Minister of Agriculture, the Director of Forestry, and the heads of the National Veld Trust, Kirstenbosch, city foresters and academic botanists should all be invited. It is regrettable that the attendance list of this meeting (21 March 1945) no longer survives, but the record includes the comment that "The questions were discussed at considerable length by the audience and the author was congratulated on the conciseness, adequacy and clarity of his report."

Thereafter arrangements were made for its printing – 1000 copies at a total cost of just over £200, to conform to the format of the *Transactions*. In August 1945, the report was on sale, at discounted prices to libraries, universities and booksellers. A couple of months later, Wicht requested that copies be given to "prominent persons in appropriate Government departments" together with a letter asking them to "make recommendations to the proper quarters in these respects", and he agreed to furnish the editor with an appropriate list of recipients. This list no longer survives and it is therefore impossible to determine the audience to whom the report was sent and one can only speculate on the influence it may have had.

The science of ecology in the Cape Floristic Region

The Wicht Committee's report deals with the vegetation of the south-western Cape as a whole. From the very earliest European explorations, the Cape flora entranced those interested in botany. The first *Flora Capensis* was a 19-page publication that appeared in 1759, written by Linnaeus and based on the work of his student Carl Wannman. In 1767 Petrus Bergius published the more expansive *Descriptiones Plantarum ex Capite Bonae Spei*. However, while the beauty of individual species was appreciated from the outset, interest in the plant life more generally was slow to develop. In the Wicht Committee Report, for example, Adamson made the distinction between "vegetation" and "flora" (Wicht, 1945). When the Cape vegetation was recognised as a "Floral Kingdom", a term devised by Ronald Good (1896–1992), eco-geographer and Professor of Botany at the University of Hull, to define a discrete geographical area in which a relatively uniform composition of plant species could be determined, and when it was regularly promoted under this name, its international reputation and significance was assured (Lighton, 1960).

In order to evaluate its importance, the Wicht Committee's report should be situated within the context of two South African sciences: the theoretical science of botany and the applied science of forestry, at a time when the two were combined into a single state department. The composition of the Royal Society's committee reflected this inter-disciplinary combination. South Africa was a country of European settlement that took little or no cognisance of the manner in which indigenous people had used the landscape before the colonial era. Like many other settler colonies, in domestic and public spaces in Cape Town, the main imperative was to replicate the flora of Europe and to create an aesthetic familiar to, and beloved by, settlers as "home". In addition, economic development necessitated the removal of the indigenous ground covering to grow agricultural crops and to provide appropriate pastures for livestock. Exploiting local timber sources and planting alien trees for ground stabilisation or timber production was also carried out energetically (Shaughnessy 1986).

It took almost 300 years before the vegetation of the Cape region was locally valued for its beauty, patriotic and national reference, sense of place, scientific interest and ecological worth, although it was, of course, of interest to foresters and botanists. And with those emerging and strengthening values, the need for its "preservation" became a matter of urgency. An almost parallel thrust concerning changing values of savanna and grassland came from the Transvaal, but it was to follow a different trajectory, led by a different group of botanists (not foresters) who built on the strength of the Botanical Survey in that region and the publication of its *Memoirs* (Carruthers, 2011). Indeed, it may be worth investigating what decided Henkel to take his idea of a survey of Cape mountain flora to the Royal Society rather than referring it to the Botanical Survey Advisory Committee which would have been the more logical forum for such a study. In addition, doing so would have assured it of government support (*Memoirs* were formal reports), a wide readership and potential influence. Indeed, Adamson had even served on that Advisory Committee. A further consideration relates to the role of "expertise" in environmental understanding. Certainly, as has been explained, the Royal Society committee consisted of well-educated foresters and botanists. They were, however, urban men who focused on mountain fynbos and were not, perhaps, familiar with the views of local people, close to the land, who lived in the Cape interior platteland – and in the lowland fynbos – nor with the initiatives of indigenous flower shows and municipal nature reserves. The emphasis in the Wicht Committee's report on initiating nature reserves as recreational outlets for city-dwellers makes this clear.

The establishment of the Union of South Africa in 1910 together with the conversion of some of the university colleges into full examining and teaching bodies after 1916 was important to the professionalisation of botany. After the collapse of the Forestry School at Tokai in 1911, South African foresters gained postgraduate professional qualifications overseas (after a BSc degree) or were trained within the Department of Forestry (Bennett, 2013). The country's unification made professional careers possible in an enlarged and influential government service as well as in higher education. Soon to head the Division of Botany in the Department of Agriculture was the Welsh mycologist from the Transvaal, Illtyd Buller Pole Evans, who – with inter-colonial rivalries still fresh – had no hesitation in crossing swords with his colleagues in the Cape. A Cambridge graduate and enthusiastic about research, Pole Evans travelled throughout sub-Saharan Africa, prioritising the ecological aspects of botany, initiating vegetation surveys, developing new fodder grasses, describing plant species and involving himself in the broader issues of soil and vegetation conservation. The botanists in the "north" seem to have regarded themselves as more scientific than those in the Cape at this time. In 1919 John F.V. Phillips wrote to Pole Evans that it was from people based in the northern parts of South Africa that real "scientific work" emanated, whereas the Cape was best known for botany "of a purely systematic nature" (quoted in Carruthers, 2011). As the Wicht

Committee's report indicates, this was changing by the mid-1940s.

In 1918 as head of the Division of Botany, Pole Evans established the Botanical Survey and he initiated the *Memoirs of the Botanical Survey of South Africa* that were presented regularly to the Minister as formal government reports. The aim of the *Memoirs* series was to enable specialists to understand South African vegetation and its ecological processes and contribute to what we would now refer to as resilience and sustainable development. From the outset the series was strongly ecological and biogeographical.

The lack of close cooperation between botanists in the Cape and those in the Transvaal was the consequence of South African political legacies from the colonial era that played out in the Department of Agriculture, the Botanical Survey and the National Garden in Kirstenbosch, in which foresters were also involved. But it was also fuelled by philosophical rifts in the international botanical community. These are evident in the Wicht Committee's report. From the 1920s onwards many South African plant specialists gained academic stature abroad and men such as Pearson, Compton, Pole Evans, Phillips, J.W. Bews and Joseph Burtt-Davy became internationally renowned. Intellectually adventurous, they formed part of the vanguard of the new scientific paradigm that was later to become fully-fledged ecology (Worthington, 1983; Kingsland, 1985; Hagen, 1992; Anker, 2001; Radkau, 2014).

Ecology was *the* science of the 20th century (Worthington, 1983; Radkau, 2014). The importance of plant ecology was first predicated on its possible benefits for increasing the production capacity of healthy grassland. There were, however, many interpretations of the meaning of the word. In Phillips's view, "I do not restrain ecology to a study of vegetation, I mean the full ecology … that of man, other animals and vegetation … " (quoted in Anker, 2001). "Oecology" (as it was spelt at the time) was more than a biological specialisation, it was the "philosophy of living nature" (Bowler, 1992). Victor Shelford, one of the leading North American early ecologists called it a set of ideas in "search of an organising principle" (quoted in Dunlap, 1988). Highly theoretical, it led to impassioned debate revolving around the "balance of nature", species stability, climax and equilibrium (Egerton & McIntosh, 1977).

McIntosh has argued that at first denoting a fuzzy obscure field of study, within a few decades ecology was the name of a distinct and respectable science, to which another word with a very similar meaning – bionomics – gave way (McIntosh, 1985). Ecology had dual origins in Britain and in the USA through vegetation studies. First introduced in the context of the "superorganism" of a plant community and succession around 1905 by Frederick E. Clements (a founder of ecology in the USA), it was strongly advocated in the 1930s by South African botanist Phillips, a regular contributor to the American journal *Ecology* (Phillips, 1934, 1935a, b). Tansley, editor of the *Journal of Ecology*, published by the BES which was founded in 1913 from the British Vegetation Committee of 1904, offered the idea of the "ecosystem" in 1935 (Tansley, 1935; Bramwell, 1989; Marshall, 1992; Golley, 1996; Bocking, 1997). He did so in an article in *Ecology* entitled "The use and abuse of vegetational concepts and terms" that took strong issue with the views of Clements and Phillips that succession was organic and developmental towards a mono-climax. In Tansley's view, ecology was a system of energy in itself, and not just one of many aspects of separated disciplines like zoology or botany that had a geographical and community dimension (McIntosh, 1985). It was thus a tool to integrate animal and plant ecology and could give direction to nature protection. At this time, however, in South Africa as well as elsewhere, botanists, zoologists, ethologists and many others working in the broader environmental field began to refer to themselves as "ecologists" although they might more accurately have been described as bio-geographers, studying populations and communities in particular habitats. Even in 1982 there was considerable truth in the comment that many "ecologists" ignored the ecosystem (Anonymous, 1982).

Despite Adamson's close relationship with Tansley, the word ecosystem does not occur in the Wicht Committee's report and there is no indication of any idea or vocabulary akin to flows of energy or trophic levels. As a product of its time, the report is highly suggestive of an ecological perspective based on climax and stasis that requires conservation, even restoration – the Clementsian view. "Deterioration", as though referring to a fall from a perfect state, is a word that occurs often in the text, perhaps not surprisingly as memories of the Depression and also the drought years of the 1920s and 1930s were still fresh. As far as Wicht himself was concerned, however, Pooley has noted that in 1958 he attempted to synthesise the theories of Clements, Tansley and even Jan Smuts (the author of Holism), using the word "bionomic" and rediscovering and employing the 1870s German term "biocoenose" rather than "biome" (Pooley, 2014), presumably on the basis of his training in Germany. Interestingly, also, although Braun-Blanquet's ideas had been published in English in 1932, scant notice of his work was taken in South Africa until the 1960s (Werger, 1978). In addition, the Wicht Committee's report predated any sophisticated post-war South African vegetation studies and its understanding seems to have been based on Adamson (1938) and perhaps also on Pole Evans (1936).

Against this background, we now examine in some detail the development of understanding that followed the publication of the Wicht Committee's report. This understanding was based on research, initially at the Jonkershoek Forest Influences Research Station near Stellenbosch, and satellite stations elsewhere, but later involving many other institutions and research sites.

PART 2: HISTORY OF SCIENTIFIC ENDEAVOUR IN THE CAPE FLORISTIC REGION

The importance of the Jonkershoek Research Site

The late 1800s saw the emergence of a commitment by State Forestry in the Cape of Good Hope to the management of mountain catchments as well as indigenous forests and plantation forests. The integrated forestry paradigm, detailed below, was a coherent policy for the achievement of the joint objectives of timber production, water resource conservation [to assure the "maximum beneficial yield of water" – as stated by J.D.M. Keet during the 1935 British Empire Forestry Conference (Union of South Africa, 1936), and emphasised repeatedly by foresters and others], and biodiversity management (at the time, "nature conservation" and "flora protection"). This implied also that the scope of thinking on fynbos necessarily extended beyond botany and elementary ecology to include ecosystems and natural resources management. This was the frame of thinking that influenced Henkel and Wicht. Following as it did on a period of strenuous propaganda against fire in the fynbos (Pooley, 2014), much of the authority of the Wicht Committee's report drew upon the background of Wicht and Henkel in fire, both arising from their experience at different times in dealing with the policy and practice of catchment management in the Forest Department.

The Wicht Committee's report was completed eight years into a research programme that ultimately endured for 65 years, and which now continues in part under the care of The South African Environmental Observation Network (SAEON). This programme contributed incrementally to an expanding body of knowledge on fynbos ecosystems – as well as on grassland and forest in South Africa, and globally, on catchment hydrology – integrating later into research of wider institutional frame and scope. It is difficult to overcome the challenges of sustaining research on ecosystems over time spans long enough to account for the effects of environmental and socio-political change on the structure and function of the ecosystems. In South Africa, as elsewhere, many attempts have foundered within a decade of their inception.

In this regard, it is therefore useful to review the history of the programme that began at Jonkershoek in 1935, under the direction of what later became the South African Forestry Research Institute (SAFRI). We use this history to argue that sustaining such a programme over several decades depended on the force of certain politically weighty paradigms that prevailed at the time, and endured for decades, as well as the force of personality, individually and later, in teams. Understanding the exceptional success of the enterprise requires a particular attention to the influences of context, time, and place. We therefore provide here an account of the history of that programme written with today's ecologists in mind.

The account begins with Jonkershoek as science locale, and the role of Chris Wicht, but takes account of the progressive widening of the scope of research through the growing engagement with a broader institutional frame. In providing a history of this long-term environmental research programme, we touch on its character in terms of institutional features, on the patrimonial path dependence of ideas, and on the role of personality. Much of the material for this account comes from and van Wilgen (2009), Pooley (2012, 2014) and Bennett & Kruger (2015).

In an important way, Jonkershoek provided the focus that enabled the integrated approach to fynbos conservation that emerged in the Wicht Committee's report. Early work by the Colonial Botanists Carl Pappe (from 1858) and John Croumbie Brown (from 1863 to 1866) had publicised their concerns about the state of Cape ecosystems and floras, the condition of mountain catchments and water resources, and related aspects of their protection and management (e.g. see the lengthy historical essay in Wicht & Kruger, 1973; also Beinart, 2003; Grove, 1997). Knowledge of plant and animal taxonomy was well advanced; Rudolf Marloth had published his intriguing observations on mutualisms, drought effects and recondite growth forms in the fynbos biota; and ideas in ecology had been transferred from their European sources by such figures as John Bews, John Phillips and Robert Adamson (see, for example, Pooley, 2010, 2014). However, until the establishment of the Jonkershoek programme, there had been little coherent work on the ecology and management of fynbos ecosystems, no more than Augusta Duthie's 1929 PhD thesis on the vegetation of the Cape Flats (Duthie, 1929; Jordaan, 1967), Robert Adamson's work on Table Mountain (Adamson, 1927; Adamson, 1931b), and Margaret Levyns' pioneering research in fire ecology (Levyns, 1929).

Founding ideas in the Wicht Committee's Report

John Henkel wrote his rather digressive memorandum to the Society when he was 72 years old. His scientific reputation was built on, among other things, his monograph *Types of Vegetation in Southern Rhodesia*, for which the University of South Africa awarded him an honorary doctorate. While Assistant Conservator of Forests in Cape Town, Henkel took on a formidable figure in colonial forestry, Sir David Hutchins (see Bennett & Kruger, 2015, on Hutchins), by opposing Hutchins' proposed policy for the Cederberg in a document he submitted to the Chief Conservator of Forests in Cape Town on 26 January 1908 (Cape Archives, 1908). Hutchins had proposed to afforest the Cederberg (or at least a part), using *Pinus pinaster*, to substitute for the loss of the cedar *Widdringtonia cedarbergensis*, had argued his case on the grounds of economic and financial benefits, and had convinced the Cape Select Committee on Crown Forests of the merits of the case. Henkel had completed a strenuous reconnaissance of the entire Cederberg during December 1907. In his meticulous report, Henkel severely criticised Hutchins' proposals for afforestation: "The Cedarbergen [sic] as a commercial proposition in forestry is wholly indefensible". Beyond this, his observations on the regeneration and senescence of the fynbos in the Cederberg as well as the incidence of fires of natural origin were the grounds for his argument in favour of controlled burning there.

While Wicht worked with his colleagues on the Committee, he also worked to change public policy regarding management of the "sclerophyll scrub", a policy then determined largely by the Department of Forestry as custodian of the mountain catchments. This he did not only from his study of the available scientific knowledge, and his own experiments, but also from his experiences in policy analysis and of practical management.

A major fire in the Jonkershoek mountains in December 1942 made an indelible imprint on Wicht's mind. Although tasked as Forest Research Officer with "forest influences research" there – a full-time assignment by any standard—Wicht also held the duty of District Forest Officer, which meant that he was responsible for the management of the 10 700 ha Jonkershoek State Forest. This fire, one of several in the entire surrounding mountain complex during the period from 16 December 1942 to 3 January 1943, spread into Jonkershoek on 17 December, later merging with a second, and continued until 28 December. Wicht directed fire-fighting operations throughout this period, sometimes remaining on guard through the night. In his report on the fire (Wicht, 1944), he emphasised the lessons of first-hand experience, of the difficulties of controlling fire in precipitous terrain under severe conditions of weather, and the necessity of coordination of both management plans and firefighting.

In a 1944 memorandum addressed to the Conservator of Forests of the Western Conservancy (in which he alludes to the work of the Royal Society Committee), Wicht used his experience to justify a policy of controlled burning in a coordinated fire management plan for the whole of the Hottentots-Holland mountain range, on the hypothesis that "veldburning, provided it is not too frequently repeated and grazing is excluded, will not cause the sclerophyll scrub to deteriorate, or even be modified to any marked degree" (see District Forest Officer to the Conservator of Forests, Cape Town, M.600, 22 March 1944, copy in the Jonkershoek Forestry Collection, CSIR, Stellenbosch). Wicht's memorandum was a request for policy change, from fire protection to a programme of controlled burning, to be implemented under the auspices of the Committee for Combating Fires in the Stellenbosch Division. He explicitly acknowledged that this required a revision of the then current "traditional" policy of complete protection [of vegetation against fire], and refers to a letter to the President of the Royal Society from the Director of Forestry, dated 14 July 1943, which had affirmed this "traditional" policy. We know that it was to be two decades before the policy of controlled burning in mountain catchments was to become official (Wicht & Kruger, 1973; Wilson, 1985; Jordaan, 1987; Pooley, 2012). Wicht, in his memorandum, also raises the difficulty presented by the invasion of the mountains by fire-adapted species such as the genus *Hakea*, but that "special measures" could take care of that problem.

Henkel and Wicht brought a distinction to the work of the Committee. Both were professionally trained, with a strong sense of the scientific. But more than their colleagues, both had had direct engagement with policy and practice in the conservation of the mountain ecosystems of the Cape, and of the hustle of policy debates. They provided insights that would not have been available from a purely academic coterie. Beyond this, however, their experiences illustrate aspects of the policy context that from the early 1900s shaped a science programme that continued to the end of the century, sustained by an intense interaction among colleagues and vigorous dissent about scientific ideas and policy regarding the management of mountain ecosystems in particular and natural landscapes in general. We return to this point later.

A policy context for catchment research and the scientific context for catchment policy

In 1910, the new Union Forest Department was the leading nature conservation agency in South Africa. Its statute provided for the acquisition to the forest estate of land for conservation purposes (the Cape Forest Act, and later, the 1913 Union Forest Act). Its management responsibility extended to nearly 490 000 ha of public forest estate – demarcated forests – of which just less than 160 000 ha was under forest, and the rest mainly "veld". Demarcated Crown Forests – later, State Forests – were proclaimed as protected areas in terms of the Cape, and later, the Union Forest Act No. 16 of 1913, and entrenched as such because their de-proclamation required acquiescence of a two-thirds majority in Parliament. By 1935, when Parliament formally assigned mountain catchment management to the forest department (in response to the 1923 report of the Drought Commission, and the recommendations of its predecessors), the extent of the public forest estate was nearly 1.5 million ha, and over 1.0 million was catchment, under natural vegetation.

These lands included the Cape Crown Forests, such as the Cederberg, the Swartberg and the Kouga mountains, and the Drakensberg, where the Cathkin Peak Crown Forest was demarcated in 1922. Foresters at the time saw catchment conservation as being the suppression of fire, prevention of overgrazing and control of extractive activities by limiting access to land; for example, the 1927/1928 Annual Plan of Operations for the Monk's Cowl Crown Forest in the Drakensberg focuses solely on these objects. Colleagues charged with irrigation development strongly supported this role for State Forestry. Francis Kanthack, the Director of Irrigation for the Union of South Africa from 1911 to 1920, saw foresters as the natural guardians of the headwaters of rivers and streams. In a lecture to the South African Association for the Advancement of Science in Grahamstown in 1908 he proposed that, "the [Forestry] Department should have control of the land wherever the physical conditions are such that the removal of the protection afforded by vegetation must result … in the destruction or deterioration of agricultural conditions" (Kanthack, 1908; Beinart, 2008); in this connection, see also Wicht & Kruger (1973). In 1909, C. Dimond H. Braine, another senior irrigation official, declared that forestry "is of vital importance for maintaining the permanence of streams; and the forests that create natural reservoirs on every square yard of their surface, and form the chief source of water-supply, should be preserved at all costs" (Braine, 1909). The 1923 report of the Drought Commission, and the subsequent official publicity pamphlet on drought, "*The Great Drought Problem of South Africa*", tended to support this attitude (Union of South Africa, 1923; Department of Agriculture, 1926).

An accompanying, and increasingly urgent, function of State Forestry was to pursue timber security for the country. From the start of the minerals revolution, with the discovery of diamonds in 1870, and gold in 1886, an ever-growing, economy-wide demand for timber first depleted scarce domestic resources, and then bore heavily on the country's balance of payments as the new rail network permitted voluminous, cheap imports. In response government chose in 1912 to pursue an ambitious programme of import substitution, by planting forests for sawlog production, to supplement the private sector's expanding plantations of short-rotation timber crops, and assembled a team of well-educated professional foresters to advance the programme (for details, see Bennett & Kruger 2015).

An often underlying motive for afforestation was the idea of climatic forestry: that forests ameliorated climate, perhaps increased rainfall, helped to sustain water supplies and regulated the flow of rivers. This was an idea that came with good credentials, in environmental theories formulated in the early 19th century by Alexander von Humboldt and 50 years later by George Perkins Marsh, both regarded as founders of modern environmental thought (Bennett & Kruger, 2015). The Colonial Botanist John Croumbie Brown as well as leading South African foresters, from Henry Fourcade, David Hutchins, T.R. Sim, to J.D.M. Keet, all read and espoused these ideas. Government irrigation experts, including Dimond Braine and Francis Kanthack, promoted the same thinking. Climatic forestry as an idea became an important source of conflict in the unfolding debates about afforestation in South Africa, and through this dissent, helped to define the outlines of a new science programme.

The joint assignment of managing catchments as well as indigenous forests and expanding plantations, together with growing complaints about the impact of afforestation in mountain catchments (see later) placed foresters at the centre of a puzzle. The puzzle arose from the apparent conflict in the purpose of public forestry. In seeking a more coherent policy, they finally settled on an integrated forestry policy, to harmonise plantation forest management with indigenous forestry and catchment management. These objectives were to be integrated on each part of the forest estate – each Crown

Forest, or State Forest as later called – in a manner depending on the balance of the resource endowments of the individual part. This allowed economic use of scarce expertise, the sharing of infrastructure and staffing costs, and, effectively, the subsidising of conservation management costs through the provisions for afforestation. J.D.M. Keet as well as Jan Smuts communicated this policy during the 1935 British Empire Forestry Conference: "If it were not for the plantations the nation would not have been able to afford the organisation and the funds required for the protection of these areas", as Keet put it (Union of South Africa 1936). Of the overall national forest estate, four-fifths was devoted to the protection of mountain catchments and indigenous forests, and the balance was for plantations. Locally, the fractions varied: at Jonkershoek, 670 ha of 10 700 ha was planted forest, which supported the development of local industries. In the case of the Cederberg, a few hundred ha eventually was planted of the total State Forest area of 75 000 ha as a resource (since liquidated) that supported a nearby sawmill. These areas of plantation, though small, became the sources of extensive invasion of neighbouring catchment land by the offspring of the planted species of *Pinus*, controlled during the period when the Forest Department managed the State Forests and proclaimed Mountain Catchment Areas, but now out of control.

Despite the ascendant official view on climatic forestry, the policy debate was soon overwhelmed by public protest about the claimed effects of forests on water supplies (as well as effects on the natural flora and landscapes). And scepticism about climatic forestry among some forestry officials and their colleagues in irrigation had led to their establishing one of the world's first controlled paired-catchment experiments, involving three gauged and afforested catchments at Jessievale, near Swaziland, in 1910. The purpose was, according to Chief Conservator Charles Legat, to study "what influence, if any, afforestation may have on precipitation and on waterflow." The experiment ran until 1963, but was bedeviled at the outset by instrumentation faults and observer failure, and yielded no published results (Bennett & Kruger, 2015).

As state afforestation accelerated from the 1920s onwards, public controversy about afforestation and water supplies injected energy into inquiries into specific complaints of afforestation effects on water supplies. While government pursued large-scale afforestation, it simultaneously sought to advance white farming through local irrigation schemes, relying on run-of-the-river water supplies, in the same regions as those earmarked for forestry. These uncertain ventures, with farming often facing failure before (owing to poor transport, distant markets, and lack of capital and skills among landholders) and during the Great Depression, made for very insecure irrigators. Government afforestation policy confronted government local-scale irrigation development head-on. J.D.M. Keet, then Conservator for the Transvaal and the Free State, assisted by local officials, conducted several on-site investigations, attempting to verify the complaints of downstream irrigators. Often, the complaint was groundless, for example, because too little, or none, of the catchment had been afforested to have had an effect. Mostly, the claims were confounded by secular rainfall trends, the effects of any land-use change hard to discern against the background of the intense drought of the late 1920s and early 1930s.

When in 1935 the issue emerged in Parliamentary debates, Colonel Deneys Reitz, then Minister of Agriculture and Forestry, postponed the issue, choosing to have it tabled at the forum offered by the Fourth British Empire Forestry Conference, due in South Africa in September that year. Anticipating this debate, South African protagonists – Colonel Deneys Reitz (elected President of the Conference), General Jan Smuts, Simon Bekker (Administrator of the Transvaal), Professor John Phillips, and J.D.M. Keet (by then head of government forestry and elected vice-chair of the Conference) – all took pains to prepare their arguments in advance of the discussions. Keet circulated a memorandum containing detailed excerpts from various sources highlighting important dissenting views on the matter, including his polemical exchange with I.B. Pole-Evans – the "water-supply controversy that has been raging between Dr Pole-Evans and Keet", as Phillips put it in a letter to Smuts before the meeting (correspondence from Phillips to Smuts, 3 March and 4 August 1935, NASA-P Smuts Collection).

The outcome of this meeting, a resolution that South Africa should pursue "forest influences" research, is well known (e.g. Pooley, 2012; and for detailed analyses, Pooley, 2014 and Bennett & Kruger, 2015). However, it is not just the intent but also the research agenda promoted during the Conference that is important, an agenda that absorbed the weight of opinion among dissenting voices into an inclusive set of science objectives. Because this agenda was inclusive, and because the dissenting voices had been heard, the debate vitally enabled a programme of definite but wide scope. The minds of Wicht and his colleagues could reach beyond the confines of narrow interests and include from the outset the broader range of questions and research partners demanded by the comprehensive policy context of the time, as well as that of the future. The clear political support captured by Reitz's initiative gave power to the programme during difficult financial times, while Smuts's South Africanist science made space for bold scientific thinking, sympathetic to the policy concerns that motivated the work, and a commitment to generations of study.

However, it was stagecraft rather than consultation that the South Africans managed at the Conference: officials had already three years before begun to acquire the land at Jonkerhoek needed for the new research site (while maintaining the observations at Jessievale all the while). The Conference provided the forum for the full range of dissent – from climatic forestry to holistic, "organismic" ecology – and its decision gave the licence to practise the research that was needed.

This licence had an important frame, arising during the Conference from the contributions of Jan Smuts, Deneys Reitz, John Phillips and J.D.M. Keet. Analysis of the proceedings (e.g. Pooley, 2012; Bennett & Kruger, 2015), especially Smuts' speech, finds the emphasis on several related, though separate topics, best summarised in excerpts from Smuts' speech. He issued a comprehensive intellectual challenge:

> We know little about our own forests, and practically nothing about the strange forms which we have been importing into South Africa. Our forestry problem is therefore one of research, and endeavour to get at the facts.

He stipulated forest policy research: "where the best national policy would dictate afforestation or the conservation of the natural vegetation … Such a policy must be based on knowledge, hence must be reviewed at regular intervals, for progressive improvement". Furthermore, "all contiguous and borderline aspects of the national heritage" needed to be considered. He added a series of research rubrics: " … careful research into the water question … "; "the soil question"; "comparative study of the water and soil building and conserving characters of natural forest, *fijnbos*, … and other vegetation, and of exotic plantations, a necessity … "; " … long range experiments upon watershed areas … "; " … the question of veld burning … "; and "aesthetic and economic issues … ".

This speech contained all the ideas that influenced the research programme that emerged with the establishment of Jonkershoek. These ideas both reflected and framed the scientific questions that arose from the integrated forestry paradigm, emphasised below.

The programme that developed continued for 65 years; some current work is still traceable to the 1935 origins, and what SAEON has taken on at Jonkershoek and Cathedral Peak picks ups where the programme left off, but constructs novel enquiries around the traces of the original. During the course of these decades of research, the knowledge generated fed directly into policy. Key policy analyses were those such as Wicht's 1949 report on *Forestry and Water Supplies in South Africa* (Wicht, 1949), and the 1968 *Report of the Interdepartmental Committee of Investigation into Afforestation and Water Supplies in South Africa* (Department of Forestry, 1968). Others were policy implementation initiatives, such as the trade-off assessments for the delineation of priority areas for afforestation (Departement van Bosbou, 1975), and the report of the Water Planning Committee for the Eastern Transvaal (Waterbeplanningskomitee vir Oos-Transvaal, 1980). Important pieces of legislation had their origins in the work, and one to strongly influence research was the Mountain Catchment Areas Management Act (Act 63 of 1970), which provided for co-management of upland catchments by the Department and private and public landowners. The National Water Act (Act 36 of 1998), aside from its provisions to regulate plantation forests, contains parts on catchment management and water allocation principles that are traceable through the 1970 *Report of the Commission of Enquiry into Water Matters* to the 1968 report on *Afforestation and Water Supplies*.

The policy-makers anxiously anticipated the findings from the programme. The Department of Forestry remained "alive to the possible effects which extensive forests of exotic trees may have on water supplies" and aware of the "considerable concern" among members of the public about this, sought an authoritative statement on the issue (Watt, Director of Forestry, quoted in Wicht, 1949). At the same time, the scientists remained bound to their duty to generate the knowledge needed, even if at times they could not keep up with the demand. That awareness, mostly at arm's length from the policy forums, sometimes through direct engagement, influenced research throughout the duration of the programme.

Long-term climatic variability and the "invisible present"

The irrigation farmers who complained (sometimes with justification, often without) of the effects on their water supply of upstream afforestation on their "guaranteed" water supply, as well as those, such as Keet, who worked case by case to uncover some truth of the matter, faced the fact of climate variability. There were few data available at the time on South Africa's climate and water resources, so many assumptions had to be made about rainfall when it came to choosing to develop an irrigation project, or to afforest. In 1934, when Keet investigated the complaints of the White River farmers, he found that before afforestation in 1927, rainfall had been 23% above the observed annual mean, and now it was 30% below, a decline of more than 50% during the period of irrigation development and early afforestation (see J.D. Keet C. 203 of 29 June 1934, "Complaints re streams drying up on Bultfontein", Wicht Papers, SAFRI Repository, CSIR, Pretoria). This problem, the weakness of our assumptions about the past and the future as deduced from the present – our "guaranteed" future – is what John Magnuson (Magnuson, 1990) called "the invisible present": "processes acting over decades are hidden and reside in what I call the invisible present". But as we shall see, the invisible present is not just about the puzzle presented by processes acting over decades, but also those of much shorter duration. Either way, the invisible present was a central challenge to Wicht and his colleagues, as it is to long-term ecological research today.

South Africa's inconstant climate, especially its droughts, had been a public issue for decades. Droughts had been a main motivator that led to such initiatives as the 1923 report of the Drought Investigation Commission. The questions were principally about whether human action was changing the climate (as "since the white man has been in South Africa enormous tracts of country have been entirely or partially denuded of their original vegetation, with the result that rivers, vleis and water holes … have dried up or disappeared", Department of Agriculture, 1926) such as through the destruction of vegetation cover, and whether the changes in climate were progressive, or merely secular cycles. The first authoritative report on rainfall (Schumann & Thompson, 1934), had revealed a tendency for secular cyclicity in rainfall, patterned geographically in discernible rainfall districts. A 10-year record at the base of the Jonkershoek valley, closely correlated with the long record for the Royal Observatory in Cape Town, going back to 1840, told the story of marked year-to-year variation in rainfall at these sites, and the tendency for slower, almost cyclical variation over time. The work at Jonkershoek began in the reality of rainfall variation in time at the forefront of the mind of the designers of the experiment (Figure 2).

Wicht was acutely aware of randomness in nature and the difficulty of detecting any kind of experimental effect, having made a close study of R.A. Fisher's book, *The Design of Experiments* (Fisher, 1937). Mindful that randomness and contingent probability – the "noise" in the variables of experimental interest – could invalidate scientific inference, he knew that claims of predictability in rainfall trends could confound experimental findings in the search for afforestation effects, or other treatment effects, on streamflow and the behaviour of catchment systems. From the outset he was intent on ensuring a statistically robust design.

He was also closely attuned to nature. Beneath his scientific education, Wicht was a mother's-milk naturalist: he had learnt a passion for the fynbos during excursions into the veld as a child growing up on the farm Schoongezicht (now Lanzerac), just outside Stellenbosch. He was an acute, enthusiastic and passionate observer of nature at Jonkershoek, repeatedly astonished by what he found there. Once the network of rain- and stream-gauges had begun operation he had opportunity to observe the behaviour of climate and hydrology over several time scales, and at different levels of detail, since he was personally involved in the gathering and analysis of

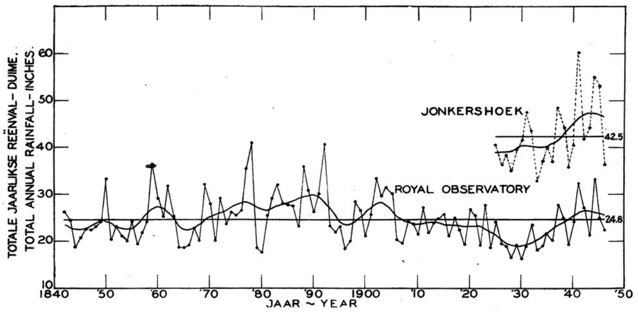


Figure 2. The time series of rainfall at Jonkershoek and Cape Town, showing annual and running mean values and illustrating the climate variability that confronted experimental design. Reproduced from Wicht (1949).

records. He was astounded to find from early gaugings that daily flow volumes of the Eerste River varied more than 1000-fold during the year, and he was deeply impressed by the destructive force of the streams after storms, such as in a major spate in 1942.

On the short time scale, during flows between rainstorms, unexplained daily fluctuations in flow intrigued him. In May 1938 he reports: " … at the beginning of the month, when warm weather prevailed, the peculiar 24 [hour] drop in the water level diagram, which although obviously associated with hot days, has not been satisfactorily explained so far … .". In catchments in general, different causes may be responsible for these fluctuations: among them, high temperatures, earth-tide effects, atmospheric pressure variations and daily courses in evapotranspiration (Inkenbrandt *et al.*, 2005; Gribovszki *et al.*, 2010). By careful analysis of the hydrographs (a graphic representation of stream flow over time), comparison between wet and dry years, and comparison between catchments differing in steepness, Wicht concluded that the cause at Jonkershoek was the effect of daily transpiration by vegetation, the midday maximum effect lagged through delay in transmission of the draft on the groundwater to the stream. This work vindicated the idea behind the policy of leaving riparian zones unplanted in plantations, and set off a line of later studies that fed into standards for plantation forest management throughout South Africa, and justified the present-day programme of Working for Water.

Focusing close in time, Wicht generated the first annual hydrographs for two of the gauged catchments at Jonkershoek, revealing the pronounced variation in time in the catchment flows, from day to day and seasonally, as well as the contrasting behaviour of neighbouring catchments. His observations of streamflow and rainfall had within the first few years of the programme told him enough about secular, seasonal and erratic variation in these variables, and their spatial variation, to reveal the magnitude of the challenge in experimental design presented by the programme.

The Jonkershoek project benefited from lessons learnt from the faults at Jessievale and the unsatisfactory attempts to explain complaints of streamflow losses at various sites, at White River and elsewhere. The first was that the climate, especially rainfall, was so variable – in time and in space – and climate variability so pronounced that there could be no reliance on short-term observation and common sense to confirm and explain claims about vegetation effects, either way.

Writing several years after his assignment, Wicht reflected on his experience, arguing that government policy required "unimpeachable scientific experiments": "To accept unverified evidence, obtained by quick approximations, and present it as conclusive, will *not* save time or money, but lead to costly failures in catchment conservation, and thus loss of faith in catchment research" (Wicht, 1963). He continued: "Special requirements needed to be met in stream-flow, or catchment experiments, which were large in scale, necessarily long-term, involving high costs, and should therefore be extremely carefully planned from the outset" (Wicht, 1943). It is obvious that he and his colleagues had learnt from the failures and difficulties encountered in the Jessievale project, and the ambiguities encountered in case studies such as that at White River. They also had in mind the prerequisites set by Smuts and Phillips during the Empire Forestry Conference.

In 1935, the research questions and hypotheses set for the programme were vague and broad. J.J. Kotzé, in his capacity as Chief Forest Research Officer, stated an ambitious goal: " … an intensive long-range investigation into the effects of afforestation upon such basic factors as run-off, erosion, soil moisture, humidity, soil and air temperatures, evaporation, transpiration, soil (both physical and chemical), organic matter, plant succession and stream flow … " (Annual Report, 1935). The treatments to be tested included not just afforestation with alien *Pinus radiata*, but also with yellowwoods and other indigenous trees, broadleaved aliens such as oaks and poplars; as well as veld-burning in the fynbos, with and without grazing (by goats); and complete protection of the fynbos against fire (Table 2). "Observations will determine, quantitatively, the variation in the dispersal of precipitation under different circumstances"; this would be achieved " … by recording rainfall, evaporation, transpiration, run-off, seepage, streamflow and all natural phenomena which might influence the hydrological processes" (Annual Report, 1935).

Design of hydrological experiments at Jonkershoek

It was eight years after the start of work that Wicht and his colleagues reached final agreement on the design of the programme (though, during this time, Wicht issued a steady stream of scientific papers while working with colleagues from universities and elsewhere to solve technical problems of gauging rainfall and streamflow). Kotzé's initial, wide brief set in train an intensive process of design and redesign as they faced the realities of natural variation in time and space, and the technical constraints and resource limitations (Wicht carried the extra burden of his colleagues' duties while they served in World War II) that bore down on the work. The final design was the outcome of several iterations, with Wicht in intensive debate with his well-qualified colleagues and critics – masters and doctoral graduates of Edinburgh, Oxford and Yale. In November 1936, J.J. Kotzé spent four days at Jonkershoek discussing the plan; his successor Ian Craib spent another four days with Wicht in 1938 to discuss a revised programme (Craib had also led the team searching for the next site at Cathedral Peak in 1936; Annual Report, 1936; 1937). The first version of the research programme was approved in October 1937; the third revision was "finally" approved in 1943, following Wicht's paper on the experiment in the proceedings of the American Geophysical Union, "Determination of the effects of watershed-management on mountain streams" (Wicht, 1943).

In 1935, Wicht had thought he would follow the "water balance" approach: to achieve an equation that balanced the relationship between rainfall and all the elements of its dispersal – evaporation, infiltration, transpiration, overland flow, lateral seepage and exit as streamflow. Once established, the research would proceed to measure effects on each variable in the equation of afforestation, or other change, and this would allow computation of these effects on the "natural" balance.

By 1939 the experimental design was to be the "single basin approach" (for the different forms of catchment experiment, see Hewlett & Pienaar (1973), in which "Each stream is to be studied independently and compared with itself before and after treatment" (Wicht, 1939). Later he had to exclude this approach, and then the paired-catchment design: his research by this point had " … shown that the variability of streamflow is also normally so great that a single comparison between two watersheds, or between two periods – before and after treatment – will be so burdened with chance-errors that the results must necessarily be uncertain" (Wicht, 1943). By 1943 his preferred design was the multiple catchment experiment.

John Hewlett and Leon Pienaar (one of Wicht's postgraduate students) describe the multiple-catchment experiment as follows (Hewlett & Pienaar, 1973):

> Pine was planted on one basin the first year and for eight years the developing pine stand was matched against five control basins under the more slowly-developing fynbos vegetation. In the ninth year, another basin was planted to pine, and in the 17th year still another, and so on. One control basin remains as an index to changing climate and developing fynbos to the end of the experiment [Langrivier, see Table 2]. The multiple controls decrease in number while the treatment is replicated through time. One clear advantage is the built-in check upon the quality of control; if one control basin is for any reason a renegade (perhaps a slow subsurface leak is developing) the interrelation among the controls in the absence of treatment will reveal it.

Hewlett & Pienaar continue with a caveat: "This advantage, however, is gained at considerable cost and it is difficult to see any other design advantage over a series of paired catchment experiments."

Wicht's new design for Jonkershoek (and later, Cathedral Peak in the Drakensberg) formed an experiment "replicated in time" (Wilm, 1945), over a period of 40 years, but with earlier findings possible. This was a profound evolution in design, motivated by the lessons of earlier trials, the big issues in forest and water policy, and the newly acquired knowledge of the variability in Jonkershoek's streams. This design would uncover "the invisible present" and yield real advantage that it would provide the "unimpeachable" findings that the forest researchers sought. It also provided the scientific foundation for secure inference from findings to be delivered from the expanded network of simpler paired-catchment experiments that would follow: a network that justified the "considerable cost" of the Jonkershoek experiment. Further, the experiment effectively committed to a programme of at least 40 years, it served to create a psychological readiness to face the long term and a basis to justify such a commitment.

Equally important in the experiences of the first decade or so of enquiry was its lesson in discovery as a process. Boundless curiosity and wonder, an openness to the surprises of time and chance, and endless attention to detail created in the minds of Wicht and his scientific colleagues a body of thought that admitted the novelty of an effective programme.

Jonkershoek: place and locale

When the foresters chose Jonkershoek as the principal site of a major science programme they did so knowing that it did not represent their main locations of interest. It was Jessievale that was in the right place: Jessievale was near the centre of the wide band of high-rainfall upland country in the northeast of South Africa that became for a time the location of the largest planted forests in the world. But Jessievale was distant and isolated, to be reached at its beginning only after a slow rail journey and a final trip on horseback or by Scotch cart or horse buggy.

Choosing Jonkershoek paid a double dividend. First, it was close to the universities of Cape Town and Stellenbosch and the rapidly-expanding intellectual resources and skills available there. There was ready access to learned societies, such as the Royal Society. Second, Wicht, just a few months back from his advanced studies overseas, knew Jonkershoek well, and was well connected with the Stellenbosch academic community. Excursions into the Jonkershoek mountains while at school and as an undergraduate student meant that he knew the challenges of the terrain, and also had an academic and a vernacular knowledge of its botany. Many leaders among the Stellenbosch academic community were also his mountaineering companions.

The programme began at Jonkershoek in 1935. Wicht was a recently appointed forest research officer in the government forest research organisation, qualified in silviculture, with degrees from the Universities of Stellenbosch, Oxford and Dresden. Wicht had wide interests, and arrived at Jonkershoek well acquainted with the fynbos biota and with its mountain setting. His brief was comprehensive: to research the effects of land management – afforestation, veld burning and grazing – on water resources and catchment condition.

Though it did provide the space for large-scale experimentation, Jonkershoek as an experimental site also presented great difficulties, owing to its rugged terrain and steep climatic gradients. But as a science locale – with a particular ecological and social context with intimate "connections between doing science and living lives" (Kohler, 2012) – it stood in bold contrast to the first attempt at the remote and lonely Jessievale. Despite the poor state of its buildings, the absence of motor vehicles, and any kind of research infrastructure, Jonkershoek immediately became the centre of intense activity. Wicht drew in Robert Adamson and Margaret Levyns of the University of Cape Town to inventory the plant life of the valley, other experts to survey geology and soils, and engineers to assist in the design and calibration of stream gauges (it helped that one of these, J.P. Kriel, a doctoral student at the time, later headed the Department of Water Affairs during crucial periods of policy development). The interest from around the country in the work was intense. It was not only the chief of forest research (first J.J. Kotzé, later Ian Craib) who visited regularly, but also J.D.M. Keet as Director of Forestry. Others among the many visitors were the new Minister of Agriculture and Forestry, Colonel Collins, John Phillips, I.B. Pole Evans and T.E.W. Schumann. Wicht immediately opened correspondence with overseas experts in catchment hydrology and "forest influences", principally those in the USA, where around the same time, major new catchment experiments were starting up. In this way Jonkerhoek quickly became the focus of exchange of ideas, techniques and methods in a network that extended to include the important local and international sources of knowledge on this new field of enquiry.

A great advantage of the Jonkershoek site, cannily chosen for its features three years before the work began, was the large number of tributaries feeding the Eerste River, each potentially an experimental unit. This spacious laboratory was what enabled the ultimate development of the multiple-catchment experiment, with its several replicates of afforested and fynbos streams.

Intensive, long-term ecological research is necessarily site-bound, but of course the work at Jonkershoek alone would not securely inform forest policy for the whole of the country. In 1936 a horse-back patrol, with Ian Craib as leading forest researcher as member, reconnoitred the foothills of the Drakensberg in present-day KwaZulu-Natal, and chose (after what was described as a raucous celebration at the end of the expedition – Craib was a famously larger-than-life figure in forestry research, but most famous for his revolutionary innovations in silviculture) the Cathedral Peak site for the next set of experiments (Nänni, 1956). Though work at Cathedral Peak could begin only after World War II had ended, researchers could use the Jonkershoek design and techniques to proceed directly with a comprehensive experiment there. Then followed a steady expansion of the catchment research network, with the next station gauged from 1956 onwards, until by 1984 eight stations were in operation, involving a total of 53 gauged catchments, from the Cape mountains to near the border with Zimbabwe.

Each of these but the last generated a substantial body of scientific literature, of real significance to South Africa and the rest of the world. As an example, the 1982 paper by Jan Bosch and John Hewlett, "A review of catchment experiments to determine the effect of vegetation changes on water yield and evapotranspiration", published in the *Journal of Hydrology* (Bosch & Hewlett, 1982), was the third-most cited paper in that journal's history at the time of its 50th anniversary. South African work provided the key information that led to the paradigm of Green Water and Blue Water resource management, and to the debunking of myths about vegetation control of floods (e.g. Hewlett & Bosch, 1984; Calder, 2005; 2006).

The programme of forest hydrology enjoyed continuing support. Gauging experimental catchments was, by the standards of the time, very expensive, and the call on human resources, both to support the carefully supervised field observations as well as data management and analysis, very demanding. These realities tempered the initial science ambitions as set out by Jan Smuts and later, by J.J. Kotzé. Wicht and his colleagues still kept these in view. Work was not confined to questions of afforestation effects. From the outset the programme, both at Jonkershoek and at Cathedral Peak, included in the catchment treatments veld burning and protection against fire. This led to early insights into hydrological responses to fire (e.g. van der Zel & Kruger, 1975).

The wider collaboration required to support catchment management as ecosystems management, as Wicht had articulated the paradigm in his 1949 report on *Forestry and Water Supplies in South Africa* (Wicht, 1949), and refined in the 1968 *Report of the Interdepartmental Committee of Investigation into Afforestation and Water Supplies in South Africa* (Department of Forestry, 1968), both promoted and demanded a comprehensively interdisciplinary approach to the work. Smuts's injunction, to "correlate scientific developments across a range of disciplines in new and creative ways, with potentially far-reaching implications for 'universal science'" (Dubow, 2006), no doubt still had its influence. Beyond enlisting Cape scientists, collaboration was found with other research bodies, such as the then National Botanical Research Institute among others, leading, for example, to John Killick's singular account of the vegetation of Cathedral Peak (Killick, 1963).

However, despite the evident support, it was not enough. The initiative had, in any event, originated in uncertain times. The Hertzog administration had appointed Dr F.E. Geldenhuys, an economist, as head of forestry in 1931, whose interventions severely weakened the organisation. After a protest movement by forestry professionals, he was replaced by J.D.M Keet, whose strenuous leadership restored the institution, but only after key figures in research, such as Colin Robertson, had been lost (Pooley, 2014; Bennett & Kruger, 2015): awareness of the vulnerability of the institution probably explains in part Keet's forceful approach during the 1935 Empire Forestry Conference. Throughout the period from 1935 to the mid-1960s, the programme was threatened with failure, not for lack of scientific skill or intent, but because of continuous problems of, especially, lack of the necessary personnel, tight financial constraints, and inter-organisational rivalries. Even by the 1960s, field observers completed much of their daily and weekly routines by bicycle and on foot. This all began to change from around 1965 onwards.

A transition and dealings with big science

From the mid-1960s onwards, the character of catchment research began to change. Continuing concerns about the country's water supplies, a renewed urgency regarding catchment protection, and the work leading to the 1968 report on afforestation and water supplies and of the Commission of Enquiry into Water Matters, all led to a focus on catchment research, a remobilisation of resources to do it, and the affirmation of the ecosystem-level approach to management (on this, see below). Revision after the apparent failure to make progress in the protection of catchments in private ownership through the Soil Conservation Act (Act No. 45 of 1946) led to the major shifts that anticipated the Mountain Catchment Areas Act (Act No. 63 of 1970).

Until this time, progress in catchment research had depended to a significant degree on the role and influence of Chris Wicht, and his direct mentoring of a succession of forest scientists, primarily working to maintain the experimental programme, and occasionally completing analyses that led to published scientific papers. Wicht himself worked with statisticians to progressively improve the statistical procedures required for proper analysis of the multiple-catchment experiment (e.g. Wicht & Schumann, 1957). He was also closely engaged in the colonial effort to extend research on natural resources throughout Africa, such as through the forums of the Commission for Technical Cooperation South of the Sahara (e.g. Wicht, 1958, 1959a, 1960, 1963), as well as testing the programme in international forums (e.g. Wicht, 1959b). But after this, the role of leadership was spread much wider, and the scope of cooperative science activity ever broadened. This related to shifts in the institutional arrangements for mountain catchment management.

Although government during the period of the 1920s and 1930s had acquired considerable areas of mountain terrain to add to the managed catchments in the forest estate, most mountain catchment areas remained in private title, or in communal tenure. The "Ross Report", from the work of a Committee appointed under the new Soil Conservation Act (Ross, 1961), delineated the important mountain catchments, and of their category A, the high-yield catchments, just 33% were in State Forests; of the total, just 17% was owned by the state by 1973 (Wicht & Kruger, 1973). These areas were mostly of little or no agricultural value (Department of Forestry, 1968). In the then Western Cape, the Committee estimated the area of Category A catchments at 814 000 ha, of which 318 000 ha were in State Forests in 1985 (Wilson, 1985). Securing the proper management of the mountain catchment resource presented a significant challenge. Government had approached the management of these private catchments, at that time used largely for low-intensity pasturage (if at all), by appointment in 1949 of Fire Protection Committees empowered by the Soil Conservation Act and regulated by the then Department of Agricultural Technical Services, initially to implement complete protection against fire in the private mountainlands. This policy failed as complete protection from fire was simply not possible. Government formulated a new policy in 1967, which allowed controlled burning in the more humid areas, but the Fire Protection Committees were not a success, partly because private landowners did not have the resources for the management of these low-value lands without real state support, and partly because the Department of Agricultural Technical Services lacked the necessary know-how. Furthermore, the recommendations on catchment management in the report of the 1968 Committee on Afforestation and Water Supplies required a change in policy (Wicht & Kruger, 1973).

Passage of a new statute, the Mountain Catchment Areas Act, and Parliament's resolution to assign the powers of the Act to the Department of Forestry (or its equivalent) opened the way to a unified approach to the management of catchments. The Act provided that the Minister may "define any area and declare that area to be a mountain catchment area", and then issue directives for its management. The practice was, as far as possible, to define catchment areas so that they abutted on and encompassed State Forests, for efficiencies in the co-management of the catchments.

"A knowledge of ecosystems as wholes is necessary in order to understand fluctuations in the discharge of streams", and change in the vegetation within the catchment determines any sustained change in streamflow. This was the overarching conclusion in Wicht's official report on forests and water in South Africa in 1949, based on the scarce experimental information from elsewhere (clearfelling experiments at Coweeta in the USA had begun to deliver results), early analyses of the water balance of the Bosboukloof catchment in Jonkershoek, and inference from first principles (Wicht, 1949). The report of the 1968 Committee affirmed this conclusion (Department of Forestry, 1968; see also Wicht & Kruger, 1973). This tenet reinforced the necessity of a similar approach to research, and since in the Cape region mountain catchment ecosystems were fynbos ecosystems, the focus shifted towards the ecology and management of fynbos.

Cooperative programmes take hold

Co-ordinated catchment research

An important turning point at the time was the establishment of an Interdepartmental Committee for Hydrological Research, whose members agreed to launch cooperative projects at Jakkalsrivier and Zachariashoek in the Cape (Table 2), and the accompanying significant expansion at Cathedral Peak. In addition, the Committee promoted the strengthening of hydrological research by the Department of Agricultural Technical Services at nThabamhlope in KwaZulu-Natal, to complement the forestry programme, and identified various lines of collaboration between forest researchers and engineers and scientists within what are now the Agricultural Research Council and The South African National Biodiversity Institute (SANBI).

These new initiatives focused on what is now termed ecohydrology, with the particular purpose of advising catchment management on an ecological basis. Expertise from different government organisations flowed into the new experiments, though the brunt of the work was borne by forestry researchers. The catchment experiments served as a springboard for extensive studies on ecology, fire management and the control of invasive plant species, work that informed management plans and practices for State Forests as well as on the co-managed private lands. This history is covered by van Wilgen (2009) and Pooley (2012).

Paradoxically, it is around this time that the consequences of the apartheid regime to science institutions in South Africa began to show. The ideology of apartheid itself was probably the most important factor in undermining a healthy science culture. Apartheid was at least partly to blame for an exodus of scientific experts and the difficulties experienced in recruiting properly qualified people, especially at universities. However, the academic boycott also began to have its effect, there was a decrease in overseas visiting experts, and South Africa was expelled from, among others, the Commission for Technical Cooperation South of the Sahara in 1962, the Food and Agriculture Organization in 1963, and suspended from the World Meteorological Organization in 1975 (e.g. see UNESCO, 1967). Many government research organisations were also weakened as a result of all this. Possibly as important as the loss of capacity and collegial networks was an apparent loss of acuity in the science community, though this was uneven, some parts becoming parochial and mediocre, others tenaciously remaining excellent.

Strong interpersonal relationships

Despite South Africa's emerging pariah status, a second development affecting the programme, concurrent with the move towards coordinated catchment research, was the progressive strengthening of personal relationships with hydrologists and ecologists around the world (see also below, on the International Hydrological Decade). Possibly this owed to the relatively apolitical topic of the programme, or the questionable ethics of a science boycott, possibly its public good was transparent and carried enough weight, or perhaps it was because of the diligent adherence to the ICSU rules on the free exchange of scientists.

One of us (FJK) spent eight months on the campus of the Australian National University in Canberra during 1974–75, linking with among others, at CSIRO, Alan MacArthur's bushfire research group, Malcolm Gill and Richard Groves, with Frank Dunin's group dealing with vegetation and hydrology. Coincidentally, Harold Mooney of Stanford, was on sabbatical there at the time and this opened the door to sharing of ideas and plans. A collegial friendship with Ray Specht, ecologist at the University of Queensland (and shared with others in

South Africa, such as Eugene Moll), opened the way to an excursion to his exemplary long-term replicated fire experiments in the sclerophyllous shrublands at Dark Island Heath in South Australia, and later collaboration in the production of the Elsevier volumes *Heathlands of the World*.

This network expanded over time, especially through the collegial expansion of the cooperative programmes. However, individuals played key roles through their exceptional leadership qualities, diplomatic skills and warmth of person. On the international scene, Hal Mooney stands out in this regard, and nationally, Brian Huntley.

These enduring relationships opened exchanges that led to several new themes that complemented the ongoing work in South Africa: fire ecology and fire behaviour studies led by Brian van Wilgen at Jonkershoek (Pooley, 2012) and Colin Everson at Cathedral Peak, gas-exchange and evapotranspiration research to complement and extend the catchment observations (Mooney *et al.*, 1983; Dye & Olbrich, 1993; Everson, 2000), and a renewed focus on the ecology and management of invasive alien plants. The contacts also led to a long-running participation the Medecos series of conferences (e.g. Kruger *et al.*, 1983), and a central role for South Africans in the SCOPE Programme on the Ecology of Biological Invasions (see e.g. Drake *et al.*, 1989). The new intellectual energy that these linkages generated positioned the catchment research community and their allies for the emerging institutional cooperative science programmes in South Africa.

New international science initiatives

The third transition was the engagement with new international science initiatives. The first of these was the International Hydrological Decade (IHD), sponsored by UNESCO as “man’s first concerted attempt to take stock of his diminishing available resources of fresh water and to co-ordinate world-wide research on ways of making better use of them” (Nace, 1969). The second, with fewer linkages to South Africa, was the International Biological Programme’s intercontinental study of Convergent Evolution of Mediterranean-Climate Evergreen Sclerophyll Shrubs (Mooney & Dunn, 1970) – tangential, but highly influential in promoting the intellectual ferment in fynbos ecology, through collegial exchange of ideas but also institutionally, through South Africa’s engagement with the International Council of Scientific Unions’ (ICSU) International Biological Program (IBP).

The Fynbos Biome Project

The fourth, with profound consequence, was the Fynbos Biome Project, part of the National Programme for Environmental Sciences and with other national science initiatives, South Africa’s contribution to the Scientific Committee on Problems of the Environment of the ICSU. This new thrust generated both new science as well as major syntheses of knowledge, while maintaining links with managing organisations, such as the Department of Forestry (in its several historic forms), provincial conservation agencies, farmers and others. Simon Pooley, among others, has provided a good history of much of these efforts, as well as the largely complete disintegration of effort from the mid-1980s onwards (Pooley, 2012).

International links to forest hydrology

From the perspective of South Africa’s catchment hydrology research, the influential event in the IHD was the International Symposium on Forest Hydrology, convened at Pennyslvania State University, USA during August–September 1965. Its purpose was for forest hydrologists to establish the current state of knowledge, to define research needs and trends, and to speculate about the future direction of forest hydrology research (Swank, 1981).

The assembly included 87 scientists from 22 countries. For the first time the forest hydrology researchers from around the world were able to expose their ideas to a global assembly of colleagues. It engaged the leading figures in water balance studies, such as Howard Penman, author of the seminal 1963 book, *Vegetation and Hydrology*; Charles Pereira, who then led the programme in East Africa; and Albert Baumgartner, from Germany, a leader in evapotranspiration studies. Pereira and others welcomed the meeting as being the unique first opportunity for the discussion of concepts, methods and terminology in forest hydrology in a representative international forum. From South Africa, Wicht and Ugs Nänni attended; Wicht delivered two papers, and compiled the report on the session on forests and evapotranspiration (Wicht, 1967a, b, c). This forum served as an important opportunity for critical review of South Africa’s work by eminent hydrologists, and Wicht returned confident in the soundness of the South African programme.

The South African findings had a good reception. For example, the concept of the catchment as an ecosystem had important influence: some time after, Wayne Swank, one of the US’s leading forest hydrologists, commended Wicht’s position as “perhaps one of the most perceptive observations” at the meeting, when he noted that " … a complete, integrated whole – the ecosystem of the forest" is the appropriate level for understanding evapotranspiration (Swank, 1981). But it also had to withstand criticism. Penman was especially sharp. He questioned a purely empirical approach to catchment hydrology, as in the multiple catchment design, emphasised the water balance approach, which with a sound theoretical basis would have greater explanatory power, and caused a heated debate on whether transpiration was a purely physical process or whether it was biologically mediated, as in Wicht’s view. Wicht was largely unmoved by this criticism, but alert to the need for fundamental research as well as experimentation.

Although Wicht maintained an exchange over time with Penman’s colleagues Pereira and others (e.g. H.C. Perreira to Wicht, 11 January 1962, re Wicht’s concerns about the East African hydrological research methodology; Wicht Papers, SAFRI Collection, CSIR, Pretoria), on the question of hydrological methodology and fundamental studies, it was with US forest hydrologists that the most important links emerged. Wicht had corresponded with US counterparts from the beginning, and cited Charles Hursh from Coweeta as long ago as 1943, but it was at this meeting that the hydrologists from South Africa would meet their colleagues from the USA face-to-face for the first time. Wicht and Nänni visited Coweeta during a study tour after the conference. They came away affirmed in their belief in the design of the South African programme. “The basic designs and observation techniques applied in the South African experimental investigations catchments experiments is sound and often better than those seen in the United States”, though the staff was too small and facilities inadequate, and there was an urgent need for advanced modern computational aids. There was a sense of urgency about getting the results out from South Africa's "sound foundation for watershed management research", and an emphasis on the value of cooperative research that is "free and by mutual agreement", an ethos which later paid dividends (Wicht, 1965). This confidence stabilised the programme and maintained the basis for the expansion of the research that followed.

From this conference and tour, Wicht began to realise how place played a key role in design and methodology (and showed how the question of research design was a constant intellectual concern for him). The focus on fundamental hydrological studies promoted by Penman originated not only in what was called the "philosophical" approach, but "also by circumstances in the region where hydrological research is undertaken". In the USA and South Africa, extensive regions were [then] available "where many experimental watersheds could be selected and experimentally investigated for long periods", but not so in Britain and European countries, where in consequence "disjunctive, fundamental research must be relied upon". Though the results of investigations of individual hydrological processes may then be integrated to estimate the aggregate effects of vegetation on water supplies, "*What* happens when vegetal cover is modified, replaced or removed is therefore *not* observed" (Wicht, 1965), while the concern about the impossibility of accurate measurement at catchment scale of any water balance term other than streamflow remained.

The links with the Coweeta experiment led to substantial dividends, principally through the relationship that developed with John Hewlett of the University of Georgia. Technical improvements, learnt from the Coweeta team, led to more efficient and effective analyses in South Africa. Perhaps the most important indicators of this scientific collaboration were the historic papers that came from Jan Bosch's collaboration with John Hewlett (Bosch & Hewlett, 1982; Hewlett & Bosch, 1984). The first of these provided a synthesis of findings from controlled catchment experiments in South Africa and elsewhere around the world, yielding early estimates of afforestation effects on streamflow, as well as the contrasts between forests and other forms of vegetation. The second paper reported on an intensive analysis of over 1500 storm events from eight experimental catchments within the South African network, with differing vegetation, and gave vital insights into the distinct hydrological behaviour of mountain catchments: heavy rainstorms generated very little stormflow (on average, just 2.0–6.0% of rainstorms exceeding 20 mm), most of the rain that reached the ground being held in the soil and released slowly to evaporation and streamflow; the state of vegetation (e.g. whether forested or not) had very little influence on spateflow rates and volumes, hence little effect on flood control. This paper, proving how in these conditions 50% or more of larger rainstorms is absorbed by the soil mantle for later slow release to "baseflow" (the balance of around 40% going to evapotranspiration), justifies the intuition underlying the concept of the "mountain catchment".

The wider penumbra: inputs from broader initiatives

With the inception of the Fynbos Biome Project in 1977 the scope of the science–policy interface broadened; an overview of the state of research and the intended programme appears in the plan of 1978 (Kruger, 1978). The programme brought new leadership, including Brian Huntley but also the urbane Gideon Louw, then professor of Zoology at the University of Cape Town, and others. In addition to foresters and forest research scientists consulting outwards about policy and practice for fynbos catchment management, the programme introduced inclusive structures that served as larger clearing houses for ideas and policy guidelines. Participants included the Cape universities, the then Botanical Research Institute, the then Cape Department of Nature and Environmental Conservation, research bodies of the Department of Agriculture, engineers of Water Affairs, as well as private individuals (Table 1). This programme of work included the coordinating and leadership work of the Fynbos Biome Steering Committee, its short-term synthesis initiatives (e.g. Day *et al.*, 1979; Campbell *et al.*, 1981; Deacon *et al.*, 1983; Kruger *et al.*, 1985), the stimulation of new work, and annual symposia. Small amounts of funding via the Committee supported new ideas, but participating organisations funded most research.

The centre of gravity for fynbos management remained in the catchment conservation programme, but the intellectual scope of fynbos research expanded purposefully, to include enquiry into questions fundamental to ecosystem function, spanning the space between the "big paradigms", population and ecosystem. Further, there was a gradual expansion to address lowland ecology, and the emerging field of conservation biology. While it is difficult to isolate what work in this period is directly attributable to the Fynbos Biome Project, there is little doubt that its direct effects as well as its contagion stimulated flourishing and highly creative lines of work, illustrated by the examples below.

At the one pole were fresh initiatives into soil microbiology and rhizosphere mutualisms (e.g. Coley & Mitchell, 1980; Mitchell & Read, 1985; Allsopp *et al.*, 1987). At the other was the intensive examination of ecosystem response to fire at Swartboskloof, Jonkershoek, the latter making many important contributions, for example, regarding erosion, sediment yield, and ecosystem minerals balance (van Wyk, 1982; van Wilgen *et al.*, 1992b), and limnology (King *et al.*, 1987). The programme was to concentrate on several "primary study sites", at Jonkershoek, in the Arid Fynbos, Coastal Fynbos and Strandveld, but it was only at Swartboskloof that this ambition was realised (see Kruger, 1978). New work began elsewhere on fire, mineral nutrients and nutrient cycling, for nitrogen (e.g. Stock & Lewis, 1986) and soil phosphorous (Brown & Mitchell, 1986). In between were, for example, manifold studies in plant demography in relation to fire and other environmental factors (e.g. Bond *et al.*, 1984; Brits, 1987), as well as on mutualisms immediately or ultimately relevant to conservation (e.g. Mostert *et al.*, 1980).

Excursions into biogeography, at the local scale, such as in the "fynbos islands" of Knysna (Bond *et al.*, 1988) and forest-fynbos contrasts in ant species diversity (Koen & Breytenbach, 1988), or intercontinentally, for birds (Cody, 1983) and vegetation structure (Cowling & Campbell, 1980) introduced landscape ecology into the mix of conservation principles. When the Fynbos Biome Project, like its counterparts, closed in the late 1980s, it culminated in the compilation a large synthesis volume, *The Ecology of Fynbos: Nutrients, Fire and Diversity*, edited by Richard Cowling (Cowling, 1992).

Illustrating the value of long-term ecological research

Although gradually tailing off, the catchment research programme continued to deliver important scientific findings

Table 1. Major ecological research programmes, in order of establishment, that were active in the Cape Floristic Region between 1945 and present, with examples of key products arising from the research.

Research programme	Responsible institution	Dates active	Focus	Examples of key products or reviews
Catchment conservation	South African Forestry Research Institute, Department of Forestry	1936–1990	Ecology, hydrology and management of fynbos catchment areas	Global review of catchment experiments (Bosch & Hewlett, 1982) Detailed documentation of effects of fire on fynbos and forests (van Wilgen *et al.*, 1992b) Review of impacts of afforestation on catchment hydrology (Scott & Prinsloo, 2008) Influential publication linking afforestation effects to the effects of invasive alien trees on streamflow reduction (Le Maitre *et al.*, 1996).
Vegetation classification and mapping	Botanical Research Institute (later National Botanical Institute), Department of Agriculture	1950–2003	Descriptions of fynbos plant communities; vegetation mapping	Review of Cape Floristic Region (Taylor, 1978) Veld types of South Africa (Acocks, 1953) Vegetation types of South Africa (Low & Rebelo, 1996) Atlas of Proteaceae (Forshaw, 1998)
Biological control of invasive alien plants	Plant Protection Research Institute, Agricultural Research Council	1967–present	Biological control of invasive alien plants	Review of 100 years of weed biological control research in South Africa (Moran *et al.*, 2013)
Fynbos Biome Project	Council for Scientific and Industrial research (later Foundation for Research Development)	1977–1989	Research funding to academic institutions; co-ordination of research across participating institutions	Review of national programmes (Huntley, 1987) Comprehensive multi-author scientific book on fynbos ecology (Cowling, 1992)
Ornithology	Percy Fitzpatrick Institute for African Ornithology, University of Cape Town	1965–present	Distribution and ecology of birds; pollination ecology	Review of bird diversity in relation to plants (Siegfried & Crowe, 1983)
Plant conservation	Institute for Plant Conservation, University of Cape Town	1990–present	Conservation in the fynbos and succulent karoo biomes	Popular illustrated account of fynbos ecology (Cowling & Richardson, 1995) Major review of fynbos vegetation ecology (Cowling *et al.*, 1997) Development of a comprehensive conservation plan for the Cape Floristic Region (Cowling *et al.*, 2003).
Fynbos Forum	Interdepartmental organising committee	1990–present	Forum for the exchange of research findings and ideas	Multi-author scientific book on fynbos ecology, evolution and conservation (Allsopp *et al.*, 2014b) Guidelines for managers of fynbos ecosystems (Esler *et al.*, 2014).
Invasive alien species	DST/NRF Centre for Invasion Biology, Stellenbosch University	2004–present	Ecology and management of biological invasions	Review of Centre's activities and achievements (van Wilgen *et al.*, 2014).
State of biodiversity	South African National Biodiversity Institute	2004–present	Foundational biodiversity research, monitoring, and policy advice	Comprehensive review of conservation status of all plants (Raimondo *et al.*, 2009). Detailed description of vegetation types (Rebelo *et al.*, 2006) Comprehensive annotated plant species checklist (Manning & Goldblatt, 2012)

into the 21st century. A few papers serve to illustrate the unexpected benefits of a carefully sustained long-term programme, findings that complement the main intentions of the programme in important ways. High-intensity accidental wildfires gave the opportunity to investigate the effects of ecological catastrophe. Wildfires passed through one of the afforested catchments at Cathedral Peak in 1981, when the plantation was 26 years old, through Bosboukloof at Jonkershoek in 1986, and a catchment monitored by the then University of Natal in the Drakensberg foothills near Cathedral Peak in 1987. The very intense fires caused a water repellent condition, effectively neutralising the infiltration capacity of the soil; the resulting overland flow caused the relative increase in stormflow, and with the loss of soil structure, carried the surface soil to the stream. In comparison with fires in catchments under fynbos and grassland, the plantation fires transformed erosion and the hydrological regime absolutely. The catchment conditions found in the stormflow study by Hewlett & Bosch (1984) – permeable catchments with high infiltration capacity, minimal overland flow, and small stormflows – were radically changed. Stormflow volumes doubled but most important, erosion, measured as sediment delivered from the catchment per ha per year, multiplied 20- to 100-fold and more (Scott & van Wyk, 1990; Scott, 1993; Scott, 1997). The catchments recovered comparatively quickly – in Bosboukloof, stormflow volume had declined by two-thirds by the second year after the fire – but the sharp effects illustrated the serious environmental risks of wildfire in plantations.

A second demonstration of the value of long-term observation arose when answers began to emerge on one of the old forestry ideas, that of the "true forest". This was the idea that the development of a plantation forest ecosystem resembled the process of ecological succession that generates the natural forest. In the case of the eucalyptus plantation, if the stand is thinned and grown on a long rotation, "then true forest conditions are approached", indigenous forest species invade the plantation as the eucalypts are "not making excessive demands on water" (Wicht, 1949; Wicht here revives arguments expressed during the 1935 British Empire Forestry Conference). Wicht argued that in "true forestry sites" mature plantations would be unlikely to use more water than indigenous forests. Other observers went further, arguing that "true forest" conditions would favour water supplies. A related aspect was the benefit expected from afforestation of degraded sites.

David Scott and Eric Prinsloo used paired-catchment analyses of Bosboukloof at Jonkershoek, involving afforestation with *Pinus radiata* that had been maintained for 43 years, and another with *Eucalyptus grandis* at Westfalia, maintained for 21 years. Both cases were on sites that Wicht classified as "true forest" sites. They found that the sharp decreases in streamflow that result from rapid establishment and growth of plantation trees reached a maximum and then reversed, to levels that prevailed before afforestation, or nearly so. For example, the *Pinus radiata* plantation at Bosboukloof took 6 years to significantly reduce streamflows and maximum reductions in flows were evident between 10 and 20 years after planting. However, at around 20 years streamflow reductions diminished, and by 45 years the streamflows approached the initial condition (Scott & Prinsloo, 2008). These results are consistent with long-term experiments in Mountain Ash forests in Australia, and find their explanation in new knowledge on the decline in transpiration as the tree, or the whole forest, ages (Langford, 1976; Ryan & Yoder, 1997). Scott and Prinsloo concluded that "trees may have a useful role in catchment restoration provided they are managed on long rotations". The research provides new insight into what ecologists are now calling novel ecosystems, "those types of ecosystems containing new combinations of species that arise through human action, environmental change, and the impacts of the deliberate and inadvertent introduction of species from other parts of the world" (Hobbs *et al.*, 2006).

The effects of political change

Johan Mouton and colleagues speak of "the ambivalent legacy of apartheid science. On the one hand, the apartheid regime poured huge amounts of money into military, defence and energy research that led to innovations in various fields. On the other hand, it created an isolationist, inward-looking and 'technicist' science, without regard for accountability or justice" (Mouton *et al.*, 2001). From our analysis of the research that followed on the establishment of Jonkershoek, and the issuing of the Royal Society report, this field seems to have escaped the impediments of "apartheid science". Rather, participants were able, individually and collectively, to maintain their openness to the wider world of ideas, to overcome potentially divisive ideological differences, and to entrain, continuously, younger people who today play important roles across South African society. The major success of South Africa's make-work Extended Public Works Programme, Working for Water and its adjuncts, owes its origin to the legacy of this research, and continues to find its science underpinned by the intellectual capacity of the programme that Wicht began. Perhaps the challenges of fynbos ecology and its "environmentalist" flavour transcended the political setting.

Diverse political, policy, and organisational changes took place immediately before and after South Africa's democratic transition (see, for example, Pooley, 2012, and for the science field as a whole Mouton *et al.*, 2001), and with it research for fynbos management also entered an entirely new institutional frame. With the closure of the Cooperative Scientific Programmes, research at academic institutions largely retreated into their various disciplines. SAFRI merged with elements of the CSIR to form Forestek (the Division of Forest Science and Technology) and with a five-year contract with government and baseline funding, was able for a time to maintain a coherent programme that included the fynbos work, but this dissipated as government reduced funding for this kind of research, distributing the little there was into competing smaller segments. Much of the main aspects of catchment management shifted into what is now the government's Natural Resources Management line of the Extended Public Works Programme (Working for Water, Working on Wetlands, Working on Fire), an important source of short-term research funding, but subject to the politics of employment creation. SAEON has emerged as a key component of the infrastructure of long-term environmental studies, but does not have a coherent funding programme. The future is unclear.

The interface between research and catchment management

The focus on mountain catchments provided an excellent organising principle for the development of knowledge on the management of these ecosystems. The question of afforestation as well as the protection of mountain catchments dictated a national scale of analysis and understanding, with the necessary attention to Jan Smuts' stated requirement for knowledge of "where the best national policy would dictate afforestation or the conservation of the natural vegetation". Recognising that catchment management was in effect ecosystem management (as it was about the relationship between vegetation and water supplies) dictated an ecological approach, rather than engineering, to knowledge development and the implementation of this knowledge. The ecological approach determined that research questions would arise at different levels of organisation, from the level of the catchment itself (the effective ecosystem unit), to the demographics of single species and their interaction with fire. In the same way, the interface between the science and policy development came to be organised to address different cycles and scales of need. Examining the way in which the programme addressed this could help in thinking about the same kind of requirements today.

Developing policy and practice for afforestation and catchment protection followed a slow but progressive cycle, and addressed as first priority the need for a national scheme, and then second, regional approaches (Figure 3). Research scientists were closely embedded in the structures and processes of policy development and implementation, assuring continuity in the flow of scientific information and the interchange of ideas needing research. The figure illustrates the coherent arc in the science–policy interface, despite its slow cycle, and the evolution of a balanced enabling framework for catchment regulation (for details, see Bennett & Kruger, 2015).

Wicht's 1949 report comprised a global state-of-knowledge account for forest hydrology at the time, clarified the fact that the available water resource depended in the first instance on the state of the vegetation in the catchment and introduced the concept of ecosystems management for catchments. In 1966 he issued a second state-of-knowledge review to inform the work of the 1968 Interdepartmental Committee on Afforestation and Water Supplies. The fact that this review preceded the next of this kind (in the USA) by 10 years (see Anderson *et al.*, 1976) reflects the urgency in South Africa to address catchment problems. The 1968 Committee affirmed ecosystems management as official policy, and set in motion the passage of the *Mountain Catchment Areas Act*, Act 63 of 1970, adopted the Nänni Curves as a graphical heuristic model (derived from experimental findings and first principles; Nänni, 1970) for the estimation of afforestation effects, which in turn allowed the amendment to the Forest Act that introduced the afforestation permits system as a regulatory instrument governing afforestation. The 1998 National Water Act contains several of the principles and precepts established by the 1968 Committee, which flowed to the Act via the 1970 Report of the Commission of Enquiry into Water Matters (Figure 3). For details of these developments, see Bennett & Kruger (2015), and for the relationship between the 1970 Report of the Commission of Enquiry into Water Matters and the National Water Act, see Muller *et al.* (2009) and van Koppen *et al.* (2010).

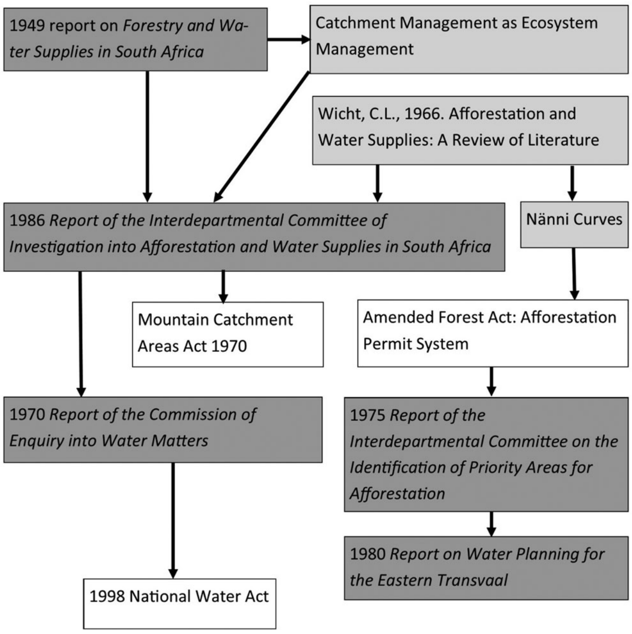


Figure 3. Schematic relationships between research and policy development addressing issues at the national and regional levels.

The Mountain Catchment Areas Act had the effect of bringing together the two "largest ecological paradigms", the ecosystem paradigm, and the population paradigm (Pickett *et al.*, 2010). By 1986, approximately 1400 km^2 of private land in fynbos ecosystems has been proclaimed Mountain Catchment Area (i.e. including State Forest catchments; Jordaan, 1987). Ultimately, nearly 20 000 km^2 of private and State land was to be managed for water conservation in terms of this Act (Kruger, 1982). To appreciate how fynbos science informed policy and practice, and vice versa, and the marriage of ecological paradigms, we need to see how scientists played their part in a larger system.

The system was one that evolved from the policy of integrated forestry, in turn with antecedents in forest policy in general. First, government developed a national policy for catchment management (by 1970, for the southern forest regions; see Wilson, 1985), and then each regional forest office developed a regional policy, coherent with national policy but taking account of the regional ecology, economy and society (e.g. Wilson, 1985). Then, for each delineated mountain catchment within a region, foresters developed a catchment-level policy memorandum, coherent with the regional policy, that took account of local circumstances and laid down principles that would apply to that particular catchment (for example, regarding fire in vegetation, recreational use or the extractive use of natural resources). Finally, subject to the policy memorandum, officials dedicated to catchment planning developed a management plan that dealt with the conservation of land for the purposes of catchment protection, for example, though the management of fire in vegetation, the prevention of soil erosion and the control of "intruding vegetation", i.e. largely invasive alien plant species (Bands, 1985). Throughout all this, foresters consulted with their counterparts in other agencies, with land-owners and their representative bodies, with civil-society bodies such as branches of the Mountain Club, and others, such as biological control experts, archaeologists, as well as up and down the management and research hierarchies. Setting out policy and principles for the management of the catchments involved the underlying ecology of fire as well as the biology and management of invasive alien plants (see sections below).

Throughout this cascade and cycle of policy-making and planning, research scientists made contributions based on the scientific knowledge of the day: each policy and plan was completed only after consultation with the research scientists. In the fynbos regions (then, the Western Cape Forest Region, the Southern Cape, and to a lesser extent, the Eastern Cape – Forest Regions did not coincide with present provinces) committees ensured structured, ongoing interaction between managers implementing catchment management plans, catchment planners and research scientists from Jonkershoek and its affiliates (the so-called MAREP Committee – management, research, and planning; see also Pooley, 2012). This approach originated in the Western Cape under the determined leadership of John Fenn, who had identified the crisis of invasive *Hakea*, *Pinus* and *Acacia*, the imperative of integrating invasive control with fire management, and the need in policy and management for progressive trial and improvement (Fenn, 1980). Research scientists were expected to maintain close relationships with scientists in other fields, especially those working on the biological control of invasive alien plant species, to make quick purposive investigations that supplemented the ongoing research programme but which addressed immediate management questions (the investigation of the status of *Serruria florida* is an early example – see Box 2) and to report on the findings of monitoring programmes.

In retrospect, this all seems obvious and simple, but the distinguishing character was the systemic binding up of the policy–management–research interaction into the statutory policy cycle, directed through strong leadership, and honed in the context of implementation by regular, structured interaction. These mechanisms, scaled from the local to the national, and time-wise from continuous to intermittent interventions, served to maintain the long-term continuity of the science–policy interface.

The present-day architecture of the science–policy interface is the outcome of the reconfiguring of the statutory and organisational structures that anticipated the democratic transition in the early 1990s. A principal factor has been the deployment of the provisions of the National Environmental Management: Biodiversity Act, especially through bioregional planning, which in turn governs the design of the protected area system, the content of local government development plans, and decisions in integrated environmental management. Policies, systems and practices in biodiversity management are distributed among the South African National Parks, provincial nature conservation agencies, Working for Water, Working on Fire, and the private land owners. Instruments vary from statutory standards for protected area management, to the suasion instruments of biodiversity stewardship and market instruments of "green" branding and product certification. Mountain catchment conservation, on the State Forest lands as well as the delineated Mountain Catchment Areas, falls to the National Parks and the provincial protected area managers. It is not clear how the science–policy interchange is working in this new milieu, but it is multiplex, multifaceted and perhaps divergent and incoherent.

Paradigms that informed ecological research in the Cape Floristic Region

Certain paradigms informed South Africa's ecological research programme in the CFR and more broadly, at least until the pervasive shift in institutions from the mid-1980s and into the 1990s. The first was the paradigm of a South African science, characterised at its origin by Jan Smuts as the South African point of view, conceived to overcome the "habits of thought and the viewpoints characteristic of its birthplace in the northern hemisphere", and to "correlate scientific developments across a range of disciplines in new and creative ways, with potentially far-reaching implications for 'universal science'" – both an injunction and an invitation to the science community to seek adventure, plainly taken up in the programme reviewed here.

The second guiding paradigm arose from the assignation to the national forest authority of a portfolio that included mountain catchment management, indigenous forest protection and timber plantation development. In reconciling the apparent contradictions in this portfolio, foresters developed an integrated forestry paradigm: resources at its disposal would be educated, shaped and deployed to balance these objectives and to manage the land as a unitary resource, with the ecosystem concept to guide the precepts of science and management. It was policy "based on knowledge, … reviewed at regular intervals, for progressive improvement", in Jan Smuts's words. Policy and practice required science, as much as the findings of science needed to be tempered by experience, or, as Keet put it in the 1935 British Empire Forestry Conference, "In the reciprocal relationship between science and experience the latter must hold sway, until at least the former has been proved in experience" (Union of South Africa, 1936).

Together, these paradigms shaped up a catchment research programme that was conceptually comprehensive, not confined to narrow interests in timber production at the one extreme, or "flora protection" at the other, and having the ecosystem concept at its heart. Hesitant at times and always vulnerable to failure, this programme nevertheless continued, delivering vital elements of new public policy, while making distinctive contributions to global knowledge in this field. It continued until such time as the world and South Africa were ready for the "Big Science" of cooperative programmes, beginning with the International Hydrological Decade in the 1960s, and later in the International Biological Programme and the work of the Scientific Committee on Problems of the Environment, especially South Africa's Cooperative Scientific Programmes. It then became a core of such cooperative work. During this period, a tremendous surge in creative and fruitful ecology, giving expression to Wicht's cooperative research that is "free and by mutual agreement", situated fynbos ecology in a global network, contributed significantly to world ecology and overcame the strictures of "apartheid science". The extended trajectory of this enterprise provided for long arcs of coherence, for example, in experimentation on and policy for the ecosystems paradigm for catchment management, or the long trial and later rapid growth in the science and management of invasive alien plants.

In the former phases of this trajectory, this enterprise depended to a large extent on the force of a few personalities, especially that of Chris Wicht. In the latter stages, the shift was towards the science team, especially through the emergence of South Africa's Cooperative Scientific Programmes.

Throughout, however, the governing force of the interface with policy and management directed and sustained the research in its coherent form, until the institutional disintegration and the demise of the integrated forestry paradigm in the mid-1980s. Traces of the programme have continued, largely though SAEON and intermittent commissions from the public works programmes. A new paradigm, that of ecological infrastructure in catchment management, now in force in biodiversity science and official policy of the Department of Environmental Affairs through the Strategic Infrastructure Programme 19 ("Ecological Infrastructure for Water Security"), may have the strength required to shape a coherent science programme as well as a new science–policy interface (see, for example, Department of Environmental Affairs, 2013; SANBI, 2014). It remains to be seen whether a recognisably coherent enterprise will emerge.

PART 3: RESEARCH AND THE DEVELOPMENT OF UNDERSTANDING

Understanding fire ecology

The Wicht Committee's views on fire

The Wicht Committee recognised fire as important in its report, but fynbos fire ecology was in its infancy in 1945. Examination of the available literature at the time (papers listed in a bibliography of fynbos ecology in the category "fire ecology" (Manders & Dicks, 1989) reveals that only 24 fire-related publications had appeared (Figure 4). Very few of these (with the exception of six papers reporting the work of Adamson, Levyns and Phillips) were serious scientific studies, and most contained only casual observations, some dating back to the 19th century. Rigorous experimental work was limited to a single study (Levyns, 1929).

At the time that the Wicht Committee's report was written, prevailing policies excluded fires from fynbos ecosystems. The fire exclusion policy was based on the commonly-held view (Levyns, 1924; Marloth, 1924; Pillans, 1924; Compton, 1926; Compton, 1934a) that fire would "cause the vegetation to deteriorate" (Wicht, 1945). This view was not universally held, though, and J.S. Henkel, for example, concluded in 1943 from personal observations that burning was necessary to maintain healthy fynbos. Wicht set out to review the scant information available on fire effects at the time, and he noted that, because fires in the Cape were so frequent, "all species … will have efficient ways of surviving fires". He went on to list four predominant mechanisms by which fynbos plants could survive fires: sprouting from below-ground organs (geophytes); sprouting from rootstocks; sprouting from buds on branches protected by corky bark; and survival in the form of seeds. However, in line with ecological thinking at the time, Wicht also interpreted the role of fire in terms of Clementsian succession, in which undisturbed ecosystems were thought to progress over time towards a (desirable) climax condition. For example, the Committee stated that "in the sense that the vegetation is seldom permitted [by frequent burning] to attain the natural climax, it is, however, undoubtedly deteriorated, because burning entails the continual interruption and renewal of succession". They were also concerned about the effects of fire on soil formation, and on the ability of the soil to store and release water, stating that "the less the natural succession of vegetation and the associated soil-building processes are disturbed, therefore, the more constant should the flow in the streams become". This last statement was based on the assumption that vegetation was a major determinant of soil formation, and that "burning continually nullifies the function of vegetation".

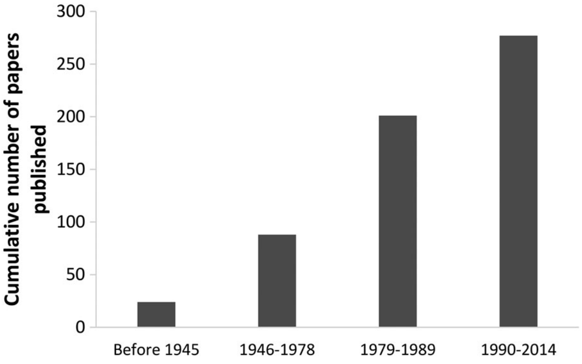


Figure 4. The total number of papers published addressing the topic of fire in fynbos at different stages over the last century. Data are from Manders and Dicks (1989) and from Google Scholar.

The Wicht Committee went on to make recommendations about two important aspects of fire management, namely fire protection and controlled burning. Regarding fire protection, they were generally supportive of a policy of fire exclusion, noting that it would "permit the development of climax communities". Because of the supposed beneficial effects of such climax communities on the soil and on soil moisture, they were of the opinion that "important catchment areas" should "undoudtedly be protected against fire". They noted that excluding fires would require "decisive, positive protective action", and that campaigns to reduce fires by raising awareness and using propaganda would be ineffective. The construction of firebreaks was recommended as the only effective measure, but because this would be expensive, it should only apply to "carefully selected areas". They also noted that protection from fire would lead to the loss of "many species characteristic of seral [i.e. early successional stage] communities", and he recommended less active protection of those catchments "that pour the major contents of their waters into the sea". Regarding controlled burning, the Committee recommended that burning "might be applied on areas not selected for water conservation, or on areas where it is desired … to originate the secondary succession which follows burning". This consolidated the views expressed earlier by Wicht and Henkel (see above) regarding the use of fire, and constituted the first serious suggestion of the deliberate use of fire in the management of fynbos ecosystems.

1945 to 1977: Initial fire experiments

A science-based understanding of the role of fire in shaping and maintaining fynbos vegetation was initially slow to develop. Starting in 1949, Prof. P.G. Jordaan at Stellenbosch University demonstrated, by analysing the accumulation with age of seed held in serotinous flower heads, that fires in summer, at intervals of at least 8 years, were "safe" for *Protea repens* (and thus probably for other fynbos species, Jordaan, 1949). Later it was also shown that the season of fire would influence the ability of *Protea repens* to reproduce (Jordaan, 1965), and that all of the 448

Table 2. Key experiments (in order of establishment) that investigated the effects of fire on fynbos ecosystems.

Experiment	Date initiated	Treatments	Notes and key findings
Langrivier catchment (Jonkershoek State Forest)	1938	Protection from fire	Langrivier was intended as a control catchment against which the hydrological effects of afforestation with pines could be compared, and in line with management practice at the time was protected from fire. Streamflow volumes were reduced by 13% following protection from fire for 33 years (van der Zel & Kruger, 1975). Protection from fire resulted in increases in above-ground biomass to 76 tonnes ha^{-1} after 37 years and led to senescence in dominant *Protea* shrubs (van Wilgen, 1982).
Abdolskloof catchment (Jonkershoek State Forest)	1938	Repeated fires at variable return intervals (3–10 years) and seasons.	Initially it was intended that fire treatments would be combined with heavy grazing by goats (to provide a contrast with afforestation), but grazing was not applied. An early analysis showed that stream discharge, and the rate of stormflow, both increased in the winter following a fire in autumn (Rycroft, 1947); no further results were published.
Overland flow plots (Jonkershoek State Forest)	1966	Plots of 0.8 ha were protected from fire, burnt, and slashed and hoed.	Increases in surface water runoff ("overland flow") were found to be negligible after burning (Versfeld, 1981).
Jakkalsrivier catchments (Lebanon State Forest)	1966	Spring, summer, winter and autumn burns applied at 5 and 10-year intervals, and protection from fire.	Jakkalsrivier was established as a research site to investigate the effects of fire, following a policy decision to initiate prescribed burning (Plathe & van der Zel, 1974). The vegetation was found to be highly stable under different burning treatments, recovering rapidly from fire. No recruitment was apparent in areas protected from fire for >25 years, leading to loss of some species (Kruger, 1986). The hydrological responses to fire from this experiment have not been analysed.
Zachariashoek catchments (Wemmershoek State Forest)	1968	Repeated fires at short (6-year) and moderate (12-year) return intervals and protection from fire	Zachariashoek was established as a research site to investigate the effects of fire, following a policy decision to initiate prescribed burning (van der Zel, 1974). Streamflow volumes increased by 11% in one catchment, and not at all in another after fire; the response was short-lived (Lindley *et al.*, 1988). Fire did not cause any marked changes to the composition and structure of fynbos communities (van Wilgen & Kruger, 1981).
Burning plots (Kogelberg State Forest)	1974	Repeated fires applied on 50 m × 50 m plots in spring, summer, autumn and winter	The Kogelberg plot burning experiment was established to compliment other experimental work, but with a focus on the ecological effects of fire season. Only one study reported short-term findings. Summer and spring burns had the least short-term effect on vegetation recovery, and autumn fires suppressed recovery; geophytes were stimulated to flower after a summer fire (Durand, 1981). Fire behaviour was quantified during experimental burns. Fire intensities ranged from 2000 to 6000 kW m^{-1} (van Wilgen *et al.*, 1985).
Burning plots (Cedarberg State Forest)	1979	Fires applied on 50 m × 50 m plots in spring, summer, autumn and winter	The Cedarberg plot burning experiment was established for the same reasons as the Kogelberg experiment, but in an area of more arid fynbos. Fire behaviour was quantified during experimental burns. Fire intensities ranged from 500 to 20 000 kW m^{-1} (van Wilgen *et al.*, 1985). No further results were published.
Swartboskloof catchment (Jonkershoek State Forest)	1984	Single late-autumn fire in 1987	Swartboskloof was managed as a Nature Reserve within the Jonkershoek State Forest. It had remained fire-free since 1958, and was scheduled to be burnt again in 1987. This provided the opportunity for a large-scale, coordinated and multidisciplinary study of responses to fire which was carried out under the auspices of the Fynbos Biome Project. Vegetation was found to be resilient to burning at intervals between 10 and 25 years, while forest patches persisted in fire-free areas. Streamflow would be marginally increased by regular (5 year intervals) burning, but some plant species would be lost at these short fire return intervals. No evidence was found that regular burning would deplete nutrient pools. See van Wilgen *et al.* (1992b) for a full account.

(*Continued*)

Table 2. Continued.

Experiment	Date initiated	Treatments	Notes and key findings
Moordkuil catchments (Ruiterbos State Forest).	1984	Three catchments to be burnt in autumn	Moordkuil was intended to expand the work on the ecological and hydrological effects of fire from the western to the southern Cape. The findings from this experiment have not been analysed.

species identified in the mountains near Stellenbosch were able to survive fire, either by sprouting or by regeneration from seed (van der Merwe, 1966). These were, however, isolated studies, and at the time of the Wicht Committee's report in 1945, only two new experiments (Abdolskloof and Langrivier, Table 2) had been established to investigate the effects of fire or its exclusion on fynbos. These two experiments were meant to provide controls against which to compare the effects of afforestation with pines, rather than to investigate the effects of fire *per se*. In 1957, the Department of Forestry resolved to conduct scientific research into the role of fire (Pooley, 2012, 2011), and experiments aimed at investigating the hydrological and ecological effects of fire were established during the 1960s and 1970s (Table 2). The appointment of Fred Kruger as research officer at Jonkershoek in 1966 led to the further development of understanding and to the publication of influential reviews on the role of fire and it's management in fynbos (for example Bands, 1977; Kruger, 1977b). Several additional researchers were appointed to work at the Jonkershoek (Stellenbosch) and Saasveld (George) Forestry Research Centres under Kruger's guidance in the early 1970s, setting the stage for the further expansion of understanding.

1978 to 1989: Developing a broad understanding

The year 1977 saw the launch of the Fynbos Biome Project, a sub-programme of the National Programme for Ecosystem Research (NPER). The NPER was established in South Africa in 1972 to address a wide diversity of complex environmental problems. Between 1977 and 1985, the Fynbos Biome Project supported 42 projects that produced 76 published papers and 8 theses (Huntley, 1987). Together with increased scientific outputs from the Department of Forestry's Jonkershoek and Saasveld Research Centres, these endeavours added at least 64 fire-related publications between 1978 and 1989 to the existing pool of knowledge (Figure 4). It was largely during this period that the ideas developed by Kruger and others were tested and results were published. These results arose from the formal experiments (Table 2), as well as from widespread studies that opportunistically used fires across the landscape to examine responses (for example, Bond *et al.*, 1984), and from review activities undertaken as part of the SCOPE programme on the ecological effects of fire (Huntley, 1978a; Kruger & Bigalke, 1984). Studies during this period focused on a number of aspects. Kruger & Bigalke (1984) documented vegetation recovery and succession at a range of sites in terms of mechanisms of fire survival, post-fire structural development and biomass accumulation. Researchers at Jonkershoek and Saasveld conducted several influential studies that focused on fire survival in serotinous (obligate reseeding) Proteaceae (Box 2), thus providing a basis for estimating the minimum and maximum fire return intervals needed for persistence (Bond, 1980; van Wilgen & Kruger, 1981), as well as responses to fires in different seasons (Bond *et al.*, 1984; van Wilgen & Viviers, 1985), and the role of small mammals in post-fire seed predation (Bond, 1984). Other studies documented the responses of myrmecochorous (obligate reseeding) Proteaceae, showing the vital roles played by ants in burying seeds (Bond, 1984), and of fire intensities needed to stimulate germination (Bond *et al.*, 1990). The ecology of cedar trees (*Widdringtonia cedarbergensis*) was documented in relation to fire (Manders, 1987), as was the ecology of important invasive alien trees (Australian *Hakea* and *Acacia* species, and European and North American *Pinus* species, Richardson & van Wilgen, 1986). Fynbos vegetation was described in terms of its fuel properties (van Wilgen, 1984b), and fire climates (van Wilgen, 1984a) and fire behaviour under a range of conditions was quantified (van Wilgen *et al.*, 1985). The effect of fire on nutrient cycling was examined (van Wyk, 1982), and the effect of burning on the yield of water from catchments was quantified (Lindley *et al.*, 1988).

Research conducted between 1978 and 1989 produced a fairly robust understanding of the ecology of fire in fynbos ecosystems. The impacts of fire return periods were interpreted in terms of their effects on serotinous Proteaceae, where short return intervals eliminated these shrubs (as they did not have time to mature and set seed between fires), and lengthy inter-fire periods resulted in senescence and poor post-fire regeneration. Fires at return intervals anywhere between 10 and 25 years were regarded as healthy and acceptable. The season of fire had been shown to have strong effects on the post-fire regeneration of serotinous Proteaceae, where winter and spring burns resulted in poor regeneration, and summer and autumn burns were characterised by good regeneration. Similar responses to seasonal variation in fire were found in flowering geophytes, and cedar trees (*Widdringtonia* species). The advantages of summer fires were also interpreted in terms of the fire climate, where summer was the time of year when fires would have occurred naturally, and to which the vegetation would have been adapted. It was further recognised that fire intensity was important, and that intense summer fires would be necessary to stimulate the germination of plant species with soil-stored seeds (see van Wilgen *et al.*, 1992b for a contemporary review).

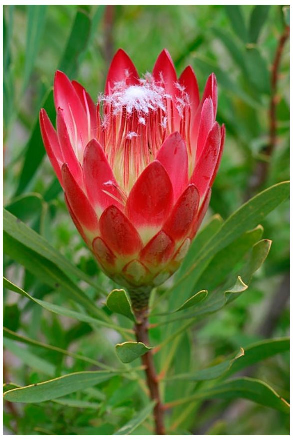
1990 to 2015: Consolidation

The Fynbos Biome Project ended in 1989, and the Department of Forestry's research programme (which had funded fire-related research in fynbos areas, see Table 1) was also scaled down and later terminated following the transfer of

Box 2. The role of Cape Proteaceae in informing fire ecology in the fynbos.

Shrub species in the family Proteaceae are often the dominant plants in fynbos vegetation. Many are killed by fire and rely on seeds for regeneration. As fire-sensitive, dominant and often charismatic species, they attracted the attention of researchers and managers alike. Several species in this family provided insights that were particularly influential in the formulation of understanding and of fire management policies.

Demonstrating safe fire return periods and seasons: Early studies of the sugarbush (*Protea repens*) provided the first estimates of appropriate fire return periods and burning seasons in fynbos ecosystems. Jordaan (1949) concluded that fires at intervals of at least 8 years were "safe" for *Protea repens* (and thus probably for other fynbos species). The same author later provided evidence that obligate re-seeding species (*P. repens* and *P. pulchella* [*now P. burchellii*]) would have "safe and dangerous fire periods", indicating that season of burn would be an important consideration (Jordaan, 1965).

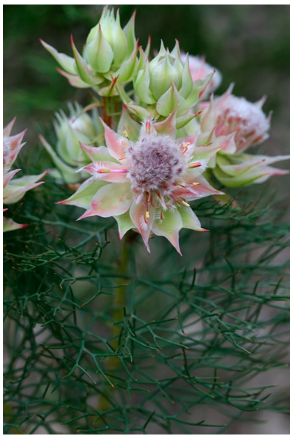


Protea repens (Photograph Sophia Turner).

Illustrating the need for fire: The charismatic marsh rose (*Orothamnus zeyheri*) was the subject of concern among early 20th century botanists as it was rare, sensitive to fire and subject to over-harvesting for the flower trade. Declining populations of the species were protected by fencing them off and hoeing a firebreak around the fence to protect the areas from fire. The immediate effect was the germination of several individuals in the hoed firebreak *outside* of the fence (Boucher & McCann, 1975). This, combined with a growing recognition of the role of fire in fynbos, led to deliberate burning of populations and subsequent substantial increases in populations regenerating from soil-stored seeds (Boucher, 1981).

Orothamnus zeyheri (Photograph Sophia Turner).

The blushing bride (*Serruria florida*) also attracted the attention of early conservationists who were concerned about the preservation of the species, given its limited distribution. Declining populations were protected by excluding fire, and in 1962 no plants remained on the protected site (Vogts, 1982). However, when the area burnt in a wildfire, many seedlings appeared and the species was re-established. A survey six years after a fire in 1979 revealed 3643 individuals, of which 57% had reached reproductive maturity, and Worth & van Wilgen (1988) suggested that the population was not yet ready for another fire, but that the post-fire recovery was additional clear evidence of the vital role of fire.



Serruria florida (Photograph Sophia Turner).

Illustrating the importance of high-intensity fires: The mace pagoda (*Mimetes stokoei*) is a spectacular, short-lived flowering shrub which was declared extinct after a series of low-intensity prescribed burns in 1971 and 1984 on sites of known historic occurrence failed to stimulate germination (Slingsby & Johns, 2009; Hilton-Taylor, 1996). Subsequently, a high-intensity wildfire in 1999 stimulated the germination of 24 seedlings, and the species' status was revised to "critically rare" (Raimondo *et al.,* 2009). This spectacularly reinforced the need for high intensity fires, which had previously also been demonstrated for *Mimetes fimbriifolius* (Bond *et al*., 1990).

Mimetes stokoei (Photograph Nigel Forshaw)

Demonstrating unsafe fire seasons: The regeneration of a wide range of shrubs in the Proteaceae family was quantified after fires in different seasons (Bond *et al.,* 1984; van Wilgen & Viviers, 1985), demonstrating that repeated fires in winter and spring could lead to poor seedling recruitment and ultimately to local extinctions.

the Department's research functions to the CSIR in 1990. This brought to an end the formal fire research programme of the 1960s to the 1980s. The period concluded with a synthesis volume outlining the current understanding (Cowling, 1992), and a second volume documenting the outcomes of the Swartboskloof burning experiment (van Wilgen & McDonald, 1992; van Wilgen *et al.*, 1992b). The latter addressed the ecological effects of fire in some detail, while the former contained a chapter that documented the ecological rationale that underpinned the policy of late-summer/early autumn prescribed burning at intervals of 12 years. However, a considerable amount of research continued, driven mainly by university-based ecologists. In their recent and comprehensive review of the drivers, ecology and management of fire in fynbos, Kraaij and van Wilgen (2014) cite over 100 papers relating to fire in fynbos that are dated 1990 or later (Figure 4). A number of significant advances in understanding, outlined below, have therefore emerged after the conclusion of the Fynbos Biome Project.

At the start of this period, the optimal fynbos fire return intervals were set at between 10 and 25 years, based on knowledge about the age to reproductive maturity, life span and seed longevity of obligate re-seeding plants (van Wilgen *et al.*, 1992b). However, evidence began to emerge that a fixed period between successive fires was not the norm, and that variation in fire return intervals on the same site was important. Variation in the intervals between fires, in fire season, or fire intensity will induce variation in the density of overstorey shrubs, which in turn maintains diversity in understorey species (Cowling & Gxaba, 1990; Vlok & Yeaton, 1999; Thuiller *et al.*, 2007). Pre-fire stand densities may also affect the density of post-fire recruitment (Bond *et al.*, 1995), resulting in alternating densities and species diversity on the same site between different fires. Recurrent fires will therefore buffer plant populations from extinction (Cowling & Gxaba, 1990), by ensuring stable co-existence over time, despite localised extirpation by individual fires.

Further evidence for the vital role of fire in the maintenance of fynbos ecosystems emerged when it was demonstrated that smoke acts as a germination cue in many fynbos plant species. De Lange & Boucher (1990) were the first authors to allude to this possibility. Subsequent testing of 221 fynbos plant species from 31 families (including the Proteaceae, Ericaceae, Restionaceae, Bruniaceae, Asteraceae, Fabaceae, Mesembryanthemaceae, Poaceae, Rutaceae, and Geraniaceae) has been conducted, mainly by Neville Brown and colleagues at Kirstenbosch (Brown, 1993). These studies have shown that 120 out of 221 species tested showed significant improvements in germination following exposure to smoke, and van Staden *et al.* (2000) concluded that the smoke response is phylogenetically widespread in the fynbos.

Important advances were also made in understanding the effects of fire on soil erosion. This arose from work by Dave Scott, a forester based at the Jonkershoek Forestry Research Centre. Scott compared stormflow responses and soil losses in two mature fynbos catchments (29 and 40 years post-fire at the time of burning) and a catchment afforested with pines. He found that neither of the fynbos catchments showed a change in storm-flow, while total flow increased by 12% in the afforested catchment, which also experienced soil losses (Scott, 1993). These soil losses amounted to 6 tonnes of soil per ha in the year following fire in pine plantations, compared to 0.1 tonnes per ha following fire in fynbos, with the losses being attributed to fire-induced water repellency in the soil, leading to erosion (Scott *et al.*, 1998). Further work following a wildfire on the Cape Peninsula concluded that similar effects followed fires in fynbos areas that had been invaded by alien trees and shrubs (van Wilgen & Scott, 2001). Although these soil losses were not sustained in subsequent years after fire, the link between fire, invasion and erosion was seen as a cause for serious concern (van Wilgen & Scott, 2001).

The relationship between co-occurring, fire-prone fynbos and fire-free Afromontane forest vegetation was elucidated during this period. Forests are relatively widespread in fire refugia, where they develop fuel properties that can exclude fires (van Wilgen *et al.*, 1990a). Coert Geldenhuys provided evidence that forests persisted in topographic shadow areas of hot, dry bergwinds that drive fires in the southern Cape areas (Geldenhuys, 1994a). Work by Pat Manders and others at the Swartboskloof research site (Table 2) led to the development of a conceptual model showing that succession to forest was possible at many sites in the fynbos in the absence of fire. Such development would require very long periods of fire exclusion (possibly a hundred years or more), so in effect the regular occurrence of fires excludes forest development (Manders & Richardson, 1992). Existing natural forests are therefore relatively stable features embedded in fire-prone fynbos landscapes.

It had long been appreciated that fires in the east of the biome were not as strongly seasonal as they were in the west, and that ecological responses to fire may differ between the east and the west. Very little ecological work had been carried out in the east, but this gap has been addressed by the work of Steffen Heelemann and Tineke Kraaij over the past 10 years. The eastern parts of the biome are characterised by shorter fire return intervals and an absence of strong responses to fire season (Heelemann *et al.*, 2008; Kraaij *et al.*, 2013b). These authors argued that the lack of strong differences in recruitment following fires in different seasons was in contrast to those in the western and central parts of the biome. Correspondingly, burning prescriptions for eastern fynbos could be less constrained by seasonal restrictions, and shorter fire return intervals could be tolerated.

Understanding fynbos fire regimes

The concept of fire regimes was originally introduced by Gill (1975), and it is currently interpreted as the pattern of fire occurrence over an extended period in a given area, characterised in terms of the frequency, seasonality, intensity and size of fires (Gill & Allan, 2008). Fynbos ecologists began to describe fire regimes in earnest about 25 years ago, once sufficient spatial fire records had accumulated, and this process was later substantially facilitated by the development of geographic information systems. The first serious attempt was initiated by Pat Brown and his colleagues at the Jonkershoek Forestry Research Centre in 1988 (Brown *et al.*, 1991). Their study sought to quantify the effects of 20 years of prescribed burning in the Cederberg mountains, and to compare the resultant fire regime with that of the previous 20 years when a policy of fire suppression was in place. Armin Seydack and his colleagues conducted a similar study in the Swartberg mountains (Seydack *et al.*, 2007, Box 3). Their aim was to elucidate the factors that drove fire regime patterns under three successive management approaches that sought firstly to promote grazing, then to control fires, and finally to conserve water and biodiversity. Further studies quantified the fire regimes in Swartboskloof in the Jonkershoek State Forest (van Wilgen & McDonald, 1992) and the Cape Peninsula (Forsyth & van Wilgen, 2008). The most comprehensive study quantified fire regimes over 40 years within 10 fynbos protected areas covering >720 000 ha (van Wilgen *et al.*, 2010), with the final gap (in the far eastern Tsitsikamma region) being addressed by Tineke Kraaij and her colleagues (Kraaij *et al.*, 2013c). The net result is that a fairly comprehensive understanding of fire regimes now exists (Figure 5). The determinants of fire and the outcomes in terms of elements of the fire regime are outlined briefly below.

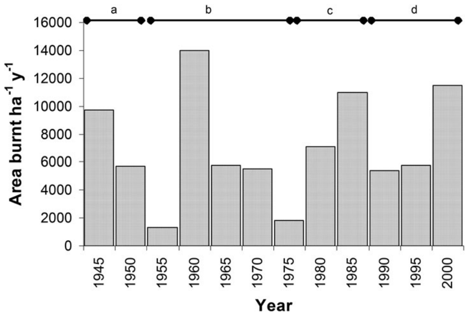
Box 3. The Swartberg natural fire experiment.

Box text and Figure provided by William J. Bond (from Keeley *et al.*, 2011).

Among the various approaches to fire management in fynbos is a unique "natural fire policy" conducted in "natural fire zones" (Seydack *et al.*, 2007). The natural fire zones are an interesting management experiment in the Cape. Seydack *et al.* (2007) provided a comparison of fire regimes under different management policies, including 20 years under natural fire management, in the Swartberg mountains of the eastern inland ranges of the CFR. The Swartberg is a narrow lozenge-shaped mountain rising to 2000m elevation from arid shrublands in the lowlands. Because fires in the mountains pose little threat to adjoining properties, a "natural fire" management regime was implemented in the 1980s and has been maintained to the present. Fires ignited by lightning were allowed to burn without interference, whereas fires of human origin were prevented from spreading wherever practical. This regime contrasts with earlier periods of fire suppression and prescribed burning in the Swartberg at different times during 20th century. The experiment provides a rare perspective on determinants of fynbos fire regimes with, and without, human intervention.

The "natural burning zone" management regime was successful in greatly reducing the area burned by anthropogenic fires (to <25% per year). Initially the annual area burned (by lightning fires) was much lower than the previous era of prescribed burning, suggesting that natural fires occurred less often than the usual assumption of ~15 years. However, the impact of fire policies on the fire regime have to be evaluated against longer term cycles in area burned. Seydack *et al.* (2007) analysed the data in 5-year periods from 1941 to 2000. There were four 5-year periods when the mean area burned annually equalled or exceeded 10 000 ha. These peak burning periods recurred at intervals of 15, 25 and 15 years, more or less the mean fire return interval for fynbos. Seydack *et al.* (2007) suggest that the peaks in fire activities are associated with periods of more active summer convectional storms bringing more summer rain and also lightning activity. However periods of high fire activity followed long periods of low activity under cool moist conditions during which fuel accumulated. This suggests that both fuel and weather conditions influenced natural fynbos fire regimes and the frequency and extent of large fires. Multi-year periodicity of fire activity also means that the effects of different management policies on fire regimes are difficult to assess unless maintained for many decades.

For the available data, fires were significantly smaller in eras of fire suppression (1951–1974) and prescribed block burning (1975–1985) versus under "natural" (lightning) fires (1986–2002) (mean and median ha: suppression 761, 84; prescribed 601, 171; "natural" 1430, 276). The area burned per year in the three eras was 5612, 9015 and 7907 ha, respectively but Seydack *et al.* (2007) attributed the variation largely to multi-annual cycles in climate patterns. The most noticeable differences between the management approaches were changes in fire season, with fires during the "natural" fire era shifting to the summer months with fewer fires in spring and autumn relative to historical fire regimes.



Mean area burned per annum for 5-year periods in the Swartberg Mountain range under different management regimes. The year indicated is the last year in the 5-year period. Management policies were: (a) burning for grazing; (b) fire exclusion and suppression; (c) prescribed burning in "blocks" separated by a network of firebreaks; and (d) natural fires. Graph modified from Seydack *et al.* (2007). They attributed the periodicity in area burned to cool moist periods during which fuel accumulates, and during which less area burns; and warm drier periods with convectional (lightning) summer storms, when more area burns.

Determinants of fire regimes: The occurrence of fires requires hot and dry weather conditions, sufficient fuel to support a spreading fire and a source of ignition. Fire regimes are determined by the frequency with which all three of the necessary conditions co-occur. Hot and dry weather is strongly seasonal in the western parts of the fynbos biome (where weather conducive to fires occurs predominantly in summer), whereas it has a bimodal seasonal distribution in the east; coastal regions experience less severe fire weather than inland regions (Figure 5). The amount of fuel (in the form of above-ground phytomass) increases with post-fire age, from 6–9 tonnes ha^{-1} 4 years post fire, to 6–15 tonnes ha^{-1}10–19 years post fire and 11–76 t tonnes ha^{-1} ≥20 years post-fire. Fynbos vegetation can build up enough fuel to support a spreading fire 4 years post-fire, so that the occurrence of fires is not limited by fuel availability once the vegetation reaches a post-fire age of 5–6 years. Lightning is an important source of ignition (Kraaij *et al.*, 2013a) and human sources are growing in importance (Forsyth & van Wilgen, 2008; Pooley, 2014).

Fire frequency: Average fire return intervals in fynbos vegetation are between 10 and 20 years, but intervals between individual fires can range from 7 to 55 years. Fire return intervals are shorter in the Tsitsikamma region and lowland fynbos, and longer in drier areas such as the Swartberg Mountains (see Kraaij & van Wilgen, 2014 for a recent review). Although average fire return intervals are a useful measure, the averages obscure the variability in burning patterns, and such variability can be ecologically important. Moisture availability affects plant growth rates, and fires generally become more frequent where the length of the dry season is reduced, e.g. from west to east in the eastern coastal region (Kraaij *et al.*, 2013c) and along altitudinal rainfall gradients (Seydack *et al.*, 2007). There is evidence that fires are becoming more frequent in some areas (Forsyth & van Wilgen, 2008; Southey, 2009;

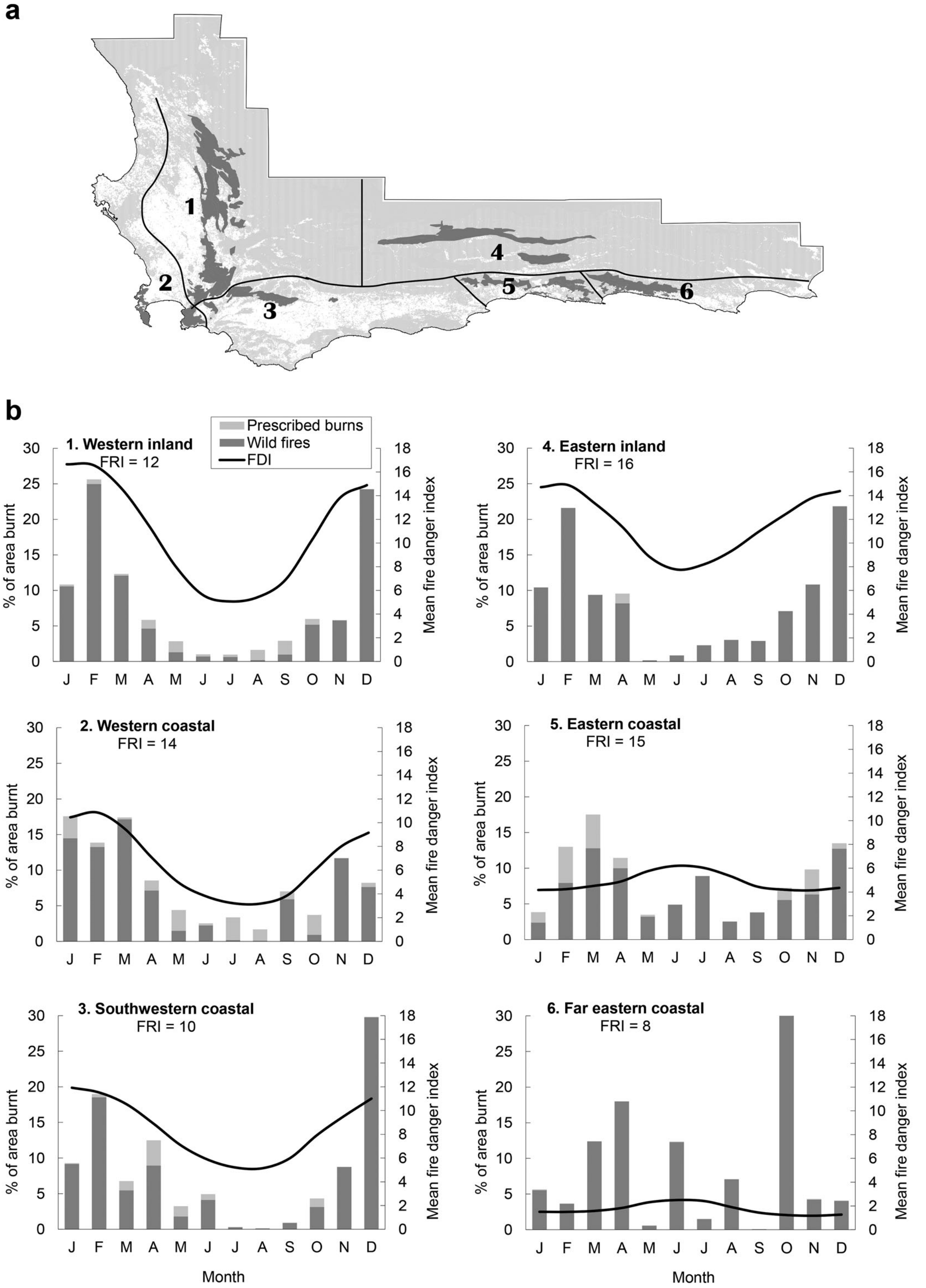


Figure 5. (a) Fire climate zones in the Cape Floristic Region also showing the extent of untransformed vegetation (light grey) and some protected areas (dark grey). (b) Monthly distribution of area burnt in wildfires (dark grey bars) and prescribed burns (light grey bars) in selected protected areas per zone in relation to mean monthly McArthur's Forest Fire Danger Index (solid lines). FRI = the mean fire return interval for each climate zone. From Kraaij and van Wilgen (2014).

Kraaij *et al.*, 2013c), at least in part because of an increase in ignitions arising from growing human populations and increased access to previously remote fynbos areas (Pooley, 2014).

Fire season: Fires can occur in fynbos vegetation throughout the year, but are concentrated in the late summer and early autumn (November–March) in the west. Towards the east, and notably in the coastal areas, fires can occur in any season, tending to occur during times of elevated fire danger conditions (Figure 5). In eastern inland areas, high evapotranspiration in the summer months results in more fires in the summer and early autumn. Fire season effects are correspondingly more marked in areas where fires are strongly seasonal, and less so in areas where fires can occur throughout the year (Kraaij & van Wilgen, 2014).

Fire intensity: Fire intensity (the rate at which energy is released during combustion) can vary by at least two orders of magnitude (from 500 to 50 000 kW m^{-1}, see van Wilgen *et al.*, 1985, 1990b), depending on the amount of fuel available, and the weather conditions under which it burns. Fire intensity tends to be much lower during prescribed burns than in wildfires, and this can have important ecological implications. Currently, though, most of the area (~ 89%, van Wilgen *et al.*, 2010) burns in relatively high-intensity wildfires.

Understanding the ecology and impacts of invasive alien plants

Understanding plant invasions globally and within South Africa before 1945

In 1945 there was no field of "invasion ecology" or even any syntheses or general appreciation of the phenomenon of biological invasions. Several 19th century naturalists, notably Charles Darwin, Alphonse De Candolle, Joseph Hooker and Charles Lyell, wrote about invasive species, but rather as curiosities, and not as major threats to local, let alone regional or global, biodiversity. Invasions started becoming much more widespread in the last few decades of the 1800s and the first few decades of the 1900s, but biologists were slow to focus attention on the phenomenon (Richardson & Pyšek, 2007, 2008). Charles Elton's book *The Ecology of Invasions by Animals and Plants* (Elton, 1958) is widely regarded as the start of the systematic, scientific study of biological invasions. Elton brought together previously disparate themes (biogeography, conservation biology, epidemiology, human history, population ecology and others) to show the true global scale of biological invasions and the severe and escalating implications that they have for life on earth (Richardson & Pyšek, 2007). Invasive plant species began to spread over large areas in the late 1800s and early 1900s, including species which are now regarded as some of the worst invaders globally. For example, *Bromus tectorum* spread across grasslands in North America reducing grazing and changing fire regimes; water hyacinth, *Eichhornia crassipes* was introduced to Egypt, India, Australia and Java well before the end of the 19th century; opuntioid cacti invaded large areas of agricultural land in Australia and South Africa; and by the 1940s *Tamarix* spp. were well established along rivers in the Western USA. However, the species and invasions mentioned by the Wicht Committee were remarkable for the rate and extent to which they were invading pristine ecosystems. Although pines started spreading from plantings in Australia and New Zealand at about the same time (Richardson & Higgins, 1998), such invasions were nowhere near as striking or as widespread as those observed in the CFR. The Wicht Committee's observation of the current and potential impacts of invasive plants on what today would be called "ecosystem services" (the term was first used in the late 1970s) was also ground-breaking.

Several obscure references from around 1850 allude to the start of the widespread invasion of alien plants in South Africa (Richardson *et al.*, 1997). Prolific natural regeneration of *Pinus pinaster* (and possibly *P. halepensis*) was observed near Caledon in around 1855 (Lister, 1959). The first campaign against an alien plant (*Xanthium spinosum*) in South Africa was launched in 1860. In 1863, farmers around Bathurst met to discuss rapid spread of *Hakea sericea* (Phillips, 1938). At this time there was, however, still little evidence that invasive plants were considered a serious threat to biodiversity. For example, Bolus (1886) wrote "it is remarkable how small upon the whole is the influence exerted upon the aspect of the vegetation and how weak … is their aggressive power against the indigenous flora". By the early 1890s, the earliest records of widespread pine invasions in the southern hemisphere started appearing. For example, Sim (1927) wrote of *P. pinaster* "gradually taking possession … of the face of the mountain above Cape Town". At around this time, the first references by botanists to the fact that invasive alien plants were starting to have impacts on indigenous vegetation appeared. Sim (1927) wrote: "the extent to which *Pinus pinaster* can take possession indicates that, if given a long enough period without check, it would probably kill out some of the endemic monotypes". Similarly, Adamson (1938) mentioned that several trees and shrubs "spreading near towns and villages … have either altered or completely changed the character of the vegetation". He also wrote about Australian wattles (*Acacia* species) which had "spread over quite large areas and become completely dominant" on parts of the Cape Flats, and *Hakea* species which were behaving in a similar way on mountain slopes. Such reports are in line with the statements in the Wicht Committee's report (Wicht, 1945).

Biological control against invasive alien plants in South Africa began in 1913, but it was not until the 1970s that concerted efforts at biological control were directed towards alien plants invading the CFR (Moran *et al.*, 2013). Some other attempts at controlling invasive alien plants also began in the early 1900s, but these, and the Weeds Act (Act 42 of 1937, see below), had very little, if any, influence on the management of woody invasive plants in the CFR. The first control efforts against the invasive acacia trees at Cape Point started in the 1940s but these efforts were poorly coordinated and there was no institutional support; there is no evidence that any of these early operations were effective in clearing areas or in slowing spread (Macdonald *et al.*, 1989).

The Wicht Committee's views on invasive plants

The Wicht Committee's report identified "suppression through the spread of vigorous exotic plant species" as "one of the greatest, if not the greatest, threats" to the preservation of vegetation in the CFR. It further emphasised that the suite of invasive plants that were spreading in the CFR were "extremely difficult to control and possibly are already out of hand". It offered the prognosis that "unless enormous sums of money are expended on their eradication or control they will become dominant everywhere except in nature reserves and other selected areas where they will constantly be destroyed." The report also succinctly detailed the potential for emerging conflicts of interest between foresters and conservationists and the potential for large impacts on water resources of the region.

What was known of the ecology of the main invasive species of the time was briefly discussed, especially the key role of fire in the proliferation of the invaders. Brief observations were made on invasions of riparian ecosystems, where it was observed that "especially in the vicinity of human habitations, the indigenous trees and tree-like species have mostly been replaced by woods composed of exotic trees". Special mention was made of poplars, oaks, acacias and pines.

The report related the phenomenon of invasion to perceptions of harm, using words such as "dangerous" and "undesirable", discussed the reasons for the introduction and dissemination of the species, identified fire as a key mediator of invasions, placed recommendations for management in the context of an overall conservation strategy, and mentioned key impacts and potential conflicts of interest. The report offered suggestions on management actions required to reduce further invasions, including the suppression of fires. Consideration was given to the scope of existing legislation (the Weeds Act, see below), and whether this instrument provided adequate power to deal with the rapid spread of invasive plants in the CFR. The report argued that the responsibility for controlling these invasive species rested with the government and considered it unrealistic to expect private landowners to deal with dense invasive stands. Importantly, given the predicted extent and scale of the problem, a key recommendation of the Wicht Committee was to confine interventions to "only … selected areas, such as proclaimed nature reserves". The reason for this was that "uncoordinated, casual attempts … are usually inadequate". The report therefore recognised that control everywhere was unrealistic, and that for management to be effective it should focus on priority areas and leave the rest.

1946 to 1969: Early concerns

Despite the observations in the Wicht Committee's Report regarding the magnitude of the threat posed by invasive alien plants to the ecosystems of the CFR, not much research was done between the 1940s and the start of the 1970s. In 1961, a "Hakea conference" was held in Stellenbosch (Serfontein, 1961), where, among other things, the possibility of investigating biological control for hakeas was discussed.

1970 to 1979: Early research on alien plant ecology and biological control

Substantial research on invasive plants was carried out between the late 1970s and early 1980s at universities in the CFR, notably the University of Cape Town. Some key products in this phase were Sue Milton's MSc thesis on Australian wattles (*Acacia* species) in the south western Cape (Milton & Hall, 1981), Gwen Shaughnessy's PhD thesis on the history of alien woody plants around Town (Shaughnessy, 1986), and publications by Anthony Hall and co-workers on the threats to fynbos plant species that included preliminary assessments of the relative role of plant invasions (e.g. Hall, 1978). This period also saw the start of substantial research on invasive plants in South Africa as part of the Cooperative Scientific Programmes (CSP) of the Foundation for Research Development (Huntley, 1987). Invasive trees and shrubs were a strong focus of work conducted as part of the Fynbos Biome Project of the CSP (Macdonald & Richardson, 1986; Holmes *et al.*, 1987; Witkowski, 1991; Richardson *et al.*, 1992; Stock *et al.*, 1995).

Research into the biological control of invasive alien plants in the CFR also started in earnest in the 1970s, with projects aimed at the control of *Hypericum perforatum* primarily in agricultural areas, and *Hakea sericea*, *H. gibbosa* and *Sesbania punicea* in natural areas (Annecke & Neser, 1977). In the 1980s, the programme was broadened to include *Acacia longifolia*, *A. melanoxylon*, *A. pycnantha*, *A. saligna* and *Paraserianthes lophantha* (Moran *et al.*, 2013). However, there was stiff resistance to the development of biological control methods aimed at *Acacia mearnsii*, because of the tree's commercial value. Stubbings (1977), in an article entitled "ACACIA" (the title was an acronym for "A case against controlling introduced acacias") argued that the species was too valuable as a timber crop in the summer rainfall areas to be subjected to biological control, a view that was countered by Lückhoff (1977), who pointed to the serious problems that the species caused in the Cape.

1980 to 1992: Contributions to global understanding

During this period, invasions in the CFR were placed in an international context, with special emphasis on comparisons with other Mediterranean-type ecosystems (MTEs; Kruger *et al.*, 1989) and protected areas worldwide (Macdonald *et al.*, 1988). The hosting of the 1980 MEDECOS conference (focusing on the ecology of MTEs) in Stellenbosch was a milestone for ecological research in the fynbos (Kruger *et al.*, 1983). One of the most lasting outcomes of this meeting was a resolution by delegates from all of the world's MTEs to approach the Scientific Committee on Problems of the Environment (SCOPE) to motivate for an international programme on the ecology and management of biological invasions (Mooney, 1998). The international SCOPE programme on biological invasions was launched in 1982 and the South Africa programme started in 1983. The international SCOPE programme on the ecology and management of invasive alien species resulted in the production of a major synthesis of all aspects of invasive species in South Africa (Macdonald *et al.*, 1986), and an assessment of invasive plants as a threat to the Cape flora was also produced (Hall, 1978).

Many research projects were initiated directly or indirectly through the SCOPE programme. The South African (Macdonald *et al.*, 1986) and global (Drake *et al.*, 1989) synthesis volumes from this programme included much material on plant invasions in the CFR (notably Breytenbach, 1986; Macdonald & Richardson, 1986; Neser & Kluge, 1986; Shaughnessy, 1986; Versfeld & van Wilgen, 1986; Kruger *et al.*, 1989). This represented the first major comparison of invasion ecology in the CFR with that from other parts of the world. The SCOPE programme also led to many publications after the completion of the formal programme, many of them inspired by collaborations initiated during the SCOPE initiative (e.g. Rejmánek & Richardson, 1996). The programme resulted in an upsurge in research interest in biological invasions globally (Richardson & Pyšek, 2007) and in the CFR (Richardson *et al.*, 1997). Among the main thrusts of invasive plant research at this time were projects on the impacts of invasions on fire regimes (van Wilgen & Richardson, 1985), nutrient dynamics (Witkowski, 1991; Stock *et al.*, 1995), coastal sediment movement (Lubke, 1985), species diversity (Richardson *et al.*, 1989), ecosystem properties (Versfeld & van Wilgen, 1986) and on understanding the invasion dynamics of key species (Pieterse & Cairns, 1986; Richardson & Brown, 1986), invasion processes in fynbos in general (Richardson & Cowling, 1992), and the development of a risk assessment framework (Tucker & Richardson, 1995). Several projects focused on compiling accurate inventories of alien plant species for particular areas (e.g. Macdonald *et al.*, 1987) and re-assessing the status of invasive species decades after previous assessments and various management efforts (e.g. Moll & Trinder-Smith, 1992). There were also detailed studies to determine the effectiveness of different control methods (e.g. Holmes *et al.*, 1987) and on approaches for ecosystem management in general (van Wilgen *et al.*, 1992a). A computerised catchment-management system which included modules for aiding decision-making for invasive species management was developed for the fynbos (Richardson *et al.*, 1994).

Research into the biological control of invasive alien plants in the CFR was also expanded in this period. After overcoming the initial resistance to biological control from the wattle industry, a project against *Acacia mearnsii* was initiated and control agents were released. Quests to find biological control agents for *Acacia cyclops*, *Leptospermum laevigatum* and *Pinus pinaster* also began. The work on *Acacia* yielded good results (Impson *et al.*, 2011), but in the case of *P. pinaster*, at least one suitable agent (the cone-feeding weevil *Pissoides validirostris*) was identified. However, the work was terminated after a decade of research, due to concerns of the forest industry about the possible interactions between the agents and a fungal pathogen, *Fusarium cincinatum* (a major pathogen of pines, Lennox *et al.*, 2009).

1993 to 2001: Demonstrating impacts on ecosystem services

At the start of the 1990s, van Wilgen *et al.* (1992a) predicted that the most likely scenarios for alien plant control (decreased or terminated funding) would lead to ongoing invasion and reductions in streamflow of between 21 and 50%. They concluded that "the real costs of this, in terms of reduced water supplies to cities, industries, and agriculture are probably enormous". This led to a determined effort by ecologists to improve the estimates that underpinned these rough scenarios, and to motivate for action. In November 1993, the broad scientific community with interests in the management of vegetation met to review progress, and to formulate an agreed and well-motivated case to the government for controlling invasive alien plants in the CFR (Boucher & Marais, 1993). The meeting recommended the compilation of a promotional "roadshow", and to and present this widely to local decision-makers.

By 1994 the underpinning research (based on afforestation experiments at Jonkershoek) estimated that, if unchecked, alien plant invasions would potentially reduce water supplies to the city of Cape Town by 30% (Le Maitre *et al.*, 1996). It was also estimated that more water could be delivered, at a lower unit cost, through the integration of alien plant control and the maintenance of water supply infrastructure (van Wilgen *et al.*, 1996). This information was presented to Kader Asmal (the Minister of Water Affairs) on 2 June 1995, and this in turn led to the establishment of the Working for Water programme that sought to combine the need for alien plant control with the opportunity to provide much-needed employment for the rural poor (van Wilgen & Wannenburgh, 2016).

A major assessment of the status of biodiversity in the Cape Peninsula was also undertaken in the mid-1990s. This included the most detailed, spatially-explicit assessment of key threats to the biodiversity of any part of the CFR undertaken until that time. The distribution of invasive alien plants was mapped using remote sensing and field surveys. These provided a key input to the overall plan for conservation management of the area and for the establishment of the Table Mountain National Park (Richardson *et al.*, 1996; Higgins *et al.*, 1999).

The Working for Water programme also provided much-needed funding for the continuation of research into biological control research during this period. In 2004, Zimmermann *et al.* (2004) summarised this as follows:

> "There is little doubt, in retrospect, that if it had not been for the active intervention of Working for Water, the practice of weed biological control in South Africa would have languished, perhaps almost stopped. Weed biological control research and support personnel at the PPRI [Plant Protection Research Unit] are beleaguered by numerous regulatory, political and financial restraints, but the funding and support from Working for Water has at least stabilised the situation, and, in many respects, has invigorated the practice. From a Working for Water perspective, support of biological control is imperative. Without biological control as an aid in the management of invasive alien plants the whole enterprise of weed control would be far more costly and, in the long term, ineffective. Current mechanical and chemical control procedures cannot be financed at present levels in perpetuity and biological control has to play an increasingly important role if Working for Water is to succeed".

2002 to 2015: The growth of invasion science

The start of the 21st century saw an upsurge in research to improve the understanding of invasions in the fynbos, much of it with clear implications for management. A milestone was the "Inaugural Working for Water Research Symposium" in 2003 which sought to collate the scientific underpinnings of invasive plant management in South Africa (van Wilgen, 2004). Key contributions from this conference that related to the CFR addressed:

- the driving forces of plant invasions in South Africa (Le Maitre *et al.*, 2004);
- issues relating to the link between invasions and water resources (Görgens & van Wilgen, 2004);
- the role of resource economics in management invasive plants (Turpie, 2004);
- the ecology and implementation (Zimmermann *et al.*, 2004) of biological control, and costs and benefits of biological control (van Wilgen *et al.*, 2004);
- impacts (Richardson & van Wilgen, 2004);
- the relative roles of plant invasions and other threats to biodiversity (Latimer *et al.*, 2004);
- costs and progress in clearing invasive plants (Marais *et al.*, 2004); and
- social benefits of the Working for Water programme (Magadlela & Mdzeke, 2004).

The 2003 conference served to raise the key scientific issues and related research challenges for a project as large and ambitious as the Working for Water programme. The papers collected in the special issue of *South African Journal of Science* (van Wilgen, 2004) have stimulated much additional research on all of the abovementioned themes. Summarising the outputs of the abovementioned 2003 conference, Macdonald (2004) emphasised the need for further research to strengthen the scientific understanding of biological invasions and their impacts. At the time, research efforts in this direction were scattered across universities and several parastatal organisations.

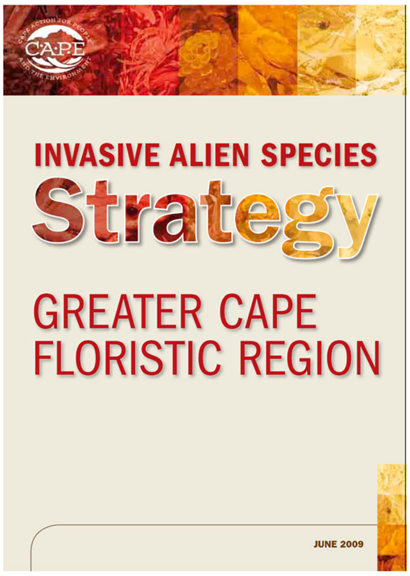
A milestone towards greater integration in research was the establishment of the Centre for Invasion Biology (C•I•B) in 2004 (van Wilgen *et al.*, 2014). The C•I•B was one of the first six "Centres of Excellence" created by South Africa's Department of Science and Technology in all fields of science in 2004, in recognition of the major challenge that biological invasions posed to the South African environment. The establishment of the C•I•B acted as a catalyst for further research initiatives and helped build the human capacity for dealing with the escalating problems of biological invasions.

In 2007 the C•I•B, with support from Cape Action for People and the Environment, held a workshop on the "Ecology and management of alien plant invasions in South African fynbos: Accommodating key complexities in objective decision making". The rationale for the workshop was that the less than ideal progress in the Working for Water programme in fynbos ecosystems was a result of "the complex interactions among factors that influence the dynamics of the invasive species, and the interplay with a wide range of socio-political issues". A product from the workshop applied two widely used decision-support tools [the DPSIR (Driving forces-Pressure-State-Impacts-Responses) framework and the Analytic Hierarchy Process (AHP) tool] to identify key barriers for effective management and to propose a strategy for prioritising management actions (Roura-Pascual *et al.*, 2009). This exercise was influential in formulating an Invasive Alien Species Strategy for the Greater Cape Floristic Region (Box 4).

In 2011 the National Biodiversity Assessment suggested that the extent of woody plant invasions in South Africa had increased substantially between the mid-1900s and 2010, although robust studies to substantiate this have yet to be published. An assessment of the progress of control operations in the CFR (van Wilgen *et al.*, 2012b), suggested that there may have been some progress with the control of some invasive alien tree species, but not all. The study found that *Acacia cyclops* and *A. saligna* may have declined in abundance as a result of the combined effects of clearing by Working for Water, significant but unrecorded clearing by firewood cutters (not accounted for in Working for Water's records) and a substantial degree of biological control. Similarly, there were indications that *Hakea* species had declined because of historic (pre-1995) mechanical clearing, ongoing clearing by Working for Water, and a substantial degree of biological control (Esler *et al.*, 2010). However, there was no indication that the extent of invasion by either *Acacia mearnsii* or *Pinus* species had decreased, despite significant spending. About 24% and 12% of the estimated area occupied by *A. mearnsii* and of *Pinus* in 1996, respectively had been treated, but there was no real indication that the invasions had decreased, and gains made in the control of *Hakea* species are probably being offset by invasion by *Pinus* species. While biological control may become more effective as the seed-reducing agents on *Acacia mearnsii* spread, there is no such solution available for *Pinus*. Van Wilgen *et al.* (2012b) concluded that invasions of the rugged and inaccessible mountain areas by *Pinus* species poses "the most significant threat to the integrity of fynbos ecosystems", echoing the predictions of the Wicht Committee 70 years previously.

This information was included in South Africa's 2011 "National Biodiversity Assessment" which added that "at least R6.5 billion of ecosystem services are lost every year as a result [of these invasions]"and that "there is huge scope to scale up natural resource management programmes such as Working for Water, with coupled job creation and ecosystem service benefits" (Driver *et al.*, 2012).

Box 4. The CAPE Invasive Alien Species Strategy for the Greater Cape Floristic Region.



In response to alien plant invasions reaching crisis proportions in the CFR, the Cape Action for People and the Environment (CAPE) commissioned the development of a comprehensive invasive alien strategy with funding from the Global Environmental Facility and the World Bank. Following a series of stakeholder workshops under the aegis of the CAPE Alien Species Task Team, the strategy was published in 2009 (Anonymous, 2009). Its vision was that by 2020 the negative impacts of invasive alien species on the economic, ecological and social assets of the greater CFR would have been significantly reduced; in the future no indigenous species will be driven to extinction by invasive alien species; and sustainable programmes will be in place to minimise any future impacts. The strategy listed six goals, briefly to:

Ensure management within appropriate policy and legislative frameworks;

Improve collaboration between all role-players;

Enable better understanding through awareness-raising and education;

Prevent new introductions, or detect and eradicate species before they become widespread;

Ensure the integration of control measures; and

Promote adaptive management.

Several research projects were undertaken and tools developed to give effect to the strategy, such as the development of a spatial decision support tool for prioritisation and scheduling of invasive alien plant interventions (Roura-Pascual *et al.*, 2009) and the prioritisation of species and primary catchments for the purposes of guiding the invasive plant operations in the terrestrial biomes of South Africa (van Wilgen *et al.*, 2007).

However, despite the best of intentions, this strategy has not achieved much. The governance models that it put forward, including the establishment of a steering committee, task teams and working groups, have not materialised. With hindsight, the strategy had several serious drawbacks. Although it recognised the need for realistic targets, none of its goals were measurable or time-bound, as would be required if they were to be effective. In addition, being externally funded, the strategy was not initiated or adopted by top management structures, and was therefore essentially ignored. The strategy provides an example of the way in which organisations tasked with the management of invasive species have little influence over implementation, especially under the current funding models (see text for further discussion).

What has changed over 70 years?

Comparisons of the text dealing with invasive plants in the Wicht Committee report with the recent review by Wilson *et al.* (2014) reveals some differences that reflect important changes over 70 years. The appreciation of invasive species as a threat to biodiversity and ecosystem services has grown and invasive alien plants are now widely appreciated as a major threat to biodiversity in the CFR. The major changes between 1945 and 2015 are summarised below.

The scale of the problem and species involved: In 1945, the Wicht Committee noted that "exotics are extremely difficult to control and possibly are already out of hand", and that " … unless enormous sums of money are expended on their eradication or control they will become dominant everywhere … ". This view has not changed (see Wilson *et al.*, 2014 and references therein). Many landscapes in the CFR are currently dominated by alien plants. Around 21% of the total untransformed area of the CFR has been invaded (Wilson *et al.*, 2014). This is mostly close to urban areas and along rivers. Many drier and more remote regions are not yet seriously invaded. The cost of reducing the size of problem and preventing further spread would probably be beyond the means of government and private landowners.

The main invasive species identified by the Wicht Committee are still by far the most troublesome in terms of management, but several additional species have become major invaders over the years. Particularly in riparian ecosystems, there have been important changes in dominance. *Acacia mearnsii* was not mentioned by the Wicht Committee, but is now the most widespread woody invasive plant in these habitats in most parts of the CFR. *Sesbania punicea* only started invading riparian systems in the Cape well after 1945 (but has now been brought under effective biological control). *Eucalyptus camaldulensis* is also a recent addition to the list of very widespread invaders. Recently, there has also been a dedicated focus on studying species before they become widespread invaders (Wilson *et al.*, 2013), e.g. on Australian *Acacia* (e.g. Zenni *et al.*, 2009), *Banksia* (Geerts *et al.*, 2013) and *Melaleuca* (e.g. Jacobs *et al.*, 2014).

Key determinants of invasions: The Wicht Committee clearly mentioned the role of introductions by different forms of forestry as the cause of the incipient invasions at that time. It was stated that "In the past afforestation with exotic pines has in places been carried out on uneconomic sites, sometimes at high cost … extraction costs are too high to render the practice remunerative … These errors are no longer made by government forest officers … [but] many unsuitable sites are still being planted up by unenlightened persons". Plantings that were made for forestry and sand stabilisation are still the key source for most invasions of *Pinus* and *Acacia* invasions in the CFR (McConnachie *et al.*, 2015). However, in the last few decades many additional invasive trees in the CFR were introduced for ornamental horticulture or for cut flowers; the importance of these causes of invasions has emerged only recently. The Wicht Committee gave no consideration to the importance of introduction pathways and on the importance of patterns of dissemination within the region as mediators of invasions, but these factors have been shown to be important (e.g. Donaldson *et al.*, 2014; Potgieter *et al.*, 2014).

Debate regarding the financial and environmental sustainability of commercial plantation forestry in the CFR has intensified, especially in the last two decades (van Wilgen & Richardson, 2012). Many afforested sites have been abandoned, and formal "exit" plans have been instituted. Fire is increasingly impacting on plantations, further questioning the economic sustainability of commercial forestry in the region. Methods have been developed to determine the extent to which plantations contribute to invasions (currently estimated at greater than 50%, McConnachie *et al.*, 2015).

Although guidelines for reducing invasions from plantations of high-risk species have been published (Richardson, 2011) and methods for monitoring invasions from plantations have been proposed (Visser *et al.*, 2014), there has been minimal compliance with, and no enforcement of, existing legislation. Voluntary guidelines for sustainability in forestry such as the Forestry Stewardship Council standards include guidelines for reducing invasions from plantations but there is no evidence that these have been implemented or have reduced spread from plantations in the CFR.

The types and overall magnitude of impacts: In the 1940s, the main concerns regarding the spread of invasive species were related to their impacts on the native flora and on water. The Wicht Committee noted that "One of the greatest, if not the greatest, threats to which the Cape vegetation is exposed, is suppression through the spread of vigorous exotic plant species", and that "the natural character of the vegetation is being changed by intruding exotic species. In many localities foreign species are dominating and replacing the indigenous ones." It was also recognised in the 1940s that "an artificial community" (e.g. *Eucalyptus*) may dry rivers through transpiration. This was viewed as particularly serious with extreme variations in flow, as perennial rivers can run dry in summer, and lead to erosion and subsequent flooding in winter.

Plant invasions are still viewed as one of the major threats to the water resources and biodiversity of the CFR. The direct reduction in water production from catchments due to the increased biomass and therefore increased transpiration and interception is a cornerstone for justifying government expenditure on the problem (Le Maitre *et al.*, 1996). To the threats listed by the Wicht Committee, two more have been added. These are urbanisation (Rouget *et al.*, 2003c), and climate change (see below). Substantial research has elaborated on how changes to the "natural character of the vegetation" can drive changes to biodiversity and ecosystem functioning. Work has also been done to document, explain and help predict the effects of invasive plants on fire regimes (van Wilgen & Richardson, 1985), nutrient cycling (Stock *et al.*, 1995; Yelenik *et al.*, 2004) and on the many ways that invasions alter habitats for native biota (e.g. Breytenbach, 1986).

Economic aspects related to alien species: The Wicht Committee noted that the spread of invasive species would be economically beneficial, and potentially good for water resources (under certain conditions). They suggested that only botanists, and other lovers of nature, would be dismayed by replacement of vegetation by aliens. Natural vegetation provides ecosystem services (including water), but has poor direct economic value. Most agriculture is based on introduced species, but there is the potential to commercialise native species.

Today, the intensity and complexity of environmental vs economic conflicts have increased substantially. Control of invasive alien plants has been effective in some situations and the Working for Water strategy has recorded some successes. Estimates show that water resources in the CFR have already been reduced by 15% due to invasive alien plants, and that this could rise to 37% (from 6765 to 4271 million m^3/year) if invasions were allowed to reach their full extent (van Wilgen *et al.*, 2008). The role of invasive plants in altering fire regimes, and in particular in increasing fire intensities (van Wilgen & Scott, 2001), was not discussed in the Wicht Committee's report, but is now regarded as a major concern. Natural vegetation still provides little direct economic value, though the utilisation of cut flowers and eco-tourism are economically important in some regions. The role of natural vegetation in providing ecosystem services has been increasingly quantified and appreciated (Turpie, 2004; van Wilgen *et al.*, 2008).

Comparisons with other regions

The Wicht Committee compared the CFR to other Mediterranean-type ecosystems (MTEs), stating that "A comparison with any or all of these regions brings out some likenesses and some dissimilarities. As compared with Australia or the Mediterranean, for example, a striking dissimilarity is the absence of trees in South Africa. In both the regions, the climax of the sclerophyll vegetation is a not very close forest or open tree community, pines and oaks in the Mediterranean, species of Eucalyptus in Australia". The Wicht Committee also noted that the alien species that are suppressing indigenous vegetation are mostly trees, but did not articulate possible reasons for this. They suggested that other species (shrubs and herbs) might become more important in future, but provided no elaboration.

The dominance of trees in the invasive flora of the CFR and the reasons for their success in the tree-poor fynbos vegetation has subsequently been explored in detail (Richardson & Cowling, 1992), drawing insights from comparisons with other MTEs and from other ecosystems around the world where alien trees are invasive (Rundel *et al.*, 2014). Global reviews have contrasted the invasive success of key invaders in the CFR with the performance of these taxa elsewhere in the world, e.g. for *Acacia* (Richardson *et al.*, 2011), *Eucalyptus* (Rejmánek & Richardson, 2011) and *Pinus* (Richardson & Higgins, 1998; Procheş *et al.*, 2012). Comparing the relative invasiveness and impact in different regions has emerged as a strong theme in invasion science, and many lessons from management attempts in one region can be transferred to other regions (Wilson *et al.*, 2011; Richardson *et al.*, 2015). Nonetheless, invasions in the CFR are still unique in terms of the species involved and the management challenges in a South African context, but there is increasing effort to learn from management failures and successes in a range of "model taxa" (Kueffer *et al.*, 2013).

Understanding related to sustainable harvesting of plant resources

The Wicht Committee's views on harvesting

Cut-flowers are probably one of South Africa's oldest exports, with records of dried wild-harvested Proteaceae being exported by ship to Europe from as early as 1886 (Bekaardt & Bester, 2010), dried wild harvested everlasting flowers (*Helichrysum vestidum*) exported to Europe and Russia for wreaths and church decorations in the late 1800s (Coetzee *et al.*, 2000; Middelmann, 2012), and the export of fresh *Ornithogalum* (Chincherinchee) flowers to Europe by ship (Coetzee & Littlejohn, 1995). Locally, a (largely) matriarchal lineage of characteristic Cape Town (Adderley St) "bloemdraers" or flower sellers emerged after the first seller sold her bouquet in 1890 (Rabe, 2010). Rooibos tea also has a long history of use in South Africa, from use by indigenous people to its first cultivation in 1904 (Joubert & Schulz, 2006; van Wyk, 2011). Indeed, these collections and exports created the concern for the need to protect wild plants (Guthrie, 1936) and eventually led to legislation being promulgated to control their harvesting.

Eight years prior to the Wicht Committee report, the Cape Provincial Wildflower Protection Ordinance (No. 15 of 1937) was promulgated, making it illegal to indiscriminately pluck or harvest wildflowers for pleasure or for gain. This policy formed part of what Walter Middelmann referred to in Cape wildflower history as the "restrictive phase" (1920–1945) (Middelmann, 2012), where the emphasis was placed firmly on protection, education and publicity around the plight of Cape Wildflowers and other harvested products. The ordinance effectively banned the harvest and sale of wildflowers by the poor, but protected landowners and the harvest of wildflowers for display in educational programmes and exhibitions (van Sittert, 2003). The Wicht Committee mentions this ordinance, further stating that; "A considerable amount of illegal flower picking still occurs, however, and this will always be extremely difficult to check." Interestingly, no mention was made of other harvesting targets, such as Restionaceae for thatching, buchu and rooibos for health-promoting teas or any species for medicinal value. At this stage these products were largely locally (and opportunistically) harvested in accordance with traditional indigenous practices.

In the rural areas, established mission stations (e.g. Elim, Genadendal, Wupperthal) formed the basis of the wildflower (cultivated and wild harvested) and rooibos industries (Coetzee & Littlejohn, 1995). Alternative cultivated sources were not yet common, although by the 1930s a single reseeding type of Rooibos (*Aspalathus linearis*) had already been selectively bred from wild stock (Morton, 1983). At the stage of the Wicht Committee's report, science-based understanding of the impacts of harvesting rooibos and wild flowers (to guide management practice) was minimal, although some knowledge of Rooibos cultivation had been published (Compton & Mathews, 1921). The primary focus in this section is therefore on wildflowers and rooibos, although other plant-based harvesting industries are briefly described under "The period 1994 and beyond".

1945 to 1959: Harvesting from the veld

Wildflowers

Air transport of flowers to Europe began shortly after World War II and was dominated by wild-harvested products. Awareness of harvested products was certainly growing but science-based understanding of the industry remained limited and informal in nature. Although a number of nurseries and farmers took early steps towards popularising fynbos wildflowers, it was not until the 1940s that small-scale commercialisation projects attempted to define cultivation and the popularity of indigenous flora. A talk by Captain E.J. Scholtz to the Natural History Club in 1949 advocated the collection of data and seeds to be deposited with

Kirstenbosch so that over-exploitation could be monitored and managed (Middelmann, 2012). An important development in this period was the establishment of the Cape Department of Nature and Environmental Conservation in 1952. Mr G.A. van Oordt, Assistant Provincial Secretary of the day, felt that the Cape Provincial Wildflower Protection Ordinance would be assisted if people could recognise protected species (Hey, 1977b). A variety of wildflower leaflets and booklets were published, including Mary Maytham Kidd's "*Wildflowers of the Cape Peninsula*" (Kidd 1950), and Marie Murray Vogts "*Proteas – know them and grow them*" in 1958. In 1957, Richard Morey published his trophy-winning essay on "How and why we must save the wild flowers of South Africa", arguing the need for awareness-raising and a "protected" list. From 1940 to the early 1970s, annual reports by the Wildflower Protection Section Committee of the Botanical Society provided updates on issues relating to the protection of wildflowers (e.g. Metelerkamp & Cartwright, 1941 through to Anonymous, 1973).

Rooibos

The first local brand of rooibos, "11 o'clock" was created in the 1940s (LeClercq *et al.,* 2009). World War II also saw an increase in international demand for rooibos as a result of a shortage of other teas, but its success at the time was short-lived, with global demand in 1955 at about 524 tons (Joubert & Schulz, 2006). Following the industry collapse (due to over-supply and renewed competition from imported teas after World War II), the Rooibos Tea Control Board was established in 1954 to control the market for the tea and operated until 1997, when the market was opened to other companies (Joubert & Schulz, 2006; van Wyk, 2011). The single-channel marketing system had ramifications – the industry entered into a period of growth and development spurred on by government protection and support, but at the same time it marginalised small-scale, mostly coloured producers of wild harvested products (Wynberg *et al.,* 2007).

1960 to 1979: The growth of commercial interests

Wildflowers

From the early 1960s, wildflower commercialisation efforts started to emerge and by 1974 an industry based on the flowers of the CFR had been established with eight harvesters and two cultivators known in the indigenous flower industry (Bekaardt & Bester, 2010 and references therein; Coetzee *et al.,* 2000). As commercial growing of wildflowers (Proteas) began, so did the need for a regulating body to deal with rights, responsibilities and issues linked to protection of both genetic resources and future growers. In 1965, the South African Wild Flower Growers Association (SAWGRA) was formed (affiliated with the SA Nurseryman's Association) to stimulate investigations into growing, marketing, quality control and regulation around the industry. The first of a suite of industry-related research papers emerged, mostly dealing with insect pests of economic importance to the export market (Myburgh *et al.,* 1973; Myburgh & Rust, 1974, 1975); however research dealing with the ecological impacts of harvesting and the management of wild-harvested products remained limited. The Cape Provincial Ordinance No. 19 of 1974 proclaimed several protected species (including several Proteaceae, Bruniaceae and the fern *Rumohra adiantiformis*), which prohibited the harvesting of proclaimed species on state land, while harvesting on private land was controlled through a permit system. With demand exceeding supply, and with traditional routes blocked, illegal exploitation was inevitable (Geldenhuys & van der Merwe, 1988), and the need to implement sustainable, well-informed control measures backed up by defensible research became urgent.

To cope with the increasing commercial interest in protea cultivation, authorities undertook an extensive survey of Cape Proteaceae, including locality and habitat information (Nel, 1965; Vogts 1972). Recognisable "ecotypes" were identified, and studied to determine if flowering time remained stable (Vogts 1971, 1977a-c; 1980). Out of 150 species with economic potential (Vogts 1972), 14 species and several ecotypes were selected for commercial cultivation; this pioneering research laid the foundation for the cultivation of proteas on a commercial scale in South Africa (Brits *et al.,* 1983). To many, commercialisation was seen as a way to deflect impact on wild harvested species (Brits *et al.,* 1983).

Rooibos

Despite growth in the rooibos industry over this time, published information on the production and harvest of rooibos tea over this period is limited; Cheney and Scholtz (1963) summarised the state of knowledge at the time, including some harvesting guidelines and noting its rapidly growing popularity, both locally and abroad. Between 1955 and 1960, in excess of 60 000 metric tons of rooibos per year was delivered to the Control Board (Cheney & Scholtz, 1963), which continued its control over the industry. From the 1970s onwards, the commercial production area of rooibos extended southwards and then westwards into the Sandveld lowlands (Leclercq *et al.,* 2009).

1980 to 1994: A shift to cultivation

Wildflowers

By the 1990s the fynbos cut-flower industry was estimated to be worth R64.5 million in fresh flowers, comprising approximately 137 popular species and cultivars, and an additional R37.2 million originating from 64 dry floral products, totalling R81.7 million (Coetzee & Middelmann, 1997). This value had increased to R149.3 million by 1999, with the bulk of harvests thought to come from the Agulhas Plain (Turpie *et al.,* 2003). In 1996, 44 cultivators and 343 harvesters were active in the industry, with overall production increasing from 1600 tons in 1976 to 2800 tons in 1996 (Coetzee *et al.,* 2000).

Inconsistent quality as well as the perception of natural resource exploitation associated with wild harvesting resulted in a decline in popularity of wild harvested flowers (Bekaardt & Bester, 2010), although the majority of fynbos foliage was still gathered from the wild. Ironically the first empirical research into harvest impact started to emerge over this period, no doubt in part stimulated by the development of the industry itself, and by the initiation of the Fynbos Biome Project in 1977.

A strong move to product cultivation as well as the prevailing political (apartheid) climate of South Africa resulted in the demographic profile of the industry shifting to a system largely in the control of (white) commercial producers and exporters. Some recognition of the plight of traditional (disadvantaged) harvesting communities came in the form of technology transfer to small-scale growers through the Fynbos Research Unit of the Agricultural Research Council (ARC) of South Africa (Coetzee & Littlejohn, 1995), although most of the research at the ARC was still focused on marketable product to commercial growers. By 1992, the first cultivars had been registered by the ARC, which still continues to research market trends and to improve the ability of growers to produce blooms of consistent quality (Blomerus *et al.*, 2010).

In June 1986, the first international Protea Research Symposium was hosted in South Africa (Ben-Jaacov & Ferreira, 1986); 34 articles were published in *Acta Horticulturae*, mostly featuring research into methods for propagation (e.g. Brits, 1986a; Ben-Jaacov & Jacobs, 1986; Brown *et al.*, 1986; Mitchell *et al.*, 1986a), growth (e.g. Napier *et al.*, 1986; Parvin, 1986), disease and control thereof (e.g. Knox-Davies *et al.*, 1986; von Broembsen & Brits, 1986) and pre-and post-harvest (e.g. Brits, 1986b; LaRue & LaRue, 1986) of Proteaceae, i.e. the cultivation of Proteaceae. One of the major problems associated with the industry was the mismatch between local flowering times (typically late summer to autumn) and peak demand for exotic cut-flowers in the European and export markets (Jacobs, 2010; Nieuwoudt & Jacobs, 2010). Much research was, and still is, focused on the manipulation of natural flowering times (e.g. Brits et al. 1986; Malan & Le Roux, 1995; Jacobs, 2010).

Some interface between the commercially-related research and basic ecological understanding was argued for, for example Rebelo and Rourke (1986) proposed a two-tier research approach to address challenges in the industry, combining traditional physiological methods with an understanding of Proteaceae ecology. Seed dormancy, identified as a major problem in the early development of the industry (Vogts, 1960), could be explained by a basic understanding of seed dispersal, in that many species have ant-dispersed seed. Bond & Slingsby (1984a,b) had only recently published their finding that myrmecochory was an important form of dispersal in the ecosystems of the CFR. A handful of papers in the special issue dealt with aspects of Proteaceae ecology in relation to the wild-cut industry, these leading to further research.

The production of seed and mortality of fynbos plants is affected by fire regime and rainfall variation, while removal of flowering stems/fruits can affect plant vigour and overall availability of seed for maintenance of populations. By this stage, much work had been done to understand the consequences of “natural” drivers of recruitment (e.g. fire), but the impact of flower harvesting on population sustainability remained patchy and speculative. Kruger (1982) stated that “Flower harvesting complicates management of Mountain and Coastal Fynbos; requirements for sustained yield management compatible with conservation of other resources must be determined and included in general policy”.

Given the nutrient poor status of CFR soils, Low and Lamont (1986) raised concerns that intense wildflower picking combined with increased fire frequencies had the potential to deplete nutrient reserves in this system. Nutrient-linked studies had only just commenced in the fynbos biome (Mitchell, 1980), pointing to low nutrient turnover and small nutrient stocks (Mitchell et al., 1986b; Stock & Lewis, 1986; Witkowski & Mitchell, 1987). The issue of nutrient loss was further explored by Esler *et al.* (1989) who tracked the accumulation of N and P in developing infructescences of two Protea species; they noted that accumulation of high concentrations of these limiting nutrients was delayed until seed-ripening, well after flower harvest stage, indicating negligible nutrient drain potentially associated with flower removal.

Removal of flowers or cones also results in the removal of (potential) seeds from the system – this assumption led to the first recommendations for harvesting levels of wild populations (van Wilgen & Lamb, 1986). Rebelo and Holmes (1988) investigated the effects of commercial exploitation on the mortality and seed production of *Brunia albiflora*, noting with concern that exploitation intensity was highly variable, often exceeding the 50% rule of van Wilgen & Lamb (1986). Where harvested, mortality levels were higher than natural levels (14–33% mortality when harvested, vs 1–3% when not) while seed production was reduced to one-third that of unexploited populations. Mustart & Cowling (1992) were the first to perform controlled harvesting experiments on four serotinous Proteaceae, showing a reduction of the standing crop of canopy-stored seed after harvesting, an effect carried over to the following season because stem-harvesting lowered cone production. Based on their results, they recommended cautious adherence to the 50% harvest level rule. The question of seed-limitation in these systems became relevant, as it was not known how many seeds are required for adequate post-fire regeneration – a fundamental question that still challenges contemporary ecologists. Based on empirical data from two Proteaceae species, Maze and Bond (1996) developed a simple harvesting model to determine how flower harvesting would affect the size of the next generation of recruits. High probabilities of seeds surviving to form seedlings indicated seed saturation and suggested that the studied populations of *Protea repens* and *P. neriifolia* could indeed sustain the recommended harvest levels.

Although the fern *Rumohra adiantiformis* had been harvested in small quantities since the 1970s, the demand for florist greenery increased substantially in the 1980s, prompting the Forestry Department to open up areas of southern Cape forest for commercial harvest of this fern in 1982. Forestry Department and fern export enterprise concerns over the sustainability of the resource prompted a range of ecological research (Geldenhuys & van der Merwe, 1988 1994; Geldenhuys, 1993, 1994b; Milton & Moll, 1987, 1988). The work, tracking the phenology and longevity of fronds and population dynamics under experimental and commercial harvest, established that this species was subject to slow, sporadic regeneration. This, and the fact that the fern’s density is dependent on the forest successional stage, resulted in recommendations for lengthening the period between harvests from every 5 weeks to every 15 months. The current system prohibits total defoliation of individual plants, and the removal of no more than 50% of mature plants during a cycle (Geldenhuys, 1994c).

Recognising that decisions around sustainable harvest require not only an understanding of the resource component (i.e. the biology of harvested species), but also an understanding of production and the economic and socio-political environment, Davis (1990) developed a computer model (Veldflow) that integrated these aspects. This model does not appear to have been taken up by the industry (nor in the academic literature), however it did highlight gaps in knowledge (Figure 6), including the need for data on a wider range of harvested species and a monitoring protocol for the industry. It also identified the need to consider this and related industries in a social-ecological context.

Rooibos

Published information on rooibos remained scant over this period, despite continued growth in the industry and a growing awareness of the health benefits associated with the

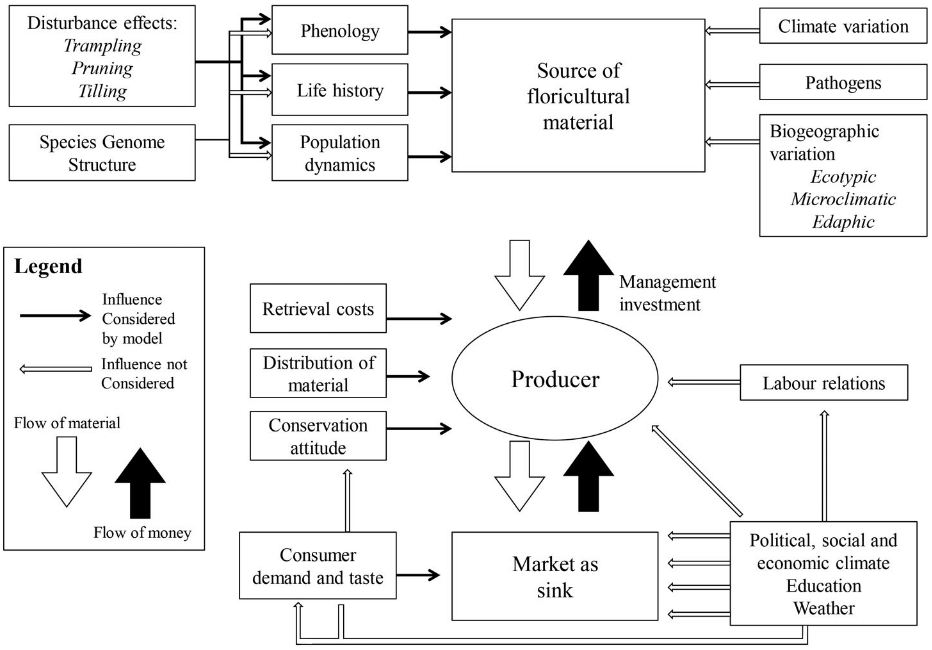


Figure 6. Decisions around sustainable harvest require not only an understanding of the resource component (i.e. the biology of harvested species), but also an understanding of production and the economic and socio-political environment and the interactions between these two (redrawn from Davis, 1990).

tea (Snyckers & Salem, 1974; Morton, 1980). The cultivation industry experienced several setbacks linked to fungal disease, drought and flooding, which temporarily reduced supply in 1980–1981 (Morton, 1983), indicating the need for research into appropriate response, although none can be found in the academic literature. In 1993, the Rooibos Tea Control Board was abolished, heralding dramatic changes for the industry along with the advent of democracy in 1994.

1994 to present: Growing pressures

In 1994, South Africa transitioned to democracy, opening up markets and scientific exchange, with associated socio-economic imperatives strongly influencing harvest-related research and activities (e.g. McEwan *et al.*, 2014). One of the major changes in the Western Cape, was the in-migration of disadvantaged people to urban centres from the former apartheid homelands, joining the global trend of urbanisation (Petersen *et al.*, 2012). Associated with this was the expansion of largely cash-based markets for traditional medicines and foods, fuelling increased local demand for wild-harvested products (Petersen *et al.*, 2012). Of significance to research in this period was the influence of the Millennium Ecosystem Assessment (2005), which popularised the concept of ecosystem services (benefits humans receive from ecosystems), emphasising the value to human well-being of their sustained flows and elevating awareness of drivers of ecosystem change. Conservationists welcomed the concept of ecosystem services (and associated valuation) as a way to persuade policy makers and broader society that funding the management of fynbos ecosystems made sense (Cowling & Costanza, 1997). During this period, the first ecological-economic valuations of fynbos emerged (Higgins *et al.*, 1997; Turpie *et al.*, 2003, Laubscher *et al.*, 2012), as did papers on impact and management (Joubert *et al.*, 2009; Privett *et al.*, 2014). Issues of social and economic inequality in the broader conservation field (Campese *et al.*, 2009) and within the flower harvesting industry also received attention (Bek *et al.*, 2013; McEwan *et al.*, 2014; Hughes *et al.*, 2015), coupled with the idea that "conserving biodiversity and progressively realizing rights of all citizens [and] now expected to be mutually reinforcing" (Crane *et al.*, 2009: 145). More recently, research into informal biodiversity-based economies other than just wildflowers has started to unpack a whole new range of potential conservation threats and opportunities (e.g. Petersen *et al.*, 2012).

Wildflowers

It is within the context of post-apartheid South Africa, now fully re-connected with global trade, that the NGO Fauna and Flora International set up the Flower Valley Conservation Trust, a registered nonprofit organisation, in 1999. Since then, this organisation has worked with the South African National Biodiversity Institute, the Global Environmental Facility, and since 2003, the Agulhas Biodiversity Initiative to develop a Sustainable Harvesting Code of Practice – a genuine attempt to combine fynbos conservation with a concern for livelihoods (Hughes *et al.*, 2015). Aspects of this Code of Practice are incorporated into a chapter in Esler *et al.* (2014) on sustainable livelihoods from fynbos.

Laubscher *et al.* (2012), estimated a net annual income of approximately US$1.15 million (~R15 million) generated by species harvested from the Agulhas Plain. Although approximately 120 farms contribute to this trade, there are still concerns that many species are being wild-harvested in the area (Laubscher *et al.*, 2012). Conradie and Knoesen (2007) estimated the proportion of wild-harvested species to be between 33% (focal flowers) and 42% (foliage and filling) of total industry production. Income of wild-harvested product likely declined in total value from the previous era, as unblemished, uniform cultivars and hybrids, arising from horticultural research, extended the market season and catered to market demand (Personal Communication, Roger Bailey, Flower Valley Conservation Trust). While intensive cultivation and wildflower harvesting from entirely natural populations have been discussed so far, a third approach now raised conservation concerns, i.e. the marginal cultivation of fynbos, where relatively undisturbed vegetation is subjected to ploughing, broadcast sowing (augmentation) or burning to increase the amount of focal species in natural vegetation (Davis, 1990; Heydenrych, 1999; Treurnicht, 2010). Research into the impact of this component of the industry on the Agulhas Plain has yielded mixed results. Joubert *et al.* (2009) showed that plant diversity can be maintained (at least in the short-term) in areas where wildflowers are cultivated if low-impact augmentation of natural vegetation is applied, e.g. through the use of shallow-ploughing and augmentation with commercial species (Joubert *et al.*, 2009). High-impact practices such as deep ploughing and repeated fires were however found to be more damaging (Joubert *et al.*, 2009). In contrast, another study on the Agulhas Pain noted impacts of shallow poughing and broadcast sowing, claiming neither practices were "diversity friendly" and therefore incompatible with biodiversity conservation initiatives (Treurnicht, 2010).

Reinten *et al.* (2011) have identified many more non-proteaceous species that could be as important as cut flowers. Given the extremely rich floral diversity of the CFR in particular, there is much potential for expanding South Africa's current significant contribution to the global cut-flower industry. However, despite continued efforts by researchers at the ARC (e.g. on gene banks: Bestera *et al.*, 2013) and elsewhere (e.g. Laubscher *et al.*, 2009) to support the wild-harvested and cultivation industry, the current small scale of the local floriculture industry has not allowed for research and breeding programmes to exploit this resource for significant benefit to local people and the economy of the country (Reinten *et al.*, 2011). Much research is currently being conducted to manipulate natural flowering times (Jacobs, 2010), while other experiments focus on cultivating South African protea species overseas (Allemand & Littlejohn, 2003).

What of the future? Elevated temperatures associated with climate change have created economic and marketing concerns for commercial cut flower producers, since vegetative growth can be prolonged at the expense of flower production where water is not limiting (Louw *et al.*, 2015). Impacts are also predicted within natural wildflower distributions (Midgley *et al.*, 2002; Schurr *et al.*, 2012; Cabral *et al.*, 2013), and these are likely to be synergistic. Large scale research that investigates multiple species will be needed to fine-tune management and policy understanding. A promising example is the work of Treurnicht *et al.* (2016) who highlight the interplay between fire and climate over the life cycle of 26 serotinous Proteaceae, describing how these determinants (fire and climate) shape the large scale dynamics of these plants. At large spatial (regional) scales, the production and accumulation of seeds in adult plant canopies strongly depends on the fire interval. The recruitment (germination and growth) of seedlings is, however, almost exclusively driven by climate factors, notably summer drought and heat conditions. Both adult and seedling life stages are additionally affected by neighbouring plants (population density). This work, a global first to incorporate multiple environmental drivers at large spatial scales for a significant number of species, has the potential to shed light on how interactions among these drivers shape the population dynamics of these plants, with obvious links to the wildflower industry. The extensive dataset supporting these findings is a product of citizen science (Protea Atlas Project data, 1991–2001), data from organisations such as SANParks and CapeNature, and large-scale demographic data collected through international collaborative partnerships (Schurr *et al.*, 2012). Large-scale population dynamics are of great interest to those seeking an understanding of the effects of global change, such as the dramatic shifts in climate patterns and fire regimes we are already experiencing in the Cape. Coupled with process-based models which examine the persistence and abundance of species subject to harvest (see e.g. Cabral *et al.*, 2011), there is now great potential to move beyond calls for more species-specific knowledge and towards predictive, trait-based understanding.

Rooibos

The democratic era saw the lifting of sanctions and the opening up of the rooibos tea industry to new producers, distributors and investors (Wynberg *et al.*, 2007). With limited access to capital and skills, the market niche for small-scale producers was not immediately opened; this only came when they were targeted for support through LandCare and NGOs such as the Environmental Monitoring Group (EMG) and A-SNAPP (see Nel *et al.*, 2007 for a detailed overview of this process).

With global markets open, demand for rooibos tea increased markedly, with sales growing from an average of 500–600 tons in the 1950s (Waarts & Kuit, 2008), to 10 600 tons (6400 tons for export) in 2003 (Joubert & Schulz, 2006) and to 20 000 tons (the bulk being for export) by the end of the decade (van Wyk, 2011). From 1997 the planted area doubled to 40 000 ha in 2008 (Waarts & Kuit, 2008), with cultivation encroaching into the deep, well-drained, sandy natural habitat of *A. linearis* in the Greater Cedarberg Area. These habitats support some of the CFRs most endemic-rich vegetation types and ironically rooibos tea, with its exotic biodiversity-linked marketing visions of indigenous people, plants and landscapes (Ives, 2014) became a conservation concern, with a 300% increase in the number of species threatened with extinction by the industry alone (from 37 threatened taxa listed in 1997 to 149 in 2009, Raimondo *et al.*, 2009). CapeNature launched two conservation programmes involving rooibos farmers on a voluntary basis – the Greater Cederberg Biodiversity Corridor in 2003, and the Rooibos Biodiversity Initiative in 2006. About the same time, consumers' demands increasingly focused on sustainable rooibos products (Leclercq *et al.*, 2009).

The opening up of international markets not only solidified large companies' stake in the industry, but also provided opportunity for the small-scale farming cooperatives in previously disadvantaged communities (Ives, 2014). Organic, wild rooibos tea is still harvested in the north of the species' distribution range, with two small-scale producers supplying wild-harvested rooibos to the international market as a fair trade product (Nel *et al.*, 2007; Malgas *et al.*, 2010), but less than 5% of the total output of rooibos is gathered from the wild (Gerz & Bienabe, 2006; Patrickson *et al.*, 2008). Wild-type rooibos differs markedly from the standard cultivated form and it is possible that multiple ecotypes exist within *Aspalathus linearis.* The conservation-worthy, genetically distinct ecotypes have received some attention through the Rooibos Biodiversity Initiative, a partnership between the South African Rooibos Council and CapeNature. Together, these organisations have been mandated to provide sustainable farming guidelines to protect biodiversity in this area via the Right Rooibos initiative (Botha, 2009; Hawkins *et al.*, 2011). Revisions and additional work is required to assist in their distinction and sustainable use (Malgas *et al.*, 2010).

Honeybush

In the early 1990s, propagation and cultivation trials at Kirstenbosch by Hannes de Lange opened up interest in the commercial production of honeybush, *Cyclopia* spp. (Joubert *et al.*, 1998). Despite a long history of use (Hofmeyer & Phillips, 1922), honeybush tea has not yet achieved the same level of popularity as rooibos. The market is small (<300 tons per annum, Joubert *et al.*, 1998) and focused on four species of commercial interest, *Cyclopia intermedia*, *C. subternata*, *C. sessiliflora* and *C. genistoides.* The industry is however growing, following renewed interest in research of the tea's medicinal benefits (Joubert *et al.*, 2008). Conservationists, anxious not to see a repeat of the same impacts generated by the rooibos industry, are actively working on models for sustainable harvest.

Reed harvest and the thatching industry

The harvest of thatching reeds remains an important local industry. The main species harvested are *Thamnochortus insignis* ("Mannetjies riet", a non-sprouter and the most economically important species) and *T. erectus* ("Wyfies riet", a sprouter), while several other species from the same genus as well as *Chondropetalum tectorum* are also harvested (Turpie *et al.*, 2003). Life-history strategies influence population growth rates of these species, with the sprouter shown to be more resilient to harvest (Ball, 1995; Campbell, 2006). Farmers use knowledge of growth phenology to inform timing of harvest which occurs every 5 years (Linder, 1990). Strong culms suitable for thatch are only available for harvest in early winter; the advantage of harvesting at this time is that seed has already been distributed back into the veld (Linder, 1990). Turpie *et al.* (2003) estimated the industry to be worth about R15.5 million based on figures from the 1990s (5.6 million bundles harvested, Cowling & Richardson, 1995). Thatching reeds (*T. insignis* and *C. tectorum*) are also harvested from Agulhas National Park as part of a benefit-sharing programme. Approximately 50 000 bundles of reeds are harvested annually, bringing in over R330 000 to the local community (SANParks, 2014, 2015, 2016). Using these prices and assuming harvests are similar to those of the 1990s, the total value of the industry now would be in the region of R40 million per annum.

Other emerging biodiversity-based industries

Besides wildflowers, rooibos and honeybush tea and thatching reeds, several other products are increasingly harvested from the ecosystems of the CFR. These include indigenous timbers from natural forests, and *Aloe ferox* products from thicket patches; however, we do not cover these here, but focus rather on products harvested from shrubland ecosystems. These additional products include honeybee farming, buchu for tea, brandy and cosmetics (*Agathosma* species) and several others. Van Wyk (2011) and Lall & Kishore (2014) detail a litany of other species that may have potential for pharmaceutical products. Like with cut-flowers, it is uncertain what impact expansion of these industries to include additional native species would have on wild plant populations, but it is currently clear that wild populations are being exploited for informal medicinal uses. Although Cowling & Richardson (1995) document few medicinal and food resources harvested from the fynbos, there is increasing evidence that this may no longer be true. Historical use of food and medicinal plants by KhoiSan people has been documented (Deacon, 1984), but the increasing human population pressure, together with high unemployment and changing cultural profiles, has led to an increasing reliance on natural resources as a form of income and/or subsistence. Petersen *et al.* (2014a) estimate based on extrapolations from their surveys that there are approximately 5100 practising traditional healers in Cape Town, as well as some 10 000 *amagqirha/amaxwhele* trainees, equating to more than three traditional healers for every university-trained medical doctor in the Western Cape Province.

Many of the locally-traded plant- and animal-derived medicinal products are sourced outside of the Western Cape, notably in the Eastern Cape and lowveld areas. However, of the 102 plants documented in the local trade by Nzue (2009), 55 were harvested in the Western Cape, while Petersen *et al.* (2012) has documented 250 locally-occurring plant species from 70 families in the informal trade in the City of Cape Town. Petersen *et al.* (2014b) further documents 28 species that are commonly harvested locally for use in 60 major Cape Town medicines. Many of the species are harvested illegally. Petersen *et al.* (2012) lists 129 illegally-harvested medicinal species, the uses of which would have been entirely beyond the Wicht Committee's reference frame. For example the harvest of *Cissampelos capensis* which is used "So I don't get caught when I'm driving around without a licence" (Petersen *et al.*, 2014b). The volumes harvested for this informal sector are also not insignificant. Petersen *et al.* (2014a) estimates that approximately 270 tonnes of biological material are harvested annually from the Western Cape for use in traditional medicines. The economic value of the collective medicinal trade in Cape Town, and a further ~370 tonnes from the fynbos biome is estimated at US $15.6 million/year, with the contribution of CFR products estimated at US $6.9 million/year (Petersen *et al.*, 2014a). In another study, inventories of the collections of 52 Rastafari bush doctors in the Western Cape indicate that 38.6 tons of 135 "ethnospecies" were traded with a market value of US $733,000 (ZAR 5 million) in 2010 (Aston Philander *et al.*, 2014). Of the 27 ethnospecies in high demand (that are targeted as conservation priorities) six plants were new to the trade, ten were unsustainably harvested species, six endemic fynbos plants, two plants with rare phylogenies and three were identified as threatened in the International Union for Conservation of Nature's (IUCN) Red List (Aston Philander *et al.*, 2014).

Formally protected areas have been identified as important contributors of material for this trade, both with and without necessary permits (Petersen *et al.*, 2012; van Wilgen *et al.*, 2013; van Wilgen & McGeoch, 2015). One hundred and sixteen indigenous plant species from 54 families were noted to be harvested from national parks within the CFR in a survey of park staff (Agulhas, Bontebok, Garden Route and Table Mountain National Parks) (van Wilgen *et al.*, 2013). Most species are used for medicinal purposes (78), while 27 plants are collected for ornamental purposes. Only 7% of these resources are harvested with authorisation in all instances (mainly timber products from the Garden Route National Park), while the rest are harvested without any permits or in excess or contravention of permitted conditions. Very few species are used solely for personal subsistence use, with most being sold for commercial gain at least some of the time. The majority of the species harvested from national parks are Least Concern taxa, but some threatened and declining taxa were also identified (van Wilgen *et al.*, 2013).

Besides the medicinal plant and cut-flower trade, another important informal trade is that of sour figs (*Carpobrotus acinaciformis,* and to a lesser extent *Carpobrotus edulis*), which are used locally to make jams. These species are widespread and listed as Least Concern on the Red Data List. Turpie *et al.* (2003) estimate that 3 kg/ha are harvested from the Strandveld areas with a total annual value of R5 million. More recent estimates are not available across the biome, although harvest is documented on the Agulhas plain, including part of the Agulhas National Park under permit from CapeNature permits and consent letters from SANParks. SANParks records an average harvest of approximately 3000 kg, which earns beneficiaries approximately R20/kg, although some of the harvested product is first made into jam before sale or use (SANParks, 2014, 2015, 2016).

Understanding related to climate change

The Wicht Committee's views on climate change

Anthropogenic climate change due to greenhouse gas emissions had not yet been widely identified as an important issue at the time of the Wicht Committee's report, and would emerge as an international and national issue only four decades later. Prior to the Wicht Committee's report, apparent rainfall change had been a widely debated phenomenon, with many convinced that land degradation had caused reduced rainfall and increasing drought risk (Anonymous, 1923, 1951). The Wicht Committee limited their views on climate to national concerns about drought and potential links to land degradation. This link was unresolved due to insufficient evidence and the lack of theoretical capacity and tools for exploring the question. Indeed, only recently have climate modellers begun exploring connections between vegetation state and local and regional climate in South Africa (Mackellar *et al.,* 2009). Wicht himself was clearly fully aware of the challenge to ecological understanding that natural climate variability and resulting inter-annual variance of rainfall patterns in the Western Cape presented.

Further development of understanding

Concerns about the implications of greenhouse gas emissions gained international recognition in the late 1980s, sparking the inception of the United Nations Framework Convention on Climate Change (UNFCCC) and its scientific body, the Intergovernmental Panel on Climate Change (IPCC). Initially, the International Geosphere-Biosphere Project (IGBP), established by the International Committee of Scientific Unions (ICSU), engaged a small group of mainly atmospheric scientists in this research area in South Africa (Tyson, 1991). Implications for South African biodiversity were identified first in a report from the Botanical Research Institute (Macdonald & Midgley, 1996). The issue was subsequently explored in much greater detail using quantitative modelling methods in the late 1990s, as part of South Africa's Initial National Communication to the UNFCCC (Rutherford *et al.,* 1999). After 2000, new modelling methods were introduced (Brotons *et al*., 2004), and niche-based predictive modelling efforts, based on Proteaceae from the CFR, were amongst the first to apply these methods. These have been influential in refining this approach globally (Williams *et al*., 2005; Midgley *et al.,* 2010; Schurr *et al.,* 2012; Cabral *et al.,* 2013) including consideration of land use change (Bomhard *et al.,* 2005) and dispersal limitations for plants (Midgley *et al*., 2006).

The current significance of different aspects of climate change for the conservation of the ecosystems of the CFR are summarised in Table 3. A major concern about the potential vulnerability of fynbos biodiversity to climate change flows from the understanding that the region has seen explosive diversification over the past 5 million years (Dupont *et al.,* 2011). This was a period of low atmospheric CO_2 and cool climatic conditions, and was associated with the establishment of a reliable winter rainfall regime. We now understand that much cooler and wetter conditions than are presently in place have predominated in the Cape for more than 80% of the Pleistocene; they were interspersed over the past million years with warmer and drier conditions globally, roughly every 70–100 thousand years (Augustin *et al.,* 2004; Masson-Delmotte *et al.,* 2006), if glacial/interglacial climatic states can be related to the position of westerly storm tracks (Chase *et al.,* 2013). While these changes must have strongly limited accumulation of species in Northern Hemisphere regional floras, the Mediterranean regions of the world, especially in South Africa and Australia, appear to have avoided species attrition. The limited temperature oscillations between a 5 degree cooler world and that of warm interglacials such as the Holocene of today hold a key to understanding how it is that the winter rainfall region of South Africa became so rich in species (Jansson, 2003).

Atmospheric CO_2 has increased globally from pre-industrial levels of roughly 280 ppm to 400 ppm today (IPCC, 2013). It is entirely plausible to argue that the very rapid rise of atmospheric CO_2 to levels unprecedented even in deep geological time, and the likely subsequent increase in global atmospheric temperature and rainfall change, could expose the rich flora of the winter rainfall zone to conditions that have not predominated for millions to tens of millions of years. This change could become an ecological and biophysical discontinuity whose impacts can only be projected through extrapolation.

While insights on future impacts of climate change can be obtained from paleo-historical changes, evidence about such change and its effects on fynbos vegetation are limited in time span (Meadows, 2001), with the best evidence available for Holocene and late Pleistocene (Chase & Meadows, 2007). Phylogenetic evidence suggests that the inception of the winter rainfall regime in the western Cape was pivotal for driving speciation in semi-arid succulent Karoo (Klak *et al.,* 2004), but that events deeper in time, such as the inception of a fire regime, were important for driving plant evolution in fynbos (Barker *et al.,* 2004) with some support for climate-driven late Quaternary shifts in geographic ranges for Renosterbos (*Elytropappus rhinocerotis*) (Bergh *et al*., 2007). There is evidence for relative stasis of fynbos biodiversity on the Cape Fold Mountains, although apparent changes in moisture conditions appear to drive changes between fynbos vegetation states, including changed fire regimes (Quick *et al.,* 2011; Valsecchi *et al.,* 2013).

In the sections that follow, we discuss briefly the development of an understanding of potential climate changes, and

Table 3. Aspects of climate change that could affect the conservation of ecosystems in the Cape Floristic Region, with projected changes and verified or observed impacts.

Aspect of climate change	Proposed impacts	Observed or verified impacts and projections
Atmospheric CO_2 concentration	40% increase since the 19th century (280 ppm, mid 1800s to 400 ppm, 2015), increase to at least 450 ppm projected by 2050, possible increase to 700–1000 ppm by 2100 depending on global mitigation policy responses (IPCC, 2013)	Experimentally verified increased nitrogen and water use efficiency of selected Proteaceae (Midgley *et al.*, 1995, 1999), projected and observed increased water use efficiency of most C_3 plant species (Drake *et al.,* 1997; Franks *et al.,* 2013), potential increased leaf area index especially in woody shrubs (based on results in Newingham *et al.*, 2013, but see Duursma *et al.*, 2015) Projected increased invasive potential of alien woody nitrogen fixing plants (higher seedling and sapling growth rates and more rapid recovery from disturbance, greater herbivore defence via secondary chemicals) (Midgley & Bond, 2015) Projected more rapid fuel accumulation rates by woody species and related shorter fire return interval (Altwegg *et al.*, 2014a)
Surface air temperature	Mean monthly increases of up to 2°C since 1960s, projected further increase in mean annual temperature of 2–3°C by 2100	Experimentally increased growing season length where water available, some positive but mostly negative effects on germination and establishment of selected endemic species (Agenbag, 2006; Arnolds *et al.*, 2015) Projected effects on growing season duration could lead to improved growing conditions for a minority of species, but less optimal growing conditions for most species (Midgley *et al.*, 2003), especially small-range endemics with specific habitat requirements
Westerly storm tracks	Southerly shift of storm tracks projected by atmospheric and climate modelling (Gillet & Thompson, 2003; Swart & Fyfe, 2012)	Projected lower frequency of frontal rainfall (IPCC 2014), particularly in winter, but observations do not yet confirm this as a trend (Department of Environmental Affairs, 2013a)
Rainfall amount and seasonality	Projected median reductions of roughly 50 mm (100 mm) in mean annual rainfall by 2050 (2100) (Engelbrecht *et al.*, 2015) Natural variability largely precludes identification of observed trends (Department of Environmental Affairs, 2013a)	Experimentally observed adverse impacts of reduced rainfall for all main fynbos plant functional types, with narrow-leaved shrubs with intermediate depth root systems first affected (West *et al.,* 2012) Projected changes in growing season interacting with warming trends, likely increases in adult plant mortality under warming and drying scenarios, possible adverse impacts on recruitment of reseeding species post fire (Hannah *et al.,* 2005,) Observed changes in optimal agricultural production, offset partly by management responses (Bradley *et al.*, 2012) Projected changes in agricultural production areas and crop selection, possibly leading to shifting patterns of land transformation and abandonment (Bradley *et al.*, 2012)
Conditions affecting plant growth (temperature, rainfall amount, rainfall seasonality)	Observed warming but no conclusive evidence yet of changing seasonality affecting growing conditions (Department of Environmental Affairs, 2013a) Projected changes in growing conditions, warmer shoulder and winter seasons to lengthen growing season, more extended dry spells and more intense rainfall events, particularly in summer (Department of Environmental Affairs, 2013a)	Observed (Wilson *et al.*, 2010; Southey, 2009) and projected (Nel *et al.*, 2014) increased fire risk and increase in frequency and number of large fires, with negative implications for reseeding species (Altwegg *et al.,* 2014b). Projected changes in species distribution, roughly 60% of Proteaceae species to require assisted migration if they are to persist, 10% of species require *ex situ* arrangements to facilitate persistence, 30% likely to endure *in situ,* with greater probability under appropriate management and corridor design to facilitate natural dispersal (Midgley *et al.,* 2003) Projected increases in risk of local and global extinction for endemic species without adequate interventions (Hannah *et al.*, 2005)

(*Continued*)

Table 3. Continued.

Aspect of climate change	Proposed impacts	Observed or verified impacts and projections
UV-b radiation	Increases observed 1979–2009 are 23% (305 nm) and 10% (310 nm), but trends have now stabilised at zero (Herman, 2010) Projections indicate UV-b radiation levels should reduce over the next few decades (Newman & McKenzie, 2011)	Experimentally observed adverse impacts of unrealistically intense UV-b radiation on germination and leaf level function in selected endemic species (Musil *et al.*, 1999), field observed resilience of endemic plant function to realistic UV-b intensities via high levels of production of secondary compounds (Musil & Wand, 1993; Wand, 1995) Unlikely further adverse impacts projected on indigenous vegetation (Midgley, 2016)

its implications for the region's biodiversity and ecosystems. We also highlight the many uncertainties that exist due to the complex nature of the interactions that need to be modelled over a large area.

Evidence for climate change

Rainfall and temperature records for the Western Cape are among the highest quality and longest duration in Africa, and show that concerns about declining rainfall totals have not yet been borne out. The understanding that developed after initial concerns about land-use driven reductions in rainfall was that of a quasi-decadal cyclicity in rainfall in the summer rainfall region of South Africa (Cohen & Tyson, 1995; Tyson *et al.*, 2000, 2002). The well-known El Niño Southern Oscillation (ENSO) cycle has been shown to play an important role in determining decadal rainfall variability (Reason *et al.*, 2004; Reason & Jagadheesha, 2005), with some evidence that the Western Cape shows an inverted pattern (wetter rather than drier under ENSO) from that of the summer rainfall zone of South Africa (Rouault, 2014).

With respect to longer-term rainfall variability, a body of climatological work since the 1960s has increasingly revealed the critical relationship between Antarctic sea ice extent and the position of the westerly storm tracks (van Zinderen Bakker, 1967, Tyson, 1986, 1991; Chase *et al.*, 2013). Northerly/equator-ward shifts in these storm tracks are associated with increased ice extent and more winter rainfall, while southerly/pole-ward shifts are associated with decreased ice extent and less winter rainfall. Because the Antarctic sea ice extent is shrinking due to anthropogenic global warming, it can therefore be expected that the proportion of winter rain will decrease in the CFR, although observations do not yet support this.

Several analyses demonstrate that the CFR has warmed significantly since the 1960s (Kruger & Shongwe, 2004; Jury, 2013; van Wilgen *et al.*, 2016). The observed warming is strongest in terms of maximum temperature, and both mean annual and maximum temperatures have shown a secular upward trend especially since the late 1970s in all four seasons, with a particularly warm first decade of the new millennium. The number of rainfall days has decreased significantly since 1960, and especially from the late 1990s, and large rainfall events have increased commensurately in frequency, thus maintaining a roughly constant mean annual rainfall total.

Observations of negative trends in windrun and open pan evaporation over the land surface (Hoffman *et al.*, 2011) run counter to the expectation of increasing evaporation under warmer conditions and contrast with remotely observed increases in windspeed along the western coastal margin and adjacent ocean and central southern Africa (Rouault *et al.*, 2010). These contradictions require further observation and analysis to resolve. However, a trend is emerging towards fewer rain days, suggesting an increase in higher intensity rainfall events and longer drought spells (New *et al.*, 2006).

Temperature trends for 1960–2010 are relatively well-reproduced by modern mechanistic models of climatic shifts over the region, but these models simulate a modest reduction in rainfall for this period (median roughly -0.5 mm/year, or 25 mm in total) that has not been observed (Department of Environmental Affairs, 2013a). The models also simulate shifts in seasonality of rainfall for 1960–2010 that have not yet been observed, with simulated increasing (decreasing) summer (winter, spring) rainfall.

Climate projection methodology has developed rapidly since the 1990s, when the first projections were made. These projections have been supported in subsequent iterations by more sophisticated modelling approaches that have incorporated ever more complex processes (Taylor *et al.*, 2011), but with the rate of change lower than originally projected. Temperature and rainfall projections for the 21st century have recently been produced for southern Africa using a high-resolution mechanistic simulation method (Engelbrecht *et al.*, 2011), but unfortunately most of the original species-based climate change risk assessment work was carried out using previous generation climate scenarios (comparative projections for a range of general circulation models such as the Hadley Center model for southern Africa are available in Ruosteenoja *et al.*, 2003).

Data extracted for the CFR (Figure 7) now indicate that a regional warming of between 1 and 1.5 °C, and between 2.5 and 3 °C, can be expected between 2020 and 2050, and 2070 and 2100, respectively. Median reductions in mean annual rainfall are projected to be between 30 and 80 mm (50 and 110 mm), between 2020 and 2050 (2070 and 2100), up to a 30% rainfall reduction by the end of this century. The projections do however suggest novel and distinct temperature conditions for each of these time periods, with little overlap in mean annual temperature between the simulation periods, but more similarity in rainfall conditions though with a strong drying tendency. This is projected to occur through an increasing proportion of drier vs wetter years, together with a gradual decrease in the minimum and maximum annual rainfall. Drier soil conditions are likely to be exacerbated by a warmer atmosphere with greater evaporative demand, all else being equal, but growing season conditions

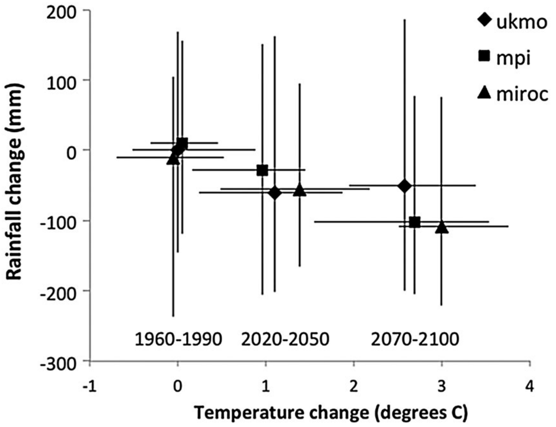


Figure 7. Changes relative to 1960–1990 averages for annual temperature and rainfall for the Cape Floristic Region projected for mid- and end-21st century, as modelled by three leading General Circulation Models (GCM): ukmo, UK Met Office Hadley Centre Model (HadCM3); mpi, Max Planck Institute ECHAM5/MPI-OPM; miroc, Centre for Climate System Research/National Institute for Environmental Studies Miroc3.2-medres. The GCM data were mechanistically downscaled to ±60 km resolution using the conformal-cubic atmospheric model (CCAM) of the Commonwealth Scientific and Industrial Research Organisation (CSIRO) (for more detail see Engelbrecht *et al*., 2015). The three GCMs were driven by the Intergovernmental Panel on Climate Change A2 emissions scenario, which increases atmospheric CO_2 concentration to ±850 ppm by 2100, representing weak international greenhouse gas mitigation action. For the time period 1960–1990, the mean annual values are plotted at the origin of both temperature and rainfall axes (slightly offset to aid clarity). The error bars indicate the full range of inter-annual variability in temperature and rainfall for this time period. For mid- and end-21st century the change in the means for each model is indicated with the solid symbols, and the full range of inter-annual variability is indicated by the bars. All three models indicate warming of up to 3 °C and mean loss of rainfall of about 100 mm by end-21st century (almost a 30% drop in mean annual rainfall from current levels).

would likely change with warmer winters and shoulder seasons providing greater opportunities for plant growth.

Climatic stability and the development of fynbos biodiversity

In order to understand the potential vulnerability of fynbos biodiversity and ecosystem function to anthropogenic climate change, it would be necessary to consider the paleoecological environment in this region, and its role in facilitating species diversification. Altwegg *et al.* (2014a) suggested that the high biodiversity of the CFR either reflects a long period of relatively stable climate conditions, or a particular resilience to climate disturbance, and phylogenetic evidence reveals that many fynbos clades evolved under the relatively low CO_2 and cool conditions that have existed since the end of the Miocene about 5 million years ago. Paleoecological evidence shows that climatic change was relatively muted in this region in comparison to much of the planet, especially during the Pleistocene (Jansson, 2003).

Together with the extremely erosion-resistant Cape geology (Bradshaw & Cowling, 2014), this has provided a rare historical combination of muted climatic change together with stable topography, including extended biophysical gradients that would have provided buffering against climatic shifts, allowing the speciation through drift and allopatry (Linder *et al.*, 2010), possibly accelerated by range shifts induced by Pleistocene climatic fluctuations (Bergh *et al.*, 2007). The existence of specialised plant–animal interactions is an independent indication of a long period of relative ecological stability (Bond, 1994). The CFR also appears to be one of the few places globally that may have become wetter during glacial times (Stuut *et al.*, 2002), and cooler wetter conditions may even have seen expansions of this biome (Midgley *et al.*, 2001b). This would suggest that the biome is currently in a natural refugial state under relatively rare interglacial conditions, and that anthropogenic warming would compound an already unusually warm climate.

Recent paleo-climatic models suggest that Pleistocene glacial stages might have been interrupted for decades to a few centuries at intervals of several tens of thousands of years by rapid warming events (Huntley *et al.*, 2014) which were associated with disruptions of ocean currents driven by land- and sea-ice melting events in the northern Hemisphere. This would indicate an inherent capacity for Fynbos diversity to withstand sudden warming and cooling spells especially through the retention of climatic refugia. However even these historical climatic disruptions seem unlikely to have induced temperature and drought conditions to rival projections for the latter half of this century.

Levels of confidence in predictions of species range changes

A high level of uncertainty has been consistently stressed in publications of species range and biodiversity responses to projected climate change, due both to uncertainties in climate projections and the modelling tools of the time. Work on geographic ranges using niche-based modelling identified significant risks of range reductions and range shifts (Midgley *et al.*, 2002, 2003), although the timing of such impacts is strongly dependent on the rate of climate change implied by climate projections. Early work raised alarm (Midgley *et al.*, 2001a), as it projected significant biodiversity loss, both locally and regionally, due to strong projected reductions in soil moisture and rapid warming for the Western Cape as a whole.

Projections of adverse impacts on species persistence for the CFR are amongst the most severe globally (Fischlin *et al.*, 2007), indicating that this vegetation type could provide an important test globally of the predictive ability of species impacts models and resulting effects on biodiversity. However, due to adjustments in climate projections, the impacts initially modelled to occur by mid-century (Midgley *et al.*, 2003) now appear exaggerated. Thus the impacts on species ranges projected by work of the late 1990s and the early 2000s to occur by mid-century might be expected between mid- and end-century (Department of Environmental Affairs, 2013b). This does not lessen the potential value of monitoring for species declines in this vegetation type, because there remains substantial uncertainty both in the climate model projections and projections of impacts on species.

Niche-based modelling approaches indicate that the potential ranges of a minority of species may significantly expand (Midgley *et al.*, 2002, 2003), possibly because they are currently limited by low temperatures. Wetter upland and south-western regions of the CFR could become more potentially productive as climate continues to warm. The dispersal abilities of endemic species will therefore play a critical role in determining their potential to adjust their geographic ranges in order to cope with these changes (Schurr *et al.*, 2007). These findings have prompted the planning of strategies to link landscapes to facilitate species range shifts, where possible, that are motivated both by immediate benefits and by their potential to increase resilience into the future (Hannah *et al.*, 2005). If cool-adapted CFR endemics with limited ranges respond weakly, species that could benefit under warmer temperatures would have an opportunity to establish and increase their ranges. Very little attention has been given to the conservation implications of the implied resilience of these "increaser" species and the ecological implications of their increased success in fynbos.

The effects of increased levels of CO_2

Atmospheric CO_2 increase potentially increases productivity, but it has long been argued that this effect will be muted in the nutrient-constrained environment of fynbos (Stock & Midgley, 1995). Atmospheric CO_2 is measured very precisely at Cape Point as part of the Global Atmosphere Watch network, and has increased along with global trends (Altwegg *et al.*, 2014a). Atmospheric CO_2, in contrast to rainfall, has been extremely stable at around 280 ppm for almost 9000 years – an element of the "invisible present" that has only recently begun to change. Levels of CO_2 are now higher than in the past million years, and could rise higher than they have been in more than 20 million years by the end of this century (Midgley & Bond 2015), a time when global vegetation was significantly more forest-dominated than the present. While the impacts of this geologically-instantaneous change on climate have been a central objective of vast amounts of meteorological research, it is extremely difficult to predict the related effects on biodiversity and ecosystem function with the tools currently at our disposal.

Limited experimental work on Proteaceae suggests a muted effect on whole plant production (Midgley *et al.*, 1995), but double-ambient CO_2 significantly increased maximum photosynthetic rates (by 40% on average for four Leucadendron species), with no significant effect on stomatal conductance (Midgley *et al.*, 1999). The resulting increase in intrinsic water use efficiency with increasing CO_2 may thus offset some of the effects of reductions in rainfall in water-limited environments for these species, even if growth may not be stimulated significantly. Furthermore, some taxonomic groups and vegetation types are less subject to nutrient constraints, including Afromontane forests, Strandveld, and endemic and invasive alien nitrogen fixers, and these may thus respond more to this stimulus. Together with increasing temperatures, rising CO_2 may therefore enhance the ecological success of key species groups and even plant functional types (e.g. broad-leaved evergreen trees, nitrogen fixers, shrubs associated with mesotrophic or eutrophic soils). It seems likely especially that relatively fast growing invasive alien nitrogen fixing evergreen trees would benefit the most, and indeed would have seen significant additional benefits of the historical increase of CO_2 of over 30% since the Wicht Committee's report was published. These effects are likely to continue to accrue in invasive aliens while the CO_2 response becomes saturated in endemics. With relatively greater rates of carbon gain, invasive alien species would have more carbon available not only for growth but also for secondary defences and reproductive effort. No primary work has been done to explore this issue experimentally.

The combined effects of climate and atmospheric CO_2 change on growing conditions seem likely to change the functional response of fynbos vegetation, as well as the performance of individual species. Rising growing season temperatures have significant ecological relevance to the relative phylogenetic isolation of fynbos from predominantly summer rainfall African biomes. Fynbos vegetation has evolved largely free of warm season C_4 grasses, and maintained a relatively long fire return interval, which has likely been the status quo for millennia. The C_4 grass growth form that expanded widely during this geological epoch over much of the tropical and sub-tropical world at the expense of woody vegetation was probably limited in the Western Cape region by a short growing season due to the winter rainfall regime and summer drought (Cowling, 1983). This is evidenced by the diversification of the grass-analogue family Restionaceae. What therefore seems to have been key to the exclusion of C_4 grass is the cool winter growing season and dry summers excluding warm season grasses. Rising growing season temperatures could provide greater opportunities for more productive growth forms and species, and the ingress of endemic and invasive C4 grasses cannot be discounted. Unfortunately, the experimental, modelling and observational work necessary to test these ideas and to improve projections of risk is currently poorly developed.

Combined effects of warming, rainfall change, fire regime and plant responses to CO_2 increase can be simulated mechanistically using a class of model called a Dynamic Global Vegetation Model (DGVM) (Woodward & Lomas, 2004). Unfortunately the mechanistic modelling of fynbos by commonly used DGVMs is limited because of the dominance of plant functional types that are either absent or poorly incorporated into these models (Zizka *et al.*, 2014). This shortcoming strongly limits credible assessment of combined effects of changing growing conditions on fynbos structure and function. Nonetheless preliminary mechanistic approaches to modelling net primary production indicate a potential increase for the southwestern Cape (Moncrieff *et al.*, 2015), and increasing potential for invasion by C4 grasses – eventualities that have dire ramifications for biodiversity and fire regime.

Climate change and fires

Climatic shifts, either cyclical or long term, have been identified as driving a long-term increase in the frequency of large fires (Southey *et al.*, 2009, Wilson *et al.*, 2010). Projections indicate that this risk will continue to increase significantly as key climate thresholds are crossed (Nel *et al.*, 2014, Engelbrecht *et al.*, 2015). One outcome of this is that conditions available for safe management burns have been reduced, and this trend will continue for some decades. This will further constrain the prospects for using prescribed burning in the management of the vegetation, given the risk-averse approaches to burning (see section on the management of fires in Part 4).

Climate change and land-use patterns

Less well understood is the indirect effect of climate on land use change, particularly intensive agriculture, and the resulting impacts on land transformation. For example, climate change is likely to threaten both commercial and wild harvested rooibos industries, with substantial range contractions and potential shifts predicted (Lötter & Le Maitre, 2014).

Areas with climatic conditions suitable for wheat production are also likely to shift with up to 2 million ha previously unsuitable becoming more suitable in the Western Cape, but currently suitable areas becoming unsuitable (Bradley *et al.,* 2012). Socio-economic pressures for greater food security and profit could change current patterns of land clearing for agricultural activity, such as has happened in the southern Cape with the expansion of wine and olive growing activities on previously untransformed land. At the same time the abandonment of land currently under intensive agriculture could provide opportunities for restoration.

Concerns about land conversion and subsequent developments

The main concerns over land use in 1945

The Wicht Committee considered pasturing, erosion and the "conversion of veld to other uses" as important land use processes which "cause the vegetation to deteriorate." These were all environmental issues that had concerned the South African government for some time prior to the Wicht Committee's report. For example, the Drought Investigation Commission (Anonymous, 1923) had highlighted a broad suite of negative impacts that inappropriate land use practices had on South African environments. However, none before the Committee's report had focused specifically on the impact of land use on the environments of the CFR.

Pasturing

It was not only the direct effect of herbivory on the vegetation of the CFR which concerned the Wicht Committee, but rather the combination of burning and browsing as well as trampling which they suggested had a far greater impact. Without regular burning, however, animal production was not considered possible on the nutrient-poor, sclerophyllous shrublands of the fynbos biome where "the development of tall, woody shrubs reduces the pasturage to practically nothing after five or six years." Continuous post-fire browsing by goats on the vegetation of steep, mountain slopes was considered especially harmful to fynbos not only because of the direct effects on the foliage but also because trampling increased the susceptibility of the landscape to erosion. Goats were perceived by the Wicht Committee as having little economic value but were the only species that could be maintained permanently on natural veld. It was perhaps for this reason that goat farming at the time was a widespread, "traditional practice still adhered to by a large, unenlightened section of the farming community." The Wicht Committee viewed those who farmed with goats in the CFR mountains to be "not far-sighted enough to be concerned about the bad effects [of goat farming]," and "hoped that the practice will disappear completely in times to come." It was not just goats, however, which were singled out for exclusion as the Committee called for the prohibition of all grazing by domestic livestock on the natural vegetation of the CFR which was considered completely unsuitable for grazing and browsing. Failure to eliminate pasturing, the Committee argued, could lead to further degradation of the sclerophyllous vegetation resulting in the disappearance of some species, the increase in invasive alien plants as well as an increase in erosion. The Committee was, however, tentative in their conclusions and called for long-term experimental research to confirm these predictions.

Erosion

Erosion was considered by the Wicht Committee to be the consequence of the "misuse of the natural vegetation", resulting from a combination of burning and browsing together with "bad land management." Erosion was also viewed as a "serious and wide-spread threat" to the natural vegetation of the CFR and when advanced could cause "the final disappearance of the last remnants of vegetation." The Wicht Committee distinguished between the "unpredictable and uncontrollable" erosion processes resulting from landslides and debris flows which are relatively common throughout the Cape Fold Mountains (Boelhouwers *et al.*, 1998) and those resulting directly from excessive burning, browsing and trampling. The Committee also appreciated that slope steepness, aspect and slope length all affected the type, rate and intensity of erosion which differed in form (e.g. sheet, donga and wind erosion), depending on whether it occurred on quartzitic-, shale- or aeolian-derived soils. Erosion was, however, perceived in such a serious light by the Committee that the suspension of owner's rights to the land or even the expropriation of land for conservation, particularly in valuable catchment areas, were not excluded as potential options, when warranted, which should be available to the State.

Land conversion

It was obvious to the Committee that the conversion of natural vegetation for urbanisation, agriculture and forestry destroyed the natural vegetation completely. The Wicht Committee predicted that as the human population increased the demand for arable land would also increase and that more marginal or "unsuitable" sites would be converted. The Wicht Committee was particularly sceptical of growing fruit, vines and other crops on steep slopes because of the potential harm caused by erosion to the natural vegetation. They argued that one could establish a crop on steep slopes but that on most such sites "erosion will ultimately reduce the productive capacity of the soil, so that the area will have to be abandoned." Although some land conversions were considered unnecessary the Committee felt that land conversion was justified if undertaken on a "sustainable yield basis." The Committee even advocated the continued conversion and modification of native vegetation "in the interests of economic development", provided that some representative areas were preserved for conservation purposes.

Major trends in land use since 1945

Human population growth and distribution

The Committee appreciated that the future impact of land use on the natural vegetation of the CFR was strongly related to human population pressure and the associated demand for land on which to build houses and to produce agricultural crops. The Committee also presciently identified the Cape Flats as the most likely target for urban expansion and where the greatest risk of extinction lay. Because of this the Wicht Committee highlighted the need for careful conservation planning around human settlements. The exponential increase of people in urban areas in the 20th century (Figure 8) and the impact of development on the Cape's unique biodiversity assets remains a critical focus for the conservation community (Pence, 2008). However, population pressures are immense (e.g. Cape Town's population of 3.7 million increases by 55 000 people/year, Holmes *et al.*, 2012) and the expansion of urban settlements remains a major

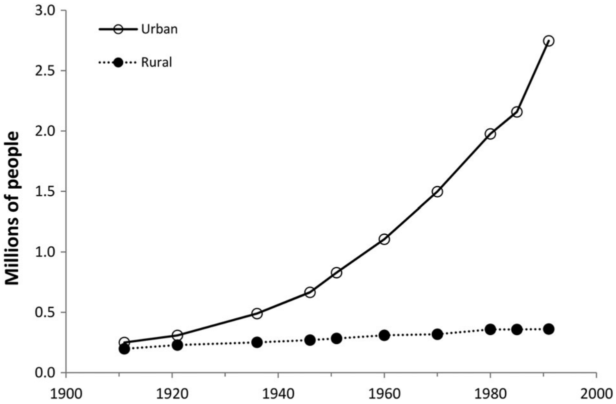


Figure 8. Change in the urban and rural population of the magisterial districts of the fynbos biome over the period 1911–1991. (Source: Compiled from various official South African government population census records published by Statistics South Africa 1911–1993).

threat to important habitats and species in the CFR (Rebelo *et al.*, 2011).

What is surprising about the population trends after 1945 is the relative stability of rural populations (Figure 8). However, even if the number of people designated as rural dwellers has hardly changed, the way in which environments of the CFR have been used has changed considerably. This is particularly true for the sclerophyllous vegetation of the mountainous upland areas of the region. The Committee would have been especially pleased to see that the relatively heavy browsing and frequent burning practices which occurred, for example, on the steep mountain slopes of the Cederberg and Groot Winterhoek mountains of the CFR had, by the 1970s, largely ceased. As bemoaned by the Wicht Committee, such environments had been used primarily as grazing lands for goats either by sedentary farmers living in the uplands (Figure 9) or by farmers who occupied the mountains on a seasonal basis (Bands, 1985; Bonora 2009). As people became more aware of the importance and value of these critical catchment areas, however, they fell increasingly under the authority of the state and were protected from the damaging impacts of livestock farming outlined by the Wicht Committee. Small-scale farmers were either moved off the land, migrated to neighbouring towns or were prevented, through a change in land ownership, from continuing with their seasonal movement patterns of using the uplands in the summer and lowlands in the winter months (Bands, 1985).

Livestock production

In addition to the changes in the way in which fynbos landscapes themselves have been used since the Committee's report, there have also been changes in the number and relative proportion of different domestic livestock species which utilise Cape environments (Figure 10). The greatest decline has been in the number of goats and equines (donkeys, horses and mules), presumably as the utility of the latter group of species for transport and draught power has declined. Goats were important for subsistence farmers in the 18th, 19th and early 20th centuries and, as noted by the Wicht Committee, were the primary species utilising the upland environments during this period. Their nearly 80% decline from 1939 to 1971 would have pleased the Committee

Figure 9. Subsistence farming practices were carried out in the uplands of many Cape Mountains in the 19th and early 20th centuries as illustrated by Kenneth Howes-Howell's original 1934 photograph (top) of the Visser's family farm at de Riff located at an elevation of 1200 m. The site was re-photographed (bottom) in 2007 by Timm Hoffman.

since goats were considered the most destructive of all livestock species in the CFR. The number of sheep and cattle, on the other hand, increased between 1911 and 1983, although such increases were probably associated with the intensification of animal production on planted and irrigated pastures and in feedlots around permanent water supplies and peri-urban environments closer to markets. The remnant patches of renosterveld on the more nutrient rich soils of the western and southern coastal platforms of the Cape would also have supported the increased population of sheep in particular.

Erosion

With the abandonment of goat farming in the uplands of the CFR the destructive practices of burning and browsing would also have disappeared together with their associated effects on erosion. As a result, erosion of the CFR mountains, which was highlighted as an important problem by the Wicht Committee, is today only considered in the context of palaeo-timescales, in association with landscape and geomorphic evolution and its influence on adaptive radiations within taxa of the Cape Floristic Region (Hoffmann *et al.*, 2015).

While there are few recent studies on erosion in the fynbos biome, Meadows (2003) investigated 20th century changes in the extent of gully erosion in the grain-producing, lowlands of the Swartland area of the CFR. At about the time that the

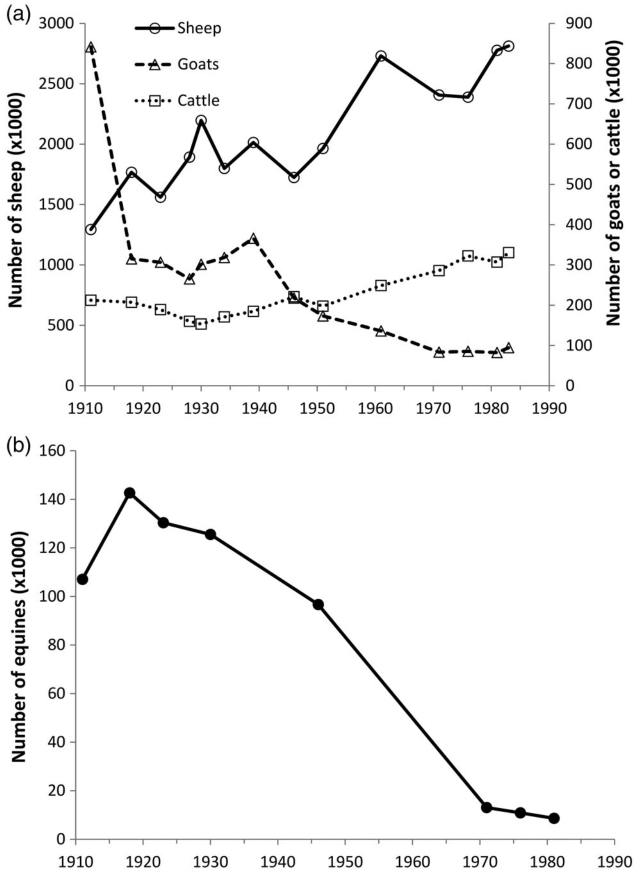


Figure 10. Changes in the number of sheep, goats and cattle (a) and equines (horses, mules and donkeys) (b) in 26 districts of the fynbos biome from 1911 to 1983 when the last official national agricultural census was undertaken in South Africa. (Source: Compiled from various agricultural census publications reviewed at Stellenbosch University, South Africa).

Committee published its findings, soil erosion was considered widespread and particularly severe in the Swartland district around Malmesbury as a direct result of decades of agricultural land use impacts (Talbot, 1947). The focus, however, was not on burning and browsing as causative agents for erosion in the sclerophyllous fynbos vegetation of the CFR but rather on inappropriate cultivation practices on steep slopes and marginal lands previously covered by renosterveld vegetation. Talbot (1947) reported, for example, that about 25% of the total area of the Swartland was considered severely eroded with 95% eroded to some extent (Meadows, 2003). This clearly posed a threat to the remaining areas of renosterveld and it is somewhat surprising that the Committee makes no mention of this in their report. This omission was presumably because renosterveld vegetation, which was dominated by renosterbos itself (i.e. *Elytropappus rhinocerotis*), was considered a degraded form of natural vegetation induced by overgrazing (Wicht, 1945). In a comprehensive re-assessment of the extent of erosion in the Swartland in the late 20th century Morel (1998) concluded that the erosion problem had declined markedly and no longer posed a significant threat to the environment. Meadows (2003) highlighted the role that state-driven soil conservation efforts, education and the raising of awareness about the issue played in this restoration. As a degradation process, erosion is not currently considered important in the CFR and would not receive the same attention today as was afforded to it by the Wicht Committee in 1945.

Land conversion

Soils which are derived from quartzitic sandstone are relatively low in nutrients and are considered unsuitable for the production, on a commercial basis, of major agricultural crops, such as wheat and oats. Because of this, most of the more mountainous parts of the CFR have been spared from large-scale transformation, although improved technologies such as centre-pivot and drip irrigation systems as well as improved fertiliser application techniques have extended the reach of cultivation considerably in the last few decades (Figure 11).

In comparison, however, soils derived from Malmesbury and Bokkeveld shales in the Swartland and Overberg regions, respectively and which support renosterveld vegetation types, have a long history of cultivation (Hoffman, 1997). They also continue to be exploited even though many areas are unsuitable for long-term crop production and yields are unacceptably low. While legislation, such as the Conservation of Agricultural Resources Act (Act 43 of 1983), which prohibits the conversion of virgin veld to crops, has slowed the rate of

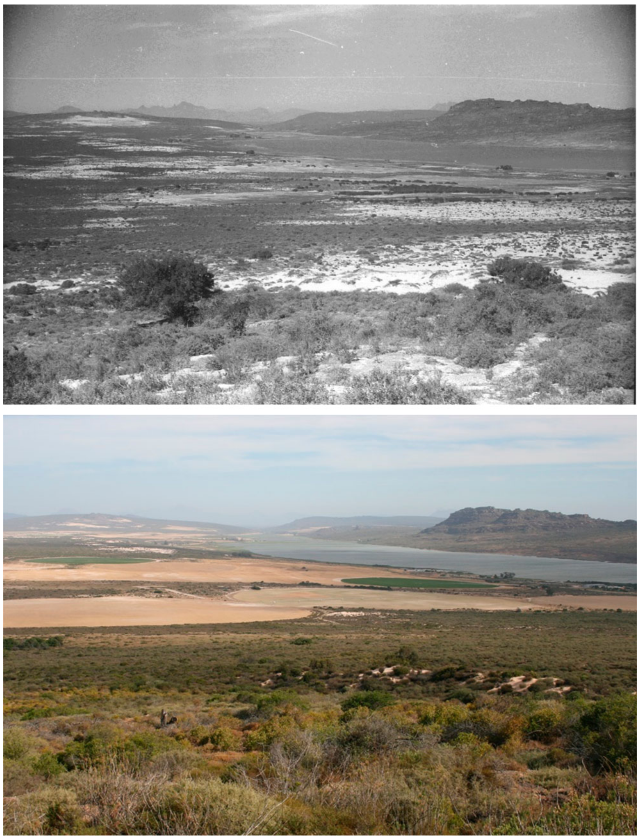


Figure 11. There was only limited cultivation present on the farm above Verlorenvlei near Elands Bay on the West Coast when the top photograph was taken by John Acocks in 1958. Fifty years later, the availability of electricity and subsequent expansion of centre pivot irrigation systems posed a serious conservation threat to large tracts of Sandplain Fynbos vegetation which had been cleared largely for the production of potatoes and wheat. (The bottom photograph was taken by Timm Hoffman in 2008).

transformation in some areas, Newton and Knight's (2005) 60-year, time series analysis suggests that significant levels of transformation continued within these regions for most of the 20th century. Because suitable sites have already been transformed, more marginal environments on steep slopes have been selectively targeted. These trends are supported by the agricultural census data showing the number of hectares cultivated in districts of the fynbos biome over the period 1922–1983. Results indicate that the rate of hectares under cultivation increased steadily over this period (Figure 12) and support the Wicht Committee's contention that land conversion was inevitable in the CFR largely because of the increase in the human population of the region and the need for continued agricultural growth.

It is not only the dominant crops such as wheat, oats and lucerne, however, which have contributed to the conversion of thousands of hectares of natural vegetation in the CFR (Figure 12). Increases in the production of other crops such as grapes, potatoes, rooibos tea and honeybush tea, along with deciduous fruit orchards, have all contributed to the overall level of transformation of indigenous vegetation in the region. The explosion of some industries in recent years could also not have been anticipated by the Wicht Committee as it depended as much on infrastructural development (e.g. the provision of grid electricity) and technological innovation (e.g. centre pivot irrigation systems) as it did on economically-favourable commodity prices and access to ready markets. For example, the increase in canola seed oil, potato and rooibos tea production in the Sandveld region of the CFR since the 1980s has seen a significant clearing of natural veld (estimated at more than 2.7 ha per day by some analyses) such that more than 50% of natural areas have now been transformed by agriculture in this region of high biodiversity (Archer *et al.*, 2009). Similarly, the extent of area under vines in the Western Cape has increased significantly over time from 13 212 ha in 1918 to nearly 100 000 ha by the end of the 20th century (Bruwer, 2003). The area under deciduous fruit production also increased from 8500 ha in 1918 to nearly 55 000 in 2007 (National Agricultural Marketing Council, 2007). Such high levels of transformation have only become possible comparatively recently and could not have been anticipated by the Wicht Committee in 1945.

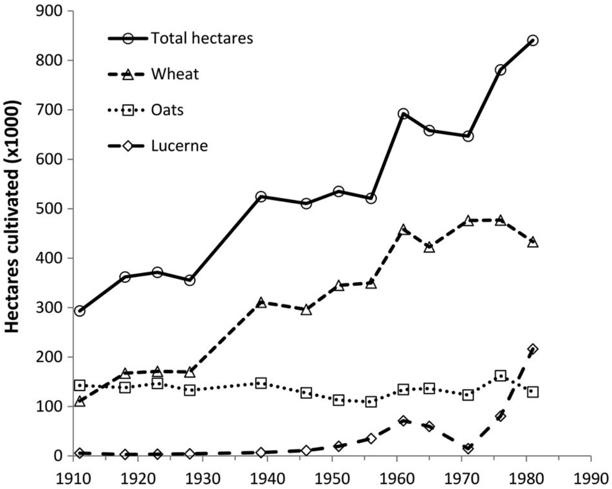


Figure 12. Changes in the total hectares cultivated together with those of the three largest crops in 26 magisterial districts of the fynbos biome from 1911–1981 as contained in the agricultural census records. (Source: Compiled from various agricultural census publications reviewed at Stellenbosch University, South Africa).

Future concerns

In terms of land use practices and their impacts on the CFR, livestock production and especially goat browsing is no longer the threat to the region that it was perceived to be in 1945. Neither is the threat from erosion perceived as being particularly important. Instead, the greatest impacts in the future are likely to arise from increasing human populations, the unregulated spread of urban settlements and an expansion of cultivation into increasingly marginal environments often associated with the production of niche crops such as olives, seed potatoes, rooibos tea and honeybush tea.

Increasing human populations will continue to put pressure on natural environments of the CFR. Formally protected areas will increasingly be targeted for their commercially-viable or culturally-important natural resources, as has already been reported for the Cape Peninsula (Petersen *et al.*, 2012) and other parts of the CFR (Aston Philander *et al.*, 2014). Tourism will continue to grow in the region and the management of large numbers of people who require access to natural environments will also be an important consideration. Because of this there will undoubtedly be a greater focus on urban ecology (Cilliers & Siebert 2012) within the conservation community and issues of access, cultural rights and environmental justice will become more important in the lexicon of fynbos researchers. Interdisciplinary studies which view the CFR as an integrated socio-ecological system (e.g. Heydinger, 2014) will also become far more common than has been the case to date.

Finally, the impact of different land use practices on CFR environments is grossly understudied where the emphasis has been more on biodiversity assessments, taxonomic descriptions and conservation planning (Allsopp *et al.*, 2014b). Apart from a few investigations into the reduction of remnant renosterveld patches very little published information is available about how land use patterns have changed in recent decades and what can be anticipated in the future. There is also an urgent need for more up-to-date census data since the last official agricultural census took place in the early 1990s. While the commercial industry maintains its own databases on hectares sown and kilogrammes harvested this information is rarely accessible to the broader research community at the appropriate level of scale.

PART 4: PROTECTION AND CONSERVATION

Vegetation conservation in South Africa in 1945

Beginning from the premise that the value of the Cape's sclerophyll scrub was its beauty and general scientific interest rather than its economic worth, making arguments for its preservation were thus predicated on the "nature conservation" philosophies of the time that linked nature protection with outdoor recreation and aesthetic appreciation. In 1913 the British Ecological Society (BES) was formed and from the outset worked closely with the Society for the Promotion of Nature Reserves to ensure study areas in which "communities" of plants were available for ecological research (Sheail, 1987). In this regard, specific reference is made in the Wicht Committee's Report to the 1944 report of the BES on Nature Conservation and Nature Reserves that eventually became interwoven with the establishment of the International Union for the Preservation of Nature as an arm of UNESCO in 1948. Max Nicholson, a close associate of Arthur Tansley, was directly responsible for the British Nature Conservancy and its reserve system (Tansley was chair of the organisation and he and Nicholson were members of the first Committee), and it was probably through Adamson (via Tansley) that that mention of the BES Report as an appropriate protectionist template found its way into the Wicht Committee Report.

However, other factors were at play in the preservation/conservation arena in the 1940s. In the USA much earlier in the century, differences in the worldviews of Chief Forester Gifford Pinchot and national park champion John Muir had resulted in a definition of conservation as "wise use" (forests) and preservation as "maintain unchanged" (pristine landscape and vegetation). Shelford, Chairman of the Committee on the Preservation of Natural Conditions of the Ecological Society of America, was also actively interested in the subject and wrote about "Conservation versus preservation" in the journal *Science* in 1933. The Wicht Committee Report deals with this matter (pp. 8–9) and takes the view that, while a stable climax should be the goal of preservation, interrupting the succession process from time to time would be required for purposes of study, modification or economic use, and advocated management goals for the preservation process.

Both Compton and Skaife were obviously familiar with reports such as those to which they contributed with Wicht, Adamson and Pearson. In 1928 Skaife had been among the first recipients of a Visitor's Grant from the Carnegie Corporation of New York (through the British Dominions and Colonies Fund). Compton's 1929 Carnegie grant enabled him to make an extended visit to study the national parks of the USA. His detailed 1934 report, which – under pressure from the Chairman of the Carnegie Visitors Fund – he was obliged "to tone down" in order to avoid causing offence, particularly to the National Parks Board of Trustees (NPB established in 1926), was based on the principle that South Africa's national parks should be accessible, adequately protected crown land that a growing urbanised population could utilise as amenities for both pleasure and education. While not denigrating game reserves as national parks, he argued that these were only one form of national park, not the general norm. In fact, he noted, viewing wildlife from a motor car window in a "game sanctuary" did nothing to encourage the healthy outdoor recreation that he believed was of the essence of nature protection, as it was, of course, in Britain. The neglect of vegetation and scenic or landscape protection in South Africa was, Compton considered, a "national disgrace" (Compton, 1934b). Compton called for the establishment of floristic or scenic national parks, including indigenous forests that were being fast destroyed by agriculture, burning and flower-picking. Compton had a reputation for his strong stance on nature protection. Together with other prominent Cape botanists, particularly Harry Bolus, Compton had championed in the early 1900s for Table Mountain to be declared national park (like Yellowstone) (Dubow, 2006), and he contributed the Foreword to Perry's 1929 book *National and other Parks*. This advocated the conservation of mountains to augment game reserves as national parks and suggested the Hex River Mountains, the Cederberg and the ranges around Tsitsikamma, the area between Bain's Kloof and the Franschhoek Pass as well as the Jonkershoek Valley (Perry, 1929). In 1948 Compton once more suggested conserving the Cape coastal belt and its mountain ranges, and argued, unsuccessfully, that the NPB should administer this region, particularly as so much of the land belonged to the state (Compton, 1948). Elements of Compton's thinking are strongly reflected in the Wicht Committee Report that proposes five "National Nature Reserves" – in the Cederberg, Hottentots Holland, Langeberg, Swartberg and the Outeniqua mountains (Figure 14a). This debate over management authority was generated from the BES report that insisted that nature reserves in Britain should have their own scientific and support staff separate from a national parks authority – a recommendation from Charles Elton.

This conversation over nature reserves was taking place in South Africa in the 1940s because there was no national, let alone provincial or municipal, structure that defined a nature reserve or national park, no guiding legislation for such conservation areas or for their management (apart from small special reserves within Crown Forests after 1935) . There were, however, some promising precedents.

It is not widely recognised that South Africa's first "national park" was an amenity in a mountain landscape: the Natal National Park in the Drakensberg, formally founded in 1916, and referred to as such in Parliament in 1926. Botanist J.W. Bews even contributed a study of the vegetation of the Mont-aux-Sources National Park in Natal (1920) (Carruthers, 2013). The more nationally visible parks that were founded in the 1920s (Kruger) and 1930s (Addo Elephant, Bontebok, Kalahari Gemsbok and Mountain Zebra) – were all wildlife protection facilities and it was clear, as Compton had pointed out, that the South African authorities seemed to be single-minded about wildlife while neglecting other biota and landscapes that were worthy of legal protection.

In the section on the "Establishment of Nature Reserves", it is interesting that the Wicht Committee's Report also does not mention an initiative that was extremely important at the very time that the committee was deliberating and that also held promise as a conservation tool. This was the Dongola Wild Life Sanctuary, established as a National Park in 1947 and abolished as soon as the National Party came to power in 1948 (Carruthers, 1992).

The idea for Dongola came originally from Pole Evans. To assist the Botanical Survey, he envisaged a number of "veld" reserves that would conserve different vegetation zones under conditions that assisted their study. In the interwar period, however, only three came about. The first, in 1918, was the Dongola Botanical Reserve, situated in the remote area of the northern Transvaal at the junction of the Limpopo and Shashe Rivers and that, after expansion in the 1930 s, included the archaeological site of Mapungubwe. The second was the Karoo Reserve in Fauresmith (1929), and the third was at Worcester (1934). After some years of successful conservation and study, Pole Evans planned to turn the Dongola Reserve into a national park protected by law, but not one focused on tourism or large mammal conservation, rather an area set aside permanently for scientific research. His vision was that it would become a site for wildlife and plant ecology and would also protect the archaeological treasure of Mapungubwe that had been discovered in 1932.

After 1939 with Smuts in power once more, the scheme was put before the public for consideration. It soon became clear that the South African population was not ready for scientific nature protection and, with the looming 1948 general election, the issue escalated into a political battle between Smuts' United Party supporters and those of D.F. Malan's National Party. Dongola was controversial not only because of its scientific focus, but because some private land would be expropriated and, in addition, an African heritage site would be conserved by the state. The contentious matter of Dongola was aired in the press and in a long Select Committee Report. Eventually, however, in 1947, the Dongola Wild Life Sanctuary Act was passed into law and thus protected for the future. But the animosity that had erupted over the scheme had its consequences when, immediately after coming to power, Malan's government abolished the national park, returned land to farmers and money to donors (Carruthers, 1992). The history of Dongola is relevant in the context of analysing the Wicht Committee Report in order to raise a question around why in 1945 the Committee did not utilise the idea of establishing botanical reserves within the institution of the Botanical Survey to secure the preservation of the vegetation of the south-western Cape that they sought.

The Committee deliberated at a time in which provincial competencies were being renegotiated. In order to understand the development of scientific research that is outlined later in this article, it is necessary to understand where it was positioned in state and other formal institutional structures. South Africa's 1909 Constitution gave the provinces control of "fish and game preservation" (Section 85 (x)) which was assumed to be an administrative function promulgating legislation and regulating hunting and fishing through licences and not a scientific endeavour. The administration of botany and forestry – and the preservation or exploitation of flora – was a central government responsibility with Cabinet Ministers in overall charge of Departments and Divisions that changed in arrangement over time. With the passage of the Financial Relations Consolidation and Amendment Act (No. 38 of 1945) provinces were obliged to establish departments or institutions to carry out the preservation (and some other) functions given to them by the Union's Constitution. Thus, in 1947 the Transvaal established a Division of Nature Conservation, as did the Orange Free State, while Natal founded the Natal Parks Game and Fish Preservation Board (a parastatal) in the same year. The Cape Province followed suit later, in 1952, with the Cape Department of Nature Conservation. The Wicht Committee's Report, therefore, was written at a time of turmoil within governance as far as nature protection was concerned, and with uncertainty as to the relationship between a national park, a botanical reserve, a forest reserve and a provincial (or other lower government) nature conservation area. Not least among the confusion was the placement of science within these multiple structures.

In his memorandum of 1943, Henkel had recommended the establishment of an organisation for nature conservation drawn from experts in a variety of disciplines. In the same year as the Wicht Committee Report was published (1945) a Provincial Consultative Committee was established to co-ordinate the activities of all bodies controlling national parks, game reserves and botanical gardens, but it did not survive the change of government in 1948 (National Archives of South Africa BNS 1/1/477, 6/5/85). Then, in January 1949, a Scientific Advisory Council for National Parks and Nature Reserves was created. In 1950 and 1952 the RSSAf put forward the names of P.J. du Toit, R.H. Compton, G. v.d.W. de Kock, J.T.R. Sim and C.L. Wicht to the Minister of Lands for consideration – none of whom was appointed. One of the eventual members of the Scientific Advisory Council, Rudolph Bigalke (Director of the National Zoological Gardens) wrote that, "Remarkable as it may seem, this is the first time in the history of South Africa that a Council of scientists will advise the Union Government on matters pertaining to the country's National Parks and Nature Reserves. I expect great things from this body" (Bigalke Archives, Bigalke to Smith, 5 January 1949). He was to be disappointed. It was an unpaid group with an advisory mandate, and it, too, did not last long.

Section IV of the Wicht Committee Report entitled "Measures for Preservation" bears the extremely strong stamp of the BES document that reported on the ecological management of nature conservation in Britain, published in 1944. While wider in focus than the Wicht Committee Report – encompassing all plant and animal species in Britain – the designation of nature reserves as "amenities" for appreciating nature, the need for national and local reserves and differential structures of management for education and ecological research are followed closely in the Wicht Committee Report (British Ecological Society, 1944). This is not surprising given the strong links of the members of the Committee as Fellows of the RSSAf to ecological and nature conservation thinking in Britain.

The situation before the Wicht Committee report

As outlined above, the Wicht Committee's report was published at a time of turmoil within governance as far as nature protection was concerned. However, there had been a long history of proclaiming State Forests, starting with the proclamation in 1811 of a piece of Afromontane Forest, near Plettenberg Bay (Grove, 1987). The reason for these initial proclamations was to protect forests for meeting the timber needs of the British Navy; subsequent proclamations were in fynbos areas identified for afforestation with alien trees (Rebelo & Siegfried, 1992). Conservation of the biota *per se* was not regarded as an issue. Indeed, the consensus amongst learned people in the Cape Colony over much of the 1800s was that the expansion of tree cover enhanced water security by increasing rainfall (Beinart, 2003). Compounding this must have been the huge economic value of wood in pre-industrial societies. Indeed, landowners who covered their properties in trees were held up by the resource management authorities of the mid 1800s as role models (Beinart, 2003). Undoubtedly, this practice subsequently contributed significantly to the invasive alien tree problem that has plagued the CFR (Shaughnessy, 1980).

Proclamation of State Forests in the CFR proceeded very slowly during the 19th century: by 1900, less than 1% of the region was thus designated (Figure 13). However, by 1910 the Cape authorities recognised the importance of protecting mountain catchments for water security. In the early 1910s, Joseph Storr Lister, the Chief Conservator of the Union, proclaimed as State Forest some 340 000 ha of the Swartberg and Langeberg mountains, specifically for the protection of water resources (Beinart, 2003). Further proclamation of State Forests as catchment areas occurred between 1920 and 1930, by which time the forestry department was divided into two branches: one dealing with afforestation and the other with water catchment management (Pooley, 2014). Management of these water catchments, all located in the fynbos-clad mountains of the CFR, had the positive outcome of increased focus on the indigenous vegetation cover. Actual management, however, was limited to, for example, attempts to rehabilitate ceder trees (*Widdringtonia cererbergensis*) in the Cederberg, resource protection, and the prevention of fire and browsing by goats belonging to neighbouring landowners (Wicht, 1945).

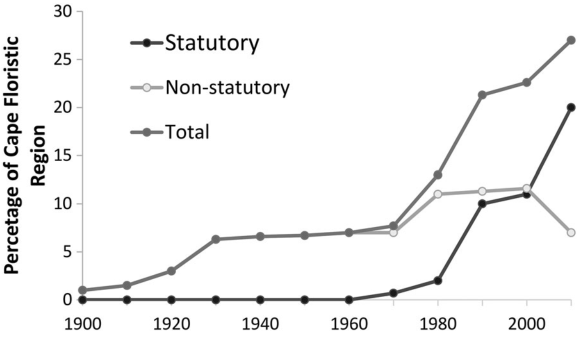


Figure 13. Development over time of the statutory and non-statutory reserve system in the Cape Floristic Region. Reserved areas are expressed as a percentage of the Cape Floristic Region (87 892 km^2). Statutory reserves are supported by strong legal and institutional structures and controlled at the national and provincial level (National Parks, Department of Water Affairs and Forestry [DWAF] Forest Nature Reserves [most proclaimed as National Parks in 2009], and Provincial Reserves); non-statutory reserves have a lower level of legal and institutional support (Local Reserves, Protected Natural Environments, Mountain Catchment Areas, Conservancies, Natural Heritage Sites, Private Nature Reserves and DWAF Demarcated Forests proclaimed as National Parks in 2009, Rebelo, 1992; Rouget *et al.*, 2003a, 2014). The decline in non-statutory reserves is due to the conversion of these areas to statutory categories, which increased after the year 2000.

The development of a protected area network

Key features of the Wicht Committee's protected area network design

By 1945, almost 10% of the CFR was proclaimed as State Forest (Figure 13), stretching from the Cederberg in the north west to the Suurberg in the south east, the vast majority designated as water catchment. The Wicht Committee's report was groundbreaking in that it was the first published pronouncement on the need to proclaim as statutory reserves representative examples of the CFR biota. It was influenced by two recently published reports on nature conservation via nature reserves in the UK and, hence, reflective of international best practice at the time. Moreover, and importantly so, the Wicht Committee's report regarded protected areas as one of several strategies to preserve the CFR's biota, the others being the prevention of transformation to agriculture, the control of erosion, the control of invasive alien plants and the judicious use of fire.

The key features of Wicht's protected area network were as follows:

- It was assumed that ultimately all non-reserved land would be transformed or degraded; therefore, in order to ensure the preservation in perpetuity of the CFR biota, the protected area network should comprise "well selected, representative, relatively large regions that should be maintained with painstaking care".
- Five core regions in the CFR (Figure 14a) were identified with the primary objective of "conserving the natural vegetation". Although the Wicht report did not appear to have consulted Weimarck's (1941) treatise on the phytogeography of the CFR, each of the reserves was located in one of his phytogeographical centres. The report emphasised that each protected area would preserve large numbers of endemic species, some of which were listed in the report.
- The emphasis was on conserving the flora rather than the fauna. By stating that the recommended protected area network "would naturally also serve to protect the fauna", the report demonstrated an understanding of the concept of surrogacy, a topic of heated debate in the conservation literature of the late 1990s and early 2000s (see Lombard *et al.*, 2003).
- A distinction was made between "National Reserves" and "National Parks", the former managed for "scientific and educational intent", the latter for "enjoyment and recreation of the general public". The Wicht Committee appeared to favour the national reserve concept for the CFR protected area network. This is based on the following statement in the monograph: "The national reserves proposed [in Figure 14a] are situated on lands controlled by the Division of Forestry, and the reserves could be maintained by this Division".
- A recommendation was made for a system of local authority reserves to complement the network of national reserves. Although not specifically invoked, the principle of complementarity (Margules & Pressey, 2000) is implicit in his comment that a reserve on Paarl Mountain "would be of particular value since it would be on granite instead of Table Mountain Sandstone like most of the others". The report went on to suggest that "every town in the Cape vegetation region" could have its own local reserve and that some of these could be very small areas set aside for educational purposes.
- Finally, and presciently, the report identifies public apathy towards a proposition that "does not offer immediate direct benefits" as a major barrier to the establishment of the proposed protected area network.

Although the science of protected area design, a sub discipline of conservation biology, only emerged in the 1980s, the Wicht Committee showed a remarkable grasp of many of its core principles, namely representation, complementarity, surrogacy and persistence (Box 5; Margules & Pressey, 2000). The report also appreciated that implementation of a protected area network required appropriate legislation and governance structures.

Box 5. Definitions of the core principles of conservation planning.

Conservation planning is a relatively new branch of science that provides a systematic approach to locating and designing protected areas. Such approaches will need to be implemented if a large proportion of today's biodiversity is to exist in the future, given the projected growth in the human population and their demands on natural resources. The core principles of conservation planning are defined below.

- Complementarity – a measure of the extent to which an area, or set of areas, contributes unrepresented features to an existing area or set of areas.
- Persistence – the extent to which targets for processes that maintain biodiversity are achieved in a real or notional system of protected areas.
- Representation – the extent to which targets for biodiversity features (e.g. higher plants, mammals) are achieved in a real or notional system of protected areas.
- Stewardship – an approach to entering into agreements with private and communal landowners to protect and manage land in biodiversity priority areas, led by conservation authorities in South Africa.
- Surrogacy – the practice of using indicator or surrogate variables (e.g. vegetation types) to represent the distribution of other biodiversity variables (e.g. avifauna).

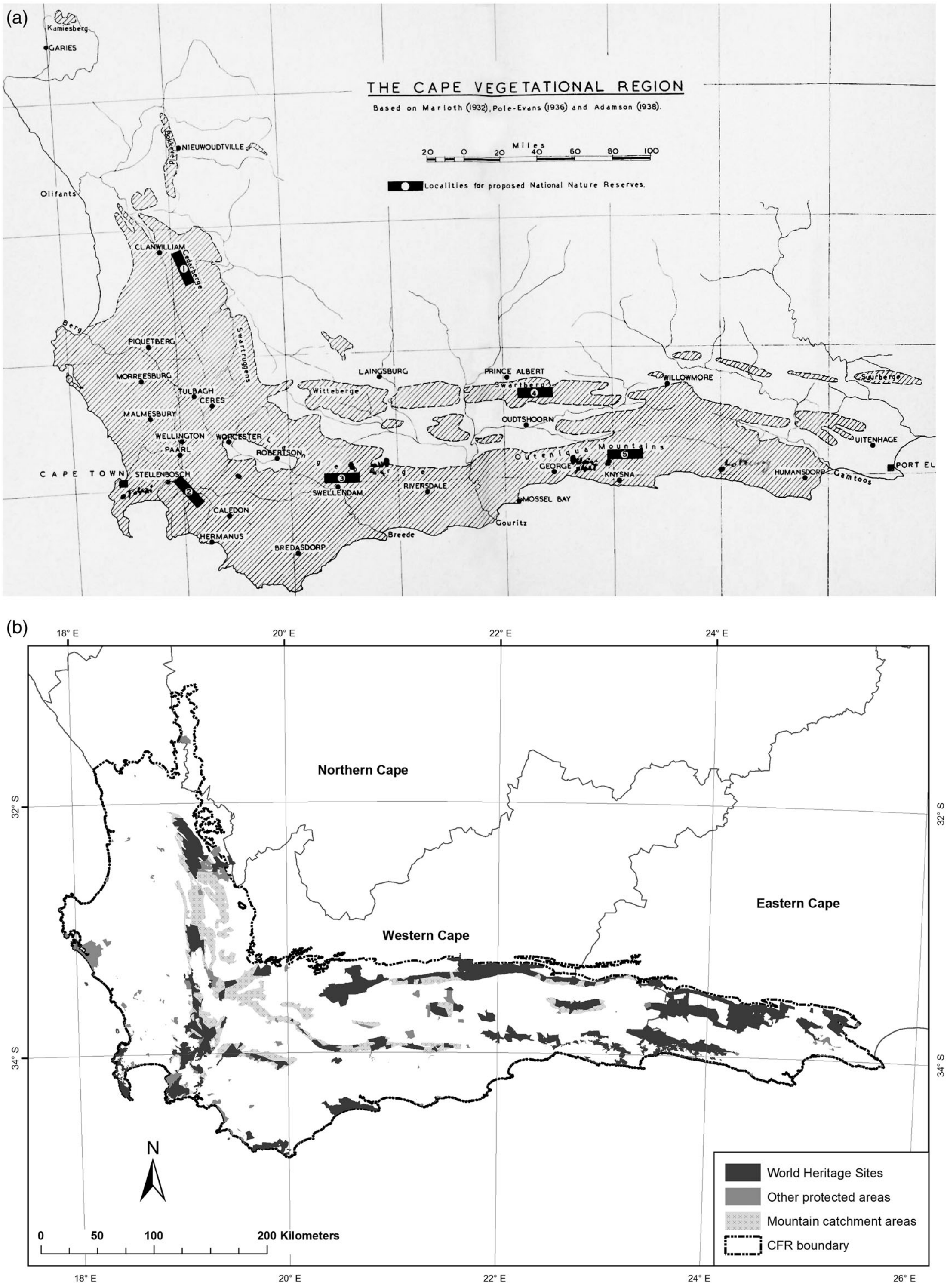


Figure 14. (a) Map showing the location of the Wicht Committee's five priorities for "National Nature Reserves" in the CFR. These are (1) Cederberg; (2) Hottentots Holland; (3) Langeberg; (4) Swartberg and (5) Outeniqua. (b) Current protected area network, showing World Heritage Sites, other protected areas, and areas proclaimed as mountain catchment areas. World Heritage Sites were inscribed on two occasions, in 2004, and again in 2015.

Interestingly, despite the potential significance of the Wicht report, almost no land was added to the conservation estate of the CFR between its publication in 1945 and the early 1970s (Figure 13). This occurred despite the fact that in the 1960s nature conservation became a core activity of the Forestry Department's water catchment programme (Pooley, 2014). While the Cape provincial conservation authority did start buying land in the early 1950s, this was intended to house "problem animal" units, and breed alien fish and rare and endangered wildlife for stocking private farms (Anonymous, 1960). The conservation philosophy of this organisation during this period, which was harshly judged by conservationists at a later time (e.g. Huntley, 1978b; Rebelo, 1992), was to support the conservation efforts of private landowners rather than manage its own estate (Hey, 1966). Ironically, private-sector "stewardship" (see below) was again to emerge as a major conservation strategy for the CFR in the mid 2000s (Von Hase *et al.*, 2010).

1970 to 1994: Progress and setbacks

This tumultuous period in South Africa's history had very mixed outcomes for the conservation of the CFR. While the ruling National Party consolidated its grip on political resistance to its apartheid policies with increasing repression, growing awareness and appreciation by statutory authorities of conservation needs resulted in significant institutional changes with positive conservation consequences. Foremost amongst these was the promulgation of the Mountain Catchment Areas Act of 1970, which led to a large increase in the area of proclaimed mountain catchment in the CFR (Rebelo, 1992). In addition, an amendment to the Forest Act led to the restriction of afforestation in the wetter Cape mountains (van der Zel, 1995). Starting in 1971, the Forestry Department proclaimed large tracts of forest reserve in the Cape mountains as formal protected areas (nature reserves or wilderness areas) (Ackermann, 1972) (Figure 14). The decade 1970–1980 was the golden era for conservation of the Cape mountain ecosystems. On the lowlands, however, conservation languished; by 1974 only 2% of Coastal Fynbos (*sensu* Acocks, 1953) and 1% of Coastal Renosterveld were formally conserved (Edwards, 1974). The lowlands, lacking the key "ecosystem service" of water delivery and where conservation competed with lucrative land uses, were a much harder nut to crack.

Two developments during the 1970s provided some relief for the embattled lowlands. Firstly, the provincial conservation authority adopted a protected area strategy aimed at preserving a representative array of vegetation types in the CFR (Scott, 1986). The same was true for National Parks authority of South Africa. As a consequence, two important lowland reserves, one a provincial reserve at De Hoop on the south coast (which had hitherto been used for wildlife breeding and was closed to the public, Anonymous, 1960), the other a national park at Langebaan on the west coast, were established (Table 4).

As was the case elsewhere in the world (Pressey, 1994), the expansion of the CFR's protected area network was entirely *ad hoc*; there was no defencible set of priority areas based on biodiversity criteria and targets. Fred Kruger, then based at the Jonkershoek Forestry Research Station near Stellenbosch, produced a comprehensive strategy for the conservation of the CFR's fynbos ecosystems that explicitly sought to be representative of the region's biota (Kruger, 1977a). This assessment incorporated the latest advances in conservation biology but was clearly constrained by a lack of data on the distribution and ecology of biological features. It assumed, like the Wicht Committee, that all intervening habitat would likely be transformed; thus the reserve network should be capable of conserving the ecological and evolutionary processes that would maintain the biota in perpetuity. Kruger (1977a) recommended a network of 19 reserves in both mountain and lowland geographies, each located in a different biological zone identified by intersecting Acocks' (1953) veld types with Weimarck's (1941) phytogeographical centres. Using both biological and management criteria, he recommended reserve sizes of between 10 000 ha and 100 000 ha. He speculated that one reserve of the desired size in each of the 19 biological zones would preserve a "considerable and probably adequate proportion of the total flora and most likely an adequate sample of community types". Interestingly, renosterveld was ignored in this assessment. However, Kruger (1977a) did recommend the establishment of smaller reserves in the areas between the major reserves to ensure that unprotected features were included.

Kruger's (1977a) assessment was complimented by an initiative of the Fynbos Biome Project (Huntley, 1992). This comprised an *ad hoc*, "wish list" (cf. Pressey, 1994) assessment of the lowlands undertaken to identify priority areas for conservation, many of which were located in renosterveld landscapes (Jarman, 1986). As we shall see below, the Cape provincial conservation authority was in no position to effectively implement any of these recommendations.

By the mid 1980s, the South African government was fighting a costly war both at home and on its borders, and economic sanctions were beginning to bite. The P.W. Botha regime embarked on a process of cost cutting through "rationalisation". One of the first victims of this neoconservative strategy was the Forestry Department. It was decided that all unafforested State Forest would be transferred to the provincial conservation authority to manage for water delivery, conservation and recreation, and all afforested areas would be privatised (Rebelo & Siegfried, 1992). Given their high afforestation potential, the fynbos-clad State Forests of the Outeniqua and Tsitsikamma mountains were excluded from this transaction, and became a "no-man's land", lacking any management; consequently, over the ensuing decades they became densely infested with invasive alien trees (Cowling *et al.*, 2009).

The transfer of management responsibility for the CFR's mountain reserves to the Cape provincial conservation authority was not accompanied by a budget adequate for the task (van Wilgen *et al.*, 1992a). Consequently, management of the vast majority of the CFR's protected area network deteriorated markedly, arousing the concern of the conservation community. This was, indeed, a very gloomy time for conservation in the region.

In the early 1990s, a period of great political flux and economic hardship, Rebelo and Siegfried (1990, 1992) produced the first systematic (target driven) conservation plan for the CFR, based on distribution records of the well-inventoried Proteaceae. Assuming that Proteaceae distributions coincide with those for other major fynbos clades, Rebelo and Siegfried (1990) argued that 93% of mountain fynbos plant species and 80% of all fynbos species were conserved in the CFR's formal reserve network. As had been pointed out by Kruger (1977a), the big gaps in the reserve system lay in the arid mountains (where no water catchments had been proclaimed) and the coastal lowlands. This research validated the *ad hoc* assessments produced by the Wicht Committee and Kruger (1977a). It also demonstrated, as Kruger (1977a) predicted, that many more reserves were required in the species- and endemic-rich southwest than elsewhere in the CFR.

An issue of particular concern was the perceived escalation in the decline in the natural ecosystems of the super-diverse Cape Peninsula as a consequence of rapid urban expansion

Table 4. Protected areas in the Cape Floristic Region. Proclamation dates refer to the earliest date of proclamation of any part of an existing protected area or complex. Status refers to the definitions in the National Environmental Management: Protected Areas Act (Act 57 of 2003); alternately, land proclaimed as State Forest under the Forest Act, 1888 (Cape Colonial Act 28 of 1888), as Mountain Catchment under the Mountain Catchment Act, 1970 (Act 63 of 1970), as a World Heritage Site under the World Heritage Convention Act (Act 49 of 1999) or as a UNESCO Biosphere Reserve (Western Cape Biosphere Reserves Bill Number 5 of 2011), or as National Botanical Gardens under the National Environmental Management: Biodiversity Act (Act 10 of 2004). An initial group of Protected Areas were inscribed as World Heritage Sites in 2004 (557 584 ha), with additional areas in 2015 (537 157 ha), as indicated. Note that stewardship sites, local authority reserves, proclaimed Mountain Catchment Areas and UNESCO Biosphere Reserves overlap in some cases, so the total area cannot be summed.

Protected area	Proclamation date	Current area (ha)	Notes	Status
Agulhas National Park	1999	21 693	Managed by South African National Parks	National Park, World Heritage Site 2015
Anysberg Nature Reserve	1912	79 629	Managed by CapeNature. This reserve was expanded through donations of land by WWF (South Africa)	State Forest, Provincial Nature Reserve, UNESCO Biosphere Reserve, World Heritage Site 2015
Baviaanskloof Nature Reserve	1923	202 596	Managed by the Eastern Cape Parks and Tourism Agency. This reserve was expanded through donations of land by WWF (South Africa)	State Forest, Provincial Nature Reserve, World Heritage Site 2004 & 2015
Bontebok National Park	1961	3 490	Managed by South African National Parks	National Park, UNESCO Biosphere Reserve, World Heritage Site 2015
Boosmansbos Wilderness Area	1896	14 653	Managed by CapeNature	State Forest, Wilderness Area, UNESCO Biosphere Reserve, World Heritage Site 2004
National Botanical Gardens (Kirstenbosch, Harold Porter, Karoo Desert, Hantam, Edith Stephens Wetland Park, Tienie Versfeld Wildflower Reserve)	Various, starting with Kirstenbosch in 1913	No data	Managed by the South African National Biodiversity Institute	National Botanical Gardens
Cederberg Wilderness Area	1897	65 043	Managed by CapeNature	State Forest, Wilderness Area, World Heritage Site 2004
De Hoop Nature Reserve	1976	34 151	Managed by CapeNature. The reserve was substantially enlarged as a result of land expropriation for military purposes in the 1980s	Provincial Nature Reserve, World Heritage Site 2004
De Mond Nature Reserve Complex	1939	1 178	Managed by CapeNature	State Forest, World Heritage Site 2015
Elandsbaai Nature Reserve	Not known	389	Managed by CapeNature	State Forest
Formosa Provincial Nature Reserve	Not known	24 605	Managed by the Eastern Cape Parks and Tourism Agency	State Forest, Provincial Nature Reserve, World Heritage Site 2015
Gamkaberg Nature Reserve Complex	1934	33 016	Managed by CapeNature. This reserve was expanded through donations of land by WWF (South Africa)	Provincial Nature Reserve, State Forest, UNESCO Biosphere Reserve, World Heritage Site 2015
Garden Route National Park	1964	115 782	Managed by South African National Parks. The current park was proclaimed as an amalgamation of State Forest, proclaimed mountain catchment areas, plantations and the Tsitsikamma National Park in 2006	State Forest, National Park, World Heritage Site 2015
Geelkrans Provincial Nature Reserve Complex	2001	1 264	Managed by CapeNature	Provincial Nature Reserve, UNESCO Biosphere Reserve, State Forest
Goukamma Nature Reserve Complex	1994	2 284	Managed by CapeNature	Provincial Nature Reserve, World Heritage Site 2015
Groendal Nature Reserve	1896	45 114	Managed by the Eastern Cape Parks and Tourism Agency	State Forest, Provincial Nature Reserve, World Heritage Site 2015

(*Continued*)

Table 4. Continued.

Protected area	Proclamation date	Current area (ha)	Notes	Status
Grootvadersbosch Nature Reserve Complex	1896	18 875	Managed by CapeNature. This reserve was expanded through donations of land by WWF (South Africa)	State Forest, Provincial Nature Reserve, UNESCO Biosphere Reserve, World Heritage Site 2015
Grootwinterhoek Nature Reserves	1913	1 609	Managed by CapeNature	State Forest, World Heritage Site 2004 & 2015
Grootwinterhoek Wilderness Area	1985	25 903	Managed by CapeNature	Wilderness Area, World Heritage Site 2004
Hexberg Nature Reserve	1897	1 674	Managed by CapeNature	State Forest
Hottentots-Holland Nature Reserve Complex	1907	33 076	Managed by CapeNature	State Forest, UNESCO Biosphere Reserve, World Heritage Site 2004
Jonkershoek Nature Reserve Complex	1907	15 397	Managed by CapeNature	State Forest, Provincial Nature Reserve, UNESCO Biosphere Reserve, World Heritage Site 2004 & 2015
Kammanassie Nature Reserve	1923	27 451	Managed by CapeNature	State Forest, UNESCO Biosphere Reserve, World Heritage Site 2015
Kapel Conservation Area	Not known	185	Managed by CapeNature	State Forest
Keurbooms River Nature Reserve	1980	1 012	Managed by CapeNature	Provincial Nature Reserve, World Heritage Site 2015
Kogelberg Nature Reserve Complex	1907	24 509	Managed by CapeNature. This reserve was expanded through donations of land by WWF (South Africa)	State Forest, Provincial Nature Reserve , UNESCO Biosphere Reserve, World Heritage Site 2004 & 2015
Limietberg Nature Reserve Complex	1913	44 934	Managed by CapeNature	State Forest, UNESCO Biosphere Reserve, World Heritage Site 2004 & 2015
Local Authority Nature Reserves	Various	42 684	Managed by Local Authorities. Examples of these are the Steenbras, Paarl Mountain, Montagu Mountain, Fernkloof and Ceres Mountain Nature Reserves	Local Authority Nature Reserve
Marloth Nature Reserve Complex	1914	14 256	Managed by CapeNature	State Forest, UNESCO Biosphere Reserve, World Heritage Site 2015
Matjiesrivier Nature Reserve	2000	12 817	Managed by CapeNature. Land purchased by WWF (South Africa)	Provincial Nature Reserve, World Heritage Site 2015
Metropolitan Protected Areas	1980	545	Managed by CapeNature. These reserves include, for example, Driftsands, Harmony Flats and JN Briers Louw	Provincial Nature Reserve
Proclaimed Mountain Catchment Areas	1970	616 267	Privately owned and managed	Mountain Catchment Area
Oorlogskloof Nature Reserve	1994	4 789	Managed by Northern Cape Department of Nature Conservation	Provincial Nature Reserve
Outeniqua Nature Reserve Complex	1936	38 903	Managed by CapeNature	Wilderness Area, State Forest, UNESCO Biosphere Reserve, World Heritage Site 2015
Quoin Point Nature Reserve	Not known	1 127	Managed by CapeNature	State Forest, World Heritage Site 2015
Riverlands Nature Reserve	1994	1 716	Managed by CapeNature. This reserve was expanded through donations of land by WWF (South Africa)	Provincial Nature Reserve, UNESCO Biosphere Reserve

(*Continued*)

Table 4. Continued.

Protected area	Proclamation date	Current area (ha)	Notes	Status
Riviersonderend Nature Reserve	1900	26 619	Managed by CapeNature	State Forest, World Heritage Site 2015
Robberg Nature Reserve	1980	186	Managed by CapeNature	Provincial Nature Reserve, World Heritage Site 2015
Rocherpan Nature Reserve	1976	912	Managed by CapeNature	Provincial Nature Reserve
SAS Saldanha Contractual Nature Reserve	1995	948	Managed by CapeNature, on behalf of the South African Defence Force	Provincial Nature Reserve, UNESCO Biosphere Reserve
Soetendalsvlei Nature Reserve	1977	415	Managed by CapeNature	State Forest, World Heritage Site 2015
Stewardship Sites	2009	51 842	Determined by contractual agreement. Examples of these include Dwarsrivier, Elandsberg, Kromrivierkloof, Taaiboschkraal and Rooiolifantskloof	Contract Nature Reserve (declared)
Swartberg Nature Reserve Complex	1912	112 587	Managed by CapeNature. This reserve was expanded through donations of land by WWF (South Africa)	State Forest, Provincial Nature Reserve, UNESCO Biosphere Reserve, World Heritage Site 2004
Table Mountain National Park	1939	24 449	Managed by South African National Parks. Although sections were proclaimed as far back as 1939, the entire consolidated area was only proclaimed as a National Park in 1998	State Forest, National Park, World Heritage Site 2004 & 2015
Towerkop Nature Reserve	1912	18 971	Managed by CapeNature	State Forest, UNESCO Biosphere Reserve, World Heritage Site 2015
Vrolijkheid Nature Reserve	1976	1 964	Managed by CapeNature	Provincial Nature Reserve
Walker Bay Nature Reserve Complex	1895	7 520	Managed by CapeNature	State Forest, Provincial Nature Reserve
Waterval Nature Reserve Complex	1897	32 442	Managed by CapeNature	State Forest, Provincial Nature Reserve, UNESCO Biosphere Reserve, World Heritage Site 2015
West Coast National Park	1985	31 698	Managed by South African National Parks	National Park, UNESCO Biosphere Reserve

and the spread of invasive alien plants (Rebelo, 1992). This led to a concerted effort to document the Peninsula's biodiversity and identify priorities for research (Cowling *et al.*, 1996). What then followed was a protracted and sometimes bitter struggle to get the complex ownership of the Peninsula's natural areas consolidated under the management of South African National Parks, which was achieved in 1998. This positive step, which had been advocated since the early 1900s by Bolus, Compton and others, injected a strong dose of optimism into the conservation community: changing times became time for change.

The early 1990s also marked the start of a period in which conservationists began promoting private-sector conservation initiatives. In a comprehensive review of conservation in the CFR, Rebelo (1992) argued that contractual nature reserves – or stewardship, as this strategy was later to be called – were the only realistic way for increasing the conservation estate. He also stated that the problems facing conservation in the heavily fragmented renosterveld lowlands were "intractable".

1995 to 2015: Conservation planning and the expansion of protected areas

The post 1994 transition to democratic governance in South Africa created a host of opportunities for conservation, all associated with the demise of apartheid-era institutions and the emergence of new institutions unencumbered by the authoritarianism of the past (Cowling *et al.*, 2002). Furthermore, with renewed global respectability, South Africa became a signatory to international biodiversity conventions and qualified for funding from global conservation instruments such as the Global Environment Facility. However, the outlook for conservation in the "new" South Africa, at least in the eyes of the predominantly white conservation community, remained bleak. Why, many asked, should conservation be a priority in a country with such a huge backlog in providing essential services for the disadvantaged majority?

Cape ecologists found refuge in ecosystem services, arguing that the conservation of nature yielded goods and services (e.g. water production, wildflowers, ecotourism opportunities) whose value, in monetary terms, exceeded by a large margin the costs of conservation management (van Wilgen *et al.*, 1996; Higgins *et al.*, 1997). This line of reasoning worked well for the important water catchments of Cape mountains, as it had done in different guises since the early 1900s (Beinart, 2003). Thus, an impassioned plea by Cape ecologists for investment in invasive alien plant control in the Cape mountains to the Minister of Forestry and Water Affairs, resulted in the launch of the Working for Water project in 1995 (van Wilgen *et al.*, 2002). The fact that the project concept stressed both water delivery and job creation greatly enhanced its attractiveness to politicians.

The ecosystem service argument held much less traction on the embattled lowlands, where the direct, monetary opportunity costs of development vastly outweighed the vaguely valued ecosystem services derived for intact nature. Bear in mind that at this time all kinds of new export markets for agricultural produce were opening up for South Africa and the foreign tourism trade was beginning to escalate. These enterprises created jobs based on foreign exchange; intact ecosystems on the lowlands were perceived to benefit a largely white elite. Nonetheless, using systematic conservation planning protocols (Lombard *et al.*, 1997), Cape conservation scientists were able to persuade the national parks authority to incorporate extensive terrestrial holdings of the highly biodiverse and threatened Agulhas Plain lowlands into the Agulhas National Park (Heydenrych *et al.*, 1999), which was originally intended to be a marine, and not a terrestrial, protected area. This region was to receive a great deal of investment associated with the CAPE project (see below) as a case study for conserving biodiversity in an area where options were rapidly retreating in the face of ongoing land transformation and degradation.

Another strategy devised by Cape ecologists and conservation scientists was to access Global Environment Facility (GEF) funds, which were intended to cover the incremental costs (i.e. the difference between what the recipient could afford and the costs of achieving global biodiversity benefits) of conservation initiatives in developing countries. Cape conservation scientists succeeded in 1999 in securing a grant from the GEF to undertake an assessment for identifying conservation priorities in the CFR. This assessment, led by Richard Cowling, then based at the University of Cape Town's Institute for Plant Conservation, resulted in the publication of a double special issue of an international conservation journal (Cowling & Pressey, 2003) and elevated Cape conservation scientists to the cutting edge of systematic conservation planning (Balmford, 2003). The salient outcomes of this assessment and the planning process that accompanied it were:

- The generation of several important new datasets necessary for systematic conservation planning. These included present and future patterns of land transformation and degradation (Rouget *et al.*, 2003c); a CFR-wide vegetation map (Cowling & Heijnis, 2001), a detailed analysis of gaps in the existing protected area system (Rouget *et al.*, 2003a), a map of the spatial components of ecological and evolutionary processes required to sustain the CFR's biodiversity in perpetuity (Rouget *et al.*, 2003b), and assessments of the costs of implementing conservation actions (Frazee *et al.*, 2003; Pence *et al.*, 2003).
- The setting of defensible targets for a wide range of biodiversity features including vegetation types, plant species, lower vertebrates, medium and large-sized mammals and six different types of spatial components of ecological and evolutionary processes (Pressey *et al.*, 2003).
- The identification of renosterveld and other embattled lowland vegetation types as priorities based on the fact that all remaining natural habitat was required to achieve their targets (Cowling *et al.*, 2003). Earlier assessments had ignored renosterveld (Figure 15).
- The identification of 52.3% of the 95 579 km^2 of extant habitat in CFR, and 42.1% (*c.* 40 000 km^2) excluding statutory reserves for some form of conservation management in order to achieve targets for all features (Cowling *et al.*, 2003) (Figure 15).
- The recognition that three types of implementation strategies were required to ensure effective conservation management of priority areas (Gelderblom *et al.*, 2003). These were: "picking up the pieces" in highly transformed landscapes using stewardship agreements with landowners; "halting retreating options" in rapidly transforming landscapes such as the Garden Route using a combination of law enforcement, stewardship and formal protected area expansion; and "establishing mega-reserves" in largely untransformed landscapes using contractual protected areas and stewardship as instruments (three such mega-reserves were identified – the Cederberg, the Gouritz and the Baviaanskloof).

Several important lessons were learnt from this CFR-wide conservation assessment and planning process (Cowling & Pressey, 2003). First, insufficient attention was given to the incorporation of implementation issues in the assessment. Thus, the final conservation assessment (Figure 8) was too complex to be useful for potential users such as land use planners. Secondly, local government politicians and officials were not identified as key stakeholders of the process, even though most of the important decisions regarding biodiversity are made at this level of governance. Thirdly, owing to inadequate data, the assessment excluded aquatic biodiversity features, despite their importance for the conservation of both biodiversity and ecosystem services. Fourthly, the spatial scale (1:250 000) of the assessment was too coarse to provide implementable opportunities for the biologically complex and highly fragmented lowland landscapes; the appropriate scale was 1:50 000.

Nonetheless, the assessment provided the spatial priorities for the Cape Action for People and the Environment (CAPE) project, a conservation programme which was launched in 2001, funded by international donors and boosted by domestic co-financing (Younge & Fowkes, 2003; Ashwell *et al.*, 2006) (see <http://www.capeaction.org.za>). The CAPE partnership, comprising all spheres of government involved in natural resource management, as well as numerous civil society institutions, "set up biome-wide coordination and governance mechanisms, and landscape initiatives to promote alignment and integration between the spheres of government, and between government, civil society, and the private sector" (Rouget *et al.*, 2014).

The promulgation of the National Environmental Management: Biodiversity Act in 2004 had a profound influence on conservation planning in the CFR and elsewhere in South Africa. This act effectively mainstreamed conservation by making allowance for the publication of bioregional plans to achieve biodiversity conservation goals (Driver *et al.*, 2004). Cape conservation scientists conceptualised bioregional plans in terms of the principles and practices of systematic

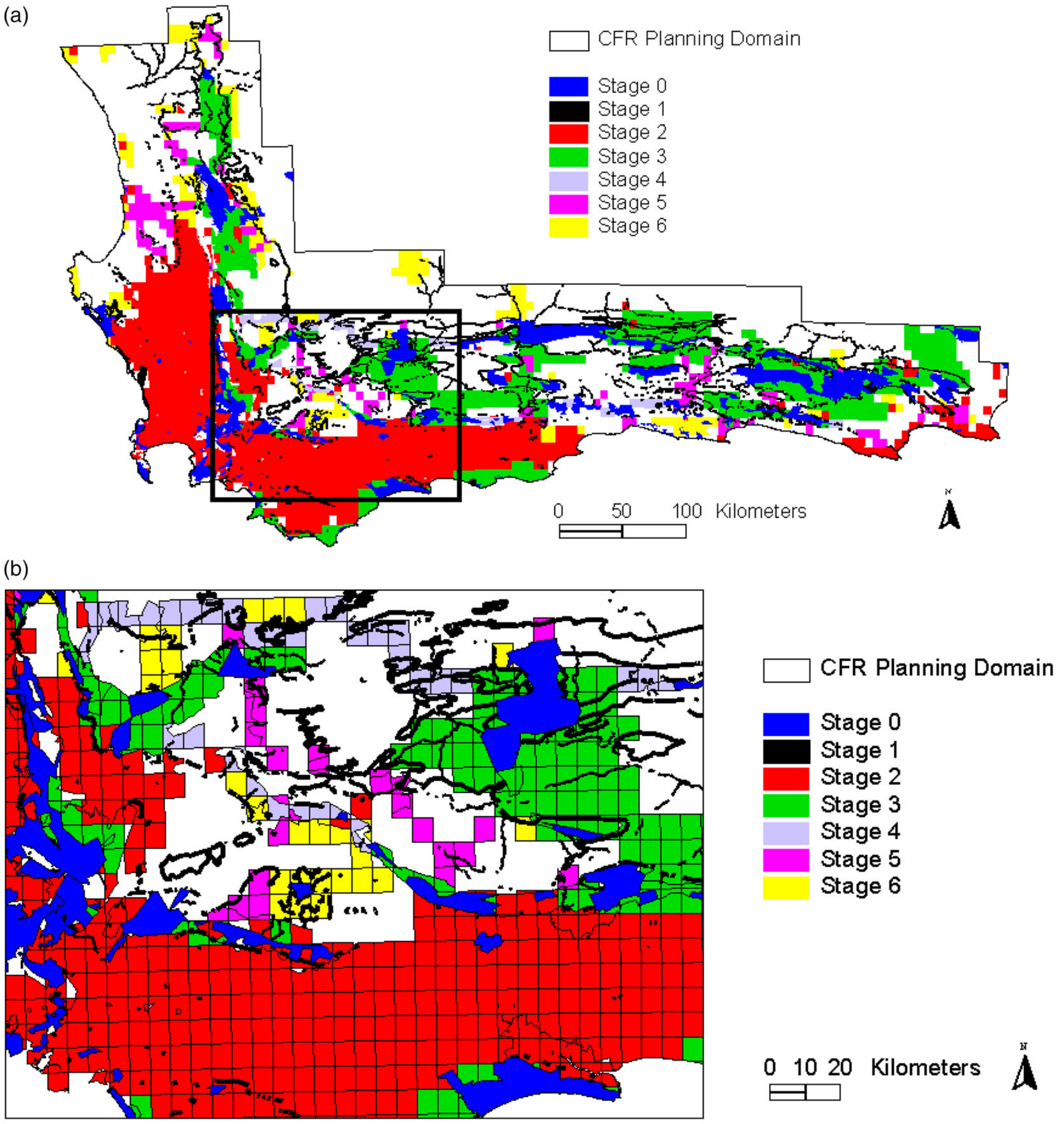


Figure 15. Map of the planning domain for the Cape Floristic Region showing a notional system of conservation areas that achieves targets for all biodiversity features. Different colours denote planning units selected for achievement of targets in six stages building on the existing statutory reserves (S0) (S1 = ecological and evolutionary processes that are fixed spatially; S2 = planning units of maximum irreplaceability for achievement of land class, Proteaceae and vertebrate target s; S3 = conservation plan for large and medium-sized mammals; S4 and S5 = macroclimatic and upland–lowland gradients; S6 = final design for achieving all targets). Inset in (a) is enlarged in part (b). Reprinted with permission from Cowling *et al.* (2003).

conservation assessment with special emphasis on producing user-useful and user-friendly planning products (Pierce *et al.*, 2005; Knight *et al.*, 2006; Figure 16). Thus, bioregional plans have two key elements: (i) a map of critical biodiversity areas, which are terrestrial and aquatic features critical for conserving biodiversity and maintaining ecosystem functioning, and which should thus remain in their natural state; (ii) accompanying land-use guidelines for avoiding loss or degradation of natural habitat in critical biodiversity areas. The purpose of a bioregional plan is to inform all planning initiatives and environmental impact assessments of the location of priority biodiversity features that must be retained in the face of economic development. Once a bioregional plan has been officially published, the recommendations for land use planning are binding on the private sector and government agencies.

The bioregional planning programme is located in the South African National Biodiversity Institute (SANBI), a public entity under the Department of Environment Affairs. Ultimately it is intended that every municipality will be served by a gazetted bioregional plan comprising spatial biodiversity priorities and associated guidelines for land use that steer development away from priority conservation areas. South Africa, and the CFR in particular, now leads the world in this "planning for implementation" approach (Driver *et al.*, 2004; Knight *et al.*, 2006; Rouget *et al.*, 2014). The conservation significance of this approach is the unambiguous focus on retaining biodiversity features of high conservation value, almost all of which are fragmented spatially and highly threatened by human impacts. This is in stark contrast to the assessments of the Wicht Committee, Kruger (Kruger, 1977a) and Rebelo & Siegfried (1992) which emphasised conservation via formal reservation. However, it is consistent with the recommendation arising from Cowling *et al.*'s (2003) assessment.

While the conservation focus in the CFR was on the retention of valued biodiversity in production landscapes (e.g. Lombard *et al.*, 2010; Von Hase *et al.*, 2010) – and appropriately so – this did not mean that no attention was placed on expanding the protected area system. In 2009, the 115 782 ha Garden Route National Park was proclaimed, incorporating most of the "no man's land" mentioned above. Unfortunately most of this new conservation estate is severely invaded by alien trees (Cowling *et al.*, 2009; Kraaij *et al.*, 2011). Furthermore, since the mid-1990s, the World Wide Fund has used various donor instruments to add tens of thousands of hectares to the CFR's formal conservation estate, notably in the Little Karoo (funded by the Leslie Hill Succulent Karoo Trust) but also elsewhere in the CFR (Table 4).

The introduction of stewardship programmes

While protected areas play an important role in conserving the ecosystems of the CFR, most land is in private ownership, and additional mechanisms, such as stewardship programmes, will be required to ensure more widespread conservation. The stewardship approach emerged out of a growing recognition that many private landowners wanted to stay on their land and formalise their involvement in conservation, and that contractual agreements could provide a degree of legal protection, as well as serving as a link to financial incentives. In 2002, a Stewardship Pilot Project was launched by the Botanical Society of South Africa and CapeNature. The project aimed to work with farmers to develop and refine workable stewardship arrangements in three priority areas identified through a lowland-specific conservation planning exercise (Ashwell *et al.*, 2006). In parallel, the Botanical Society engaged in the law reform process and successfully lobbied for the inclusion of a landmark clause in the Property Rates Act (No. 6, 2004) allowing for private property that has been formally declared in terms of the Protected Areas Act (No. 57, 2003) to be excluded from municipal rates (Giliomee, 2006).

After a successful pilot phase, the Biodiversity Stewardship Programme was officially launched in the Western Cape and the first contractual Nature Reserve, Elandsberg – a lowland renosterveld site of over 3 500 ha - was declared in 2008. Since then 39 additional Nature Reserves and one Protected Environment covering nearly 53 000 ha have been declared through the Programme (Table 4); several more are in the pipeline.

While stewardship declarations account for only about 3% of the Western Cape province's current protected area network, it is important to recognise that the formal conservation estate was not only already fairly extensive (at 1.6 million ha or about 12% of the province in 2003), but largely concentrated on infertile geological substrata, high altitudes and steep slopes (Rouget *et al.*, 2003a). In contrast, one third of the area protected through stewardship to date has been lowland habitat and two-thirds of that is threatened vegetation types (Table 5) (see also Gallo *et al.*, 2009). To help further counter the historical biases and *ad hoc* nature of the pre-millennium protected area network, the Stewardship Programme has put review structures in place to ensure that Nature Reserves status is only allocated to sites of high biodiversity value; particularly lowland habitats, threatened ecosystems, strategic corridors and under-protected vegetation types.

Biodiversity Stewardship Programmes are now also active in both the Northern and Eastern Cape provinces, allowing the stewardship mechanism to be applied throughout the CFR. In fact, in the decade since the birth of the programme, stewardship has been widely embraced by the conservation sector (conservation agencies, NGOs and some municipalities) in collaboration with private landowners, local communities, land reform initiatives and the agricultural sector. The stewardship model generally offers landowners two other conservation options (biodiversity agreements and conservation areas), which are successively less binding on the landowner and thus qualify for fewer incentives. Having this suite of options allows landowners and the relevant conservation entity to negotiate an agreement that is appropriate to the biodiversity value of the site.

Current extent of protected areas

At present, just over 18% (1 653 230 ha) of the CFR is deemed protected in terms of the National Environmental Management: Protected Areas Act (No. 57 of 2003). This is, however, only meaningful if the protection of those areas has been regularised – affording the environment the level of security intended by the Act. Protected areas can be regarded as more highly secure if they have an approved Management Plan and an appointed Management Authority. Using this as a criterion would reduce the level of protection in the CFR to around 11% or 968 750 ha (Table 5). For example, areas declared under the Mountain Catchment Areas Act (Act 63 of 1970) are currently not managed as no funding is available to do so. Significantly, Mountain Catchment Areas cover approximately 540 000 ha, or 6% of the CFR. Similarly, Local Authority Nature Reserves and Private Nature Reserves, having been proclaimed under older legislation, are deemed protected areas (as per Section 23(5) of the Act) but are not necessarily compliant in terms of having a formally appointed Management Authority, an approved management plan and the required title deed endorsement (some were not even formally proclaimed).

Levels of protection also vary for the different vegetation groupings (Table 5). While some vegetation groupings are well-protected (for example shale band vegetation, with 60% under protection, and sandstone fynbos, with 40% under protection), others fall short of adequate levels of protection. Most under-protected areas are in the lowlands of the CFR, and they include several renosterveld vegetation types that have only between 1 and 3% under conservation. Earlier assessments (Edwards, 1974; Greyling & Huntley, 1984; Rouget *et al.*, 2003a) reported even lower levels of protection, so the situation has improved. Nonetheless, today's international standards call for 17% of the land to be conserved for habitat protection (the Convention on Biological Diversity's Aichi target 11; Woodley *et al.*, 2012), and South African national biodiversity targets – the amount of an ecosystem required in the long term to maintain viable representative samples of the majority of species associated with that system – range from 16 to 34% of original extent (Desmet & Cowling, 2004; Department of Environmental Affairs and Tourism, 2003).

The achievement of World Heritage Site status

The listing of several protected areas in the CFR as World Heritage Sites in 2004, and more in 2015, has provided international recognition of their global biodiversity significance. The World Heritage Convention, in terms of which World Heritage Sites (WHS) are recognised, was adopted by UNESCO on 10 November 1972. The concept of WHS was born out of the international realisation that the cultural and

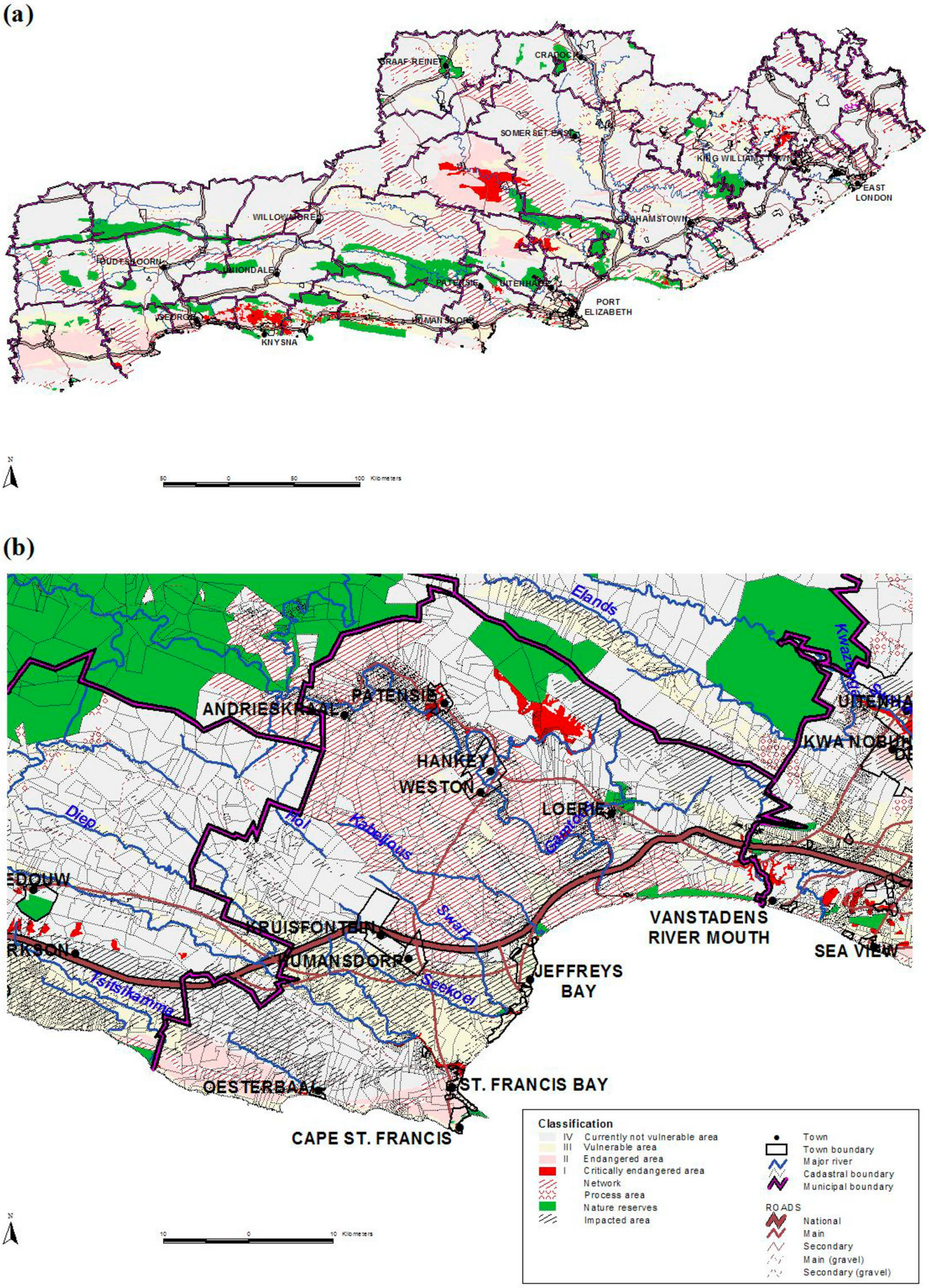


Figure 16. The first attempt to deliver user-useful and user-friendly conservation planning products was for the Subtropical Ecosystem Planning project (2000–2003). Shown here is the conservation assessment map (a) for the entire planning domain and (b) for the Kouga Municipality in the eastern CFR. Reprinted with permission from Pierce *et al*. (2005).

natural heritage assets of the world were coming under increasing threat from a wide range of sources. Countries were not always in a position to manage these assets in a manner that would ensure their persistence in the desired state for future generations. South Africa was only able to ratify this convention on 10 July 1997, following the installation of a democratically-elected government in 1994, after decades of international isolation. Since then, South Africa has promulgated additional legislation (the World Heritage Convention Act, Act 49 of 1999) and has successfully nominated numerous World Heritage Sites.

The most important aspect that has to be clearly demonstrated when nominating sites for World Heritage Status is that the property has Outstanding Universal Value (OUV)

Table 5. Major vegetation groupings (after Rebelo *et al.*, 2006) in the Cape Floristic Region, with their original pre-settlement extent, and the proportions conserved in formally-protected areas. High security protected areas include areas protected by the Forest Act, National Parks, Provincial Nature Reserves, Special Nature Reserves and World Heritage Sites. Lower security protected areas include Mountain Catchment Areas, Local Nature Reserves, and National Botanical Gardens.

Vegetation grouping	Original extent (ha)	Percentage of original extent protected (high security)	Percentage of original extent protected (lower security)	Total percentage of original extent protected
Shale Band Vegetation	76 173	27.78	32.18	59.97
Waterbodies	4 604	46.72	1.58	48.30
Zonal & Intra-zonal Forests	84 181	43.31	1.39	44.69
Sandstone Fynbos	2 946 346	22.05	17.46	39.50
Granite Fynbos	103 617	7.78	12.20	19.99
Seashore Vegetation	8 511	12.20	7.09	19.28
Estuarine Vegetation	11 427	15.22	0.28	15.50
Freshwater Wetlands	24 085	8.06	7.11	15.17
Limestone Fynbos	210 253	11.22	3.42	14.64
Shale Fynbos	231 141	5.45	9.08	14.53
Western Strandveld	401 002	10.69	3.43	14.12
Quartzite Fynbos	247 563	8.00	3.22	11.22
Conglomerate Fynbos	60 460	3.91	5.32	9.24
Albany Thicket	273 668	7.64	1.00	8.64
Eastern Strandveld	21 478	0.09	8.07	8.15
Rainshadow Valley Karoo Bioregion	867 143	6.45	1.21	7.66
Alluvium Fynbos	129 245	3.52	3.75	7.27
Ferricrete Fynbos	70 436	4.34	2.87	7.21
Alluvial Vegetation	52 750	4.38	1.35	5.72
Silcrete Fynbos	86 785	4.89	0.29	5.17
Sand Fynbos	585 381	2.83	1.86	4.70
Inland Saline Vegetation	65 151	3.12	0.51	3.63
Shale Renosterveld	1 866 782	1.79	1.71	3.50
Limestone Renosterveld	50 177	2.39	0.72	3.11
Dolerite Renosterveld	2 761	0.00	1.76	1.76
Granite Renosterveld	96 467	0.34	1.34	1.68
Alluvium Renosterveld	56 010	0.12	0.78	0.89
Knersvlakte Bioregion	54 096	0.30	0.57	0.87
Namaqualand Sandveld Bioregion	51 495	0.36	0.28	0.64
Silcrete Renosterveld	31 480	0.10	0.12	0.22
Namaqualand Hardeveld Bioregion	579	0.00	0.00	0.00
Trans-Escarpment Succulent Karoo Bioregion	14 383	0.00	0.00	0.00
Total	8 884 858	10.90	7.62	18.52

under at least one of ten criteria (six relating to cultural properties and four to natural properties). It also has to be explained what levels of protection are in place and what management capacity is in place to ensure the maintenance of the OUV of the property over the long term. The relevant knowledge regarding the CFR, laid down over many decades, proved sufficient to put together a convincing argument that the Cape Floral Region Protected Areas (CFRPA) should qualify for WHS status under:

- Criterion IX; be outstanding examples representing significant ongoing ecological and biological processes in the evolution and development of terrestrial, fresh water, coastal and marine ecosystems and communities of plants and animals;
- Criterion X; contain the most important and significant natural habitats for *in situ* conservation of biological diversity, including those containing threatened species of OUV from the point of view of science or conservation.

The idea of nominating the CFR for World Heritage status was initiated by South African National Parks (SANParks) in 1999. SANParks wanted to propose the Table Mountain National Park, TMNP (known then as the Cape Peninsula National Park) as a WHS. IUCN however suggested that a nomination should be more representative of the CFR, and James Jackelman of SANParks contacted Guy Palmer of CapeNature, to investigate this possibility. The concept was seen to have merit and by 2003, with the aid of funding from both the United Nations foundation and WWF South Africa, a nomination dossier was submitted via the Department of Environmental Affairs and Tourism (DEAT) to UNESCO in Paris. This was initially planned as a phased nomination with TMNP being phase one and the other seven selected protected areas being phase 2 (Figure 9 b). Due to several delays, phase one and two were ready for submission at the same time in 2002, and were combined into a single dossier. The nomination of the Cape Floral Region Protected Areas (CFRPA) World Heritage Site was accepted by the World

Heritage Committee (WHC) at their annual meeting in China in June, 2004.

The nomination of the CFRPA was always seen as a phased process with the larger, more secure protected areas being selected for the initial submission, with the remaining protected areas being subjected to a rigorous selection process as part of a future extension. The Extension Nomination Dossier (END) was initiated in 2008 and was finally accepted by the WHC in June 2015, increasing the total area of the CFRPA from 557 584 ha to 1 094 798 ha (Table 4) consisting of 163 additional land parcels (the original submission contained 31 land parcels) (Department of Environmental Affairs, 2014). Other protected areas, including declared Private Mountain Catchment areas and adjacent Marine Protected Areas form a buffer (see below) of 755 830 ha.

The conservation status of plant species

Plant endemism in the Cape Floristic Region

The Wicht Committee's report recognised the uniqueness of the Cape flora, stating in the introduction that "Other natural assets may be duplicated elsewhere, but the flora is unique, it is one of the richest, most varied and beautiful in the world." It was in fact Bolus (1875) who first described the distinctive nature of the Cape flora. Bolus identified it as "the only sharply demarcated flora of the subcontinent." We now have a much greater understanding of the number of species, and of endemism, in the Cape Floristic region, than was the case when the Wicht Committee report was published. The CFR covers an area of 90 760 km^2 , and has an estimated 9383 species of vascular plants, 68% (6403 species) of which are endemic to the CFR (Manning & Goldblatt, 2012). The floristic diversity of the Cape flora is unique, and certain families (Iridaceae, Aizoaceae, Ericaceae, Proteaceae and Restionaceae) are particularly well-represented. This unique floristic composition is strengthened by the presence of four endemic families (Penaeaceae, Grubbiaceae, Roridulaceae, Geissolomataceae), and two near-endemic families (Bruniaceae and Lanariaceae, Manning & Goldblatt, 2012).

History of plant descriptive work in the CFR

By 1945 botanical exploration had been intensely taking place for over a century, and several prominent collectors deposited large numbers of herbarium specimens, providing a foundation for the description of plant species. The collectors included, amongst others, F.R. Schlechter (1872–1925), C.F. Ecklon (1795–1868), K.L.P. Zeyher (1799–1858), Rudolf Marloth (1855–1931), K.P. Thunberg (1743–1828), R.H. Compton (1886–1979), C.E. Pillans (1850–1919), and Harry Bolus (1834–1911). These specimens also facilitated the understanding of plant distribution patterns and allowed for floristic treatments to be written. Extensive taxonomic description work had already taken place by 1945. *Flora Capensis* (Harvey & Sonder, 1860–1894; Thiselton-Dyer, 1896–1912) was the first floristic treatment to include plants from the CFR, but despite its name it covered the whole of southern Africa. This treatment was far from complete though, and only included 11 705 of southern Africa's estimated 20 500 plant taxa (Bond & Goldblatt, 1984); it is likely that less than 60% of plant taxa from the CFR were included in these volumes. Although the Wicht Committee recognised that some good progress on systematic understanding of the CFR had been made, they also highlighted the need for far more work to take place, stating that "Its systematic study, which has been in progress for well over a century, is still far from complete. Much of the systematic work undertaken so far has been based on dried herbarium specimens, and a great deal remains to be done on living material as it occurs in the wild state."

Despite 70 years of systematic studies, many new species are still being described, and only 62% of South Africa's plant species had been revised since 1970 (Von Staden *et al.*, 2013). Cape families most in need of revision include Aizoaceae, Ericaceae, Hyacinthaceae and Rutaceae. Despite full taxonomic treatments not being available for all taxa in the Cape flora, concise descriptions for all described taxa are included in conspectuses. The first CFR-specific flora treatment was produced in 1984 (Bond & Goldblatt, 1984), and updated in 2000 and 2012 (Goldblatt & Manning, 2000; Manning & Goldblatt, 2012).

History of conservation assessments of plant species in the Cape Floristic Region

At the time of the Wicht Committee's report, species conservation assessment work in the form of Red Listing had not begun. The International Union for the Conservation of Nature (IUCN) has led the process of assessing extinction risk and determining the conservation status of species. South Africa has, since the first Red Listing project on birds in 1964, worked closely with the IUCN. The first plant assessment process was led by the Royal Botanic Gardens at Kew. Ronald Melville, a Kew botanist, compiled the world's first Red Data Book, published in 1970, listing all the threatened plants known at the time.

Melville's publication stimulated interest from botanists based in the Cape, and Anthony Hall, professor of botany at the University of Cape Town, became involved in the IUCN processes in the early 1970s. He contributed several species accounts, many of them on fynbos plants, to the Red Data Book on plants (Lucas & Synge, 1978). This then led to the compilation of the first list of Threatened Plants of Southern Africa in 1980 (Hall *et al.*, 1980), followed by a more detailed list in 1984 (Hall *et al.*, 1984), and subsequent work to produce a Red List for the Fynbos and Succulent Karoo Biomes in 1985 (Hall & Veldhuis, 1985). The later publication covered the status of plants in the CFR at the time and included information about the conservation status of 1326 species of conservation concern, 26 of which were listed as Extinct. The work of Hall and his colleagues on assessing plant conservation status was funded by the CSIR's Cooperative Scientific Programme, then led by Brian Huntley. The Cooperative Scientific Programme also provided support for young botanists to become involved, and led to the training of future Red List scientists including Craig Hilton-Taylor and Rob Scott-Shaw. Hilton-Taylor did extensive work on threatened plants in the 1980s and 1990s and went on to produce South Africas next, and vastly expanded, Red List in 1996 and 1997 which included 3916 plant species, 1531 of which were from the Cape flora (Hilton-Taylor, 1996, 1997).

From 1996, South African botanists became involved in a regional project, the Southern African Botanical Diversity Network (SABONET), to promote the documentation and assessment of plant species in southern Africa. As part of the SABONET project a Red List was produced for southern Africa (Golding, 2002). Most of the effort for this publication was spent on helping neighbouring countries to produce Red List assessments for the first time, and only 948 South African plants were included, including a small and incomplete treatment of plants in the CFR. The SABONET Red List did however raise the profile of Red Lists for the region and allowed the then National Botanical Institute to raise significant funding from the Department of Environment Affairs to conduct a large Red Listing project to assess, for the first time, all of South Africa's c. 20 500 plant taxa. This ambitious project took seven years to complete, and in 2009 South Africa became the first mega-diverse country to comprehensively include all indigenous plant species in a comprehensive Red List (Raimondo *et al.*, 2009).

Since the first southern African plant Red List was published (Hall *et al.*, 1984), the IUCN Red List system has been continually refined towards a more objective process of categorisation of species. Quantified criteria, first introduced in 1994 (IUCN, 1994), and refined until 2001, have increased the need for data to support and justify Red List assessments. This requisite information has been assimilated from a wide range of sources, including botanical taxonomic literature, herbarium specimen data and land-use information obtained from special land-cover datasets. Due to the need for good quality field data on plant populations for species of conservation concern, a citizen science volunteer programme (Custodians of Rare and Endangered Wildflowers, CREW) was established in 2003. The CREW programme (which arose from the Protea Atlas project, Forshaw, 1998), was first trialled in the CFR, and from 2006 was expanded nationally. Over the past decade the CREW programme has become established in all parts of South Africa where there are high numbers of threatened endemic plant species, and over 20 citizen science groups conduct regular field trips and send standardised data on threatened and rare plants to a team of plant Red Listers based at SANBI. These data are used to produce an annual Red List update available online at http://redlist.sanbi.org.

Current status of red data species from the Cape Floral Region

The fact that we are now able to provide an account of the conservation status of all 9383 plant species in the CFR is remarkable, even if over 6000 of the species were simply placed in a category of Least Concern if they occupied a relatively large range; few other regions of the world have done this.The CFR contains the highest concentration of the country's threatened taxa (65%), and taxa of conservation concern (60%) (Table 6; Figure 17; Box 6). Threatened taxa are concentrated in the lowland areas where the majority of natural habitat has been transformed. The majority of the nutrient-rich shale and granite soils within the CFR have been converted to cereals, grape and deciduous fruit plantations since the time that the Wicht Committee's report was published. It was already recognised in 1945 that plants of the CFR were under threat from anthropogenic influences: "this considerable asset is in the process of being lost, through the ravages of fire, browsing and erosion; the invasion of undesirable exotic species; the illegal gathering of flowers and the indiscriminate conversion of veld to other uses." However, in 1945 the post-World War II agricultural revolution had not begun, and interestingly habitat loss for agricultural crop production, which today is regarded as the main threat to endemic plant species in the CFR (Figure 13), was not raised as a threat by the Wicht Committee (the Committee's report does make mention of conversion of natural vegetation to crops, but it was not highlighted as being as serious a threat as burning or erosion).

Crop cultivation, and urban and coastal development pose the largest threats to plant taxa endemic to the Cape flora today (Figure 13). While the Wicht Committee only mentioned housing in passing as a minor threat to plant species on the Cape Peninsula, over the past 70 years housing development has increased substantially along the southern Cape coast, in the northern suburbs of Cape Town, and on the west coast around Vredenburg. The expansion of Port Elizabeth is also impacting many of the CFR's plant taxa. This housing infrastructure development has had a major impact on plant species with 1258 plant taxa now threatened by housing developments in the Port Elizabeth area alone (Figure 18).

A further reason for the high concentration of threatened plants in the CFR, both in the lowland and upland areas, is encroachment by invasive alien species, with the lowlands being the most affected. Hall and Veldhuis (1985) listed invasion by alien plants as the most widespread threat to the survival of rare plants in the fynbos. Invasion by alien plants is currently seen as the second most severe threat (after habitat loss) to plant species of conservation concern in the CFR, with 1920 endemic plant taxa declining as a result of competition with invasive species (Figure 18).

In addition to plants, conservation assessments have been carried out for all vertebrates, as well as for a few invertebrate groups (Table 7). Clearly, at a species level, plants are the major cause for concern, but all groups assessed have examples of species of conservation concern. In particular, freshwater fishes stand out due to the high levels of endemism and the magnitude and spatial extent of threats. These threats include pollution, water extraction, impoundments and invasive alien predatory fish.

PART 5: EVOLUTION OF MANAGEMENT

Important aspects of management in the Cape Floristic Region

Managers of ecosystems in the CFR are concerned with protection and/or sustainable use, depending on the area being managed. In protected areas, the main focus of ecosystem management would be on the maintenance of processes that keep ecosystems healthy (this essentially comes down to managing fire) and the reduction of threats (the most important of which is invasive alien species). In privately-owned areas (and in some protected areas) managers seek to maximise benefits through harvesting products from natural areas on a sustainable basis. Managers of natural areas are also concerned with managing infrastructure (such as roads, bridges and tourism facilities), and the tourists themselves, while authorities have to manage the enforcement of environmental laws. In this section, we review the major ecological aspects of management in the CFR, namely fire, invasive alien plants and the harvesting of plants.

Box 6.

Examples of highly-threatened plant species in the Cape Floristic Region.

Many plant species in the Cape Floristic Region are of conservation concern, and many occur in very small populations, often in lowland areas threatened by urban development or infrastructure. Some examples that illustrate the problem of conserving species with small, isolated populations are shown here (after Raimondo *et al.,* 2013).

Serruria furcellata (Proteaceae) is a Critically Endangered plant species, currently surviving as a single individual in the wild on the Cape Flats, where it faces threats from urban and industrial expansion (Photograph Colin Patterson-Jones).

Morea loubseri (Iridaceae) is a Critically Endangered plant species, known from a single granite outcrop near Langebaan, where 14 individuals currently survive. It faces threats from urban development and quarrying (Photograph Graham Duncan).

Disa barbata (Orchidaceae) is a Critically Endangered orchid species that is now extinct on the Cape Flats, but survives in a population of 600–700 individuals near Malmesbury. It is threatened by alien plant invasions, as well as by human activities related to firewood collection and alien plant clearing (Photograph Bill Liltved).

Erica verticillata (Ericaceae) is extinct in the wild, but about 200 individuals have been re-introduced to suitable habitats on Cape Flats between Mowbray and Muizenberg. It remains threatened by urban expansion and flower harvesting (Photograph Colin Patterson-Jones).

Mimites chrysanthus (Proteaceae) was first discovered in 1987 in the Gamkaberg Nature Reserve. It is regarded as Vulnerable, and <3000 individuals occur in the Gamka and Outeniqua mountains in the southern Cape. It is threatened by invasive alien *Hakea* shrubs, and possibly also by excessively frequent fires, but no data exist to support this (Photograph SANBI).

Leucadendron floridum is a Critically Endangered shrub restricted to the Cape Peninsula, where <10 000 individuals survive. It is threatened by habitat degradation, urban expansion, invasive alien plants and harvesting for the wildflower trade (Photograph Colin Patterson-Jones).

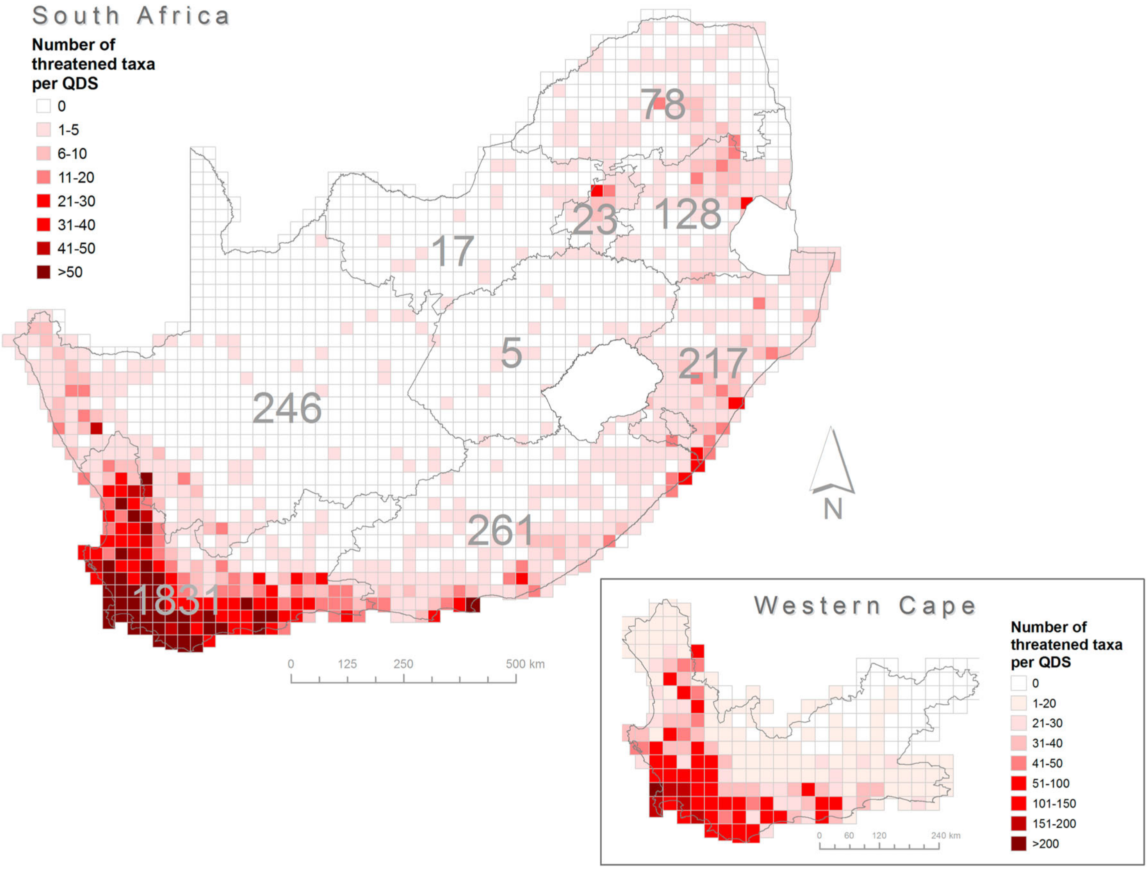


Figure 17. The number of threatened plant taxa (Critically Endangered, Endangered and Vulnerable) per quarter degree square (QDS, approximately 25 km × 25 km) in South Africa, showing concentration in the Cape Floristic Region. Numbers show totals per province; 65% of the country's threatened taxa are concentrated in the Western Cape Province (inset). The Cape Floristic Region contains 9381 plant species (6407 endemics); See Table 7 for details (maps and data from Raimondo *et al*., 2009).

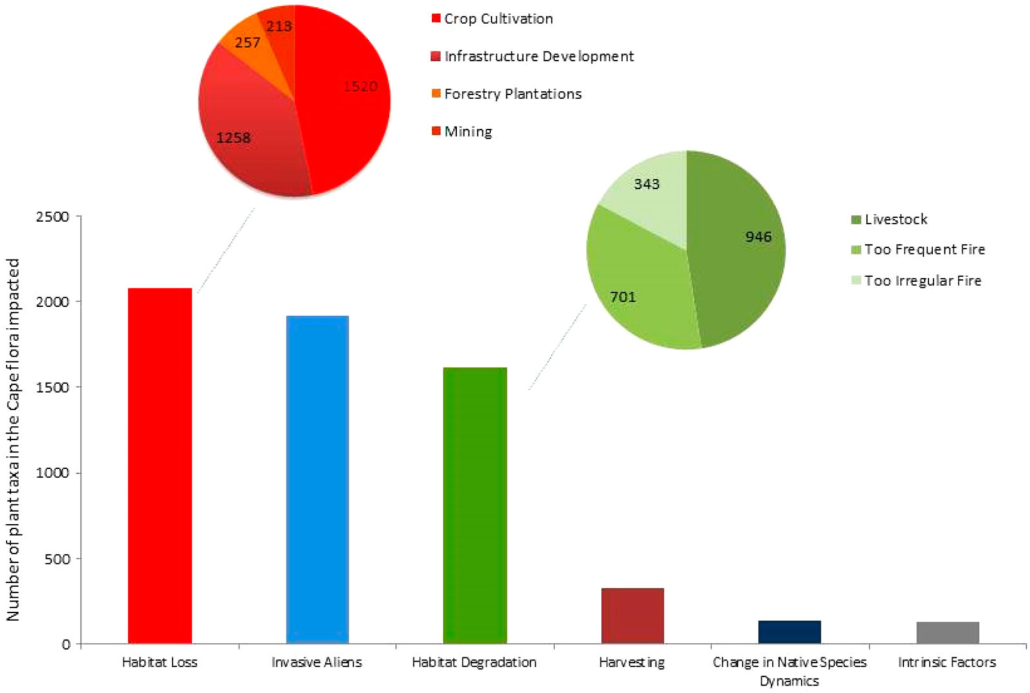


Figure 18. The main threats and pressures facing plant taxa of conservation concern (threatened and range-restricted species) in the Cape flora.

Table 6. The number of plant taxa of conservation concern in South Africa's nine biomes (Raimondo *et al.*, 2009). Threatened taxa include those in the International Union for the Conservation of Nature (IUCN) categories of Critically Endangered, Endangered and Vulnerable. Taxa of conservation concern include threatened taxa, plus taxa in the IUCN categories Extinct in the Wild, Data Deficient, Near Threatened, Critically Rare, Rare and Declining.

Biome	Threatened taxa	Endemic threatened taxa	Taxa of conservation concern	Endemic taxa of conservation concern	Extinct taxa
Albany Thicket	70	39	144	62	1
Desert	13	1	46	4	1
Forest	94	45	189	91	1
Fynbos	1805	1745	3296	3151	24
Grassland	245	171	536	343	6
Indian Ocean Coastal Belt	75	36	134	55	1
Nama Karoo	22	10	75	40	1
Savanna	146	72	317	150	1
Succulent Karoo	288	228	668	524	0

The management of fires

The introduction of prescribed burning

In 1948 the Department of Forestry, taking its lead from the Wicht Committee's report, formulated a policy for managing fynbos vegetation by applying prescribed burning. This was however not adopted and implemented, due to a "failure of nerve" by the Department in the face of strong anti-fire opinions and the restrictions on burning in terms of the Soil Conservation Act (Act 45 of 1946) (Pooley, 2012). Proposals for prescribed burning were vetoed at the time because managers felt that no firm guidelines, based on research findings, as to the appropriate fire return periods or seasons were available (Bands, 1977). The focus of fire management in fynbos ecosystems finally changed in 1968 with the resolution by the Department of Forestry to introduce a system of prescribed burning in the catchment areas under its control. There were two considerations that contributed to this decision. First the findings from the Jonkershoek hydrological experiments led the 1968 Ministerial Interdepartmental Committee on Afforestation and Water Supplies to conclude, "that protecting natural vegetation from fire reduced streamflow because [as the Wicht Committee had suggested] fires were believed to lower average veld age and reduce evapotranspiration" (Pooley, 2012). Regular burning would thus reduce the average age and biomass of fynbos vegetation, and it would consequently increase streamflow runoff. The second reason related to the growing recognition that fires were not detrimental to the vegetation, and indeed played a vital role in ensuring the survival of fire-dependent plant species (Box 2).

In 1973, Wicht & Kruger (1973) wrote that "The Department of Forestry is now poised to initiate management of the considerable areas of mountain veld on State Forests and private lands, and investigations for drafting plans are now in progress. Management cannot, however, await the results of the long-term veld management research, but must proceed by using available knowledge". Prescribed burning was to be applied to fynbos mountain catchment areas, both on state and privately-owned land (where a mandate for management of proclaimed land was created under the Mountain Catchment Areas Act, Act 63 of 1970). The principal management objective for all catchment areas was "maintenance of maximum permanent sustained flow of unpolluted, silt-free water", but on state land nature conservation enjoyed "equal status with soil and water conservation except for limited areas where timber production from plantations was permitted" (Bands, 1977).

Setting guidelines for burning

The desired average fire return period for prescribed burning was set at 12 years, although this could be varied depending on circumstances (Bands, 1977). In 1978, Fred Kruger and Alan Lamb submitted a report, based on research in the Kogelberg State Forest, in which a "rule of thumb" was recommended for determining fire return periods. They suggested that "the rotation should be long enough to permit at least 50 per cent of any seed-regenerating plant species population in a compartment [area to be burnt] to have flowered and set mature seed for three successive seasons" (Kruger & Lamb, 1978). On the basis of this rule, they recommended that "prescribed burning should be conducted on a 15-year rotation in areas containing dense fynbos on humic soils or peats, and on a 12-year rotation elsewhere".

Regarding fire season, Kruger and Lamb (1978) recommended that burning in the period April to August, inclusive, "should be avoided because of the possibility of soil erosion and because evidence from elsewhere indicates that seed regeneration is not favoured by winter burns". Burning at other times should be allowed, but fires should be timed "to obtain intensities high enough to create favourable seed beds", while still allowing for "successful fire control". This recommendation was against the prevailing notion that fires should be prescribed for mid- to late-summer, since this is when most fires would occur, and to which species would be adapted. However, they concluded that "field evidence from the Kogelberg indicates … that season of burn is not important in this respect". In effect, this led to many fires being conducted in spring (September and October), when burning conditions were relatively mild. However, subsequent research by William Bond and his colleagues concluded from extensive surveys in the southern Cape that "winter and spring burns lead to very poor seedling establishment [of Proteaceous shrubs], mostly well below replacement levels, so that successive fires in these seasons would rapidly lead to local extinction" (Bond *et al.*,

Table 7. Numbers of taxa of conservation concern in the Cape Floristic Region. Categories are according to the International Union for Conservation of Nature (IUCN) Red List. Data sources include Raimondo *et al.* (2009) for plants; O.L.F. Weyl (South African Institute for Aquatic Biodiversity) for freshwater fish; A. Turner (CapeNature) for mammals; Birdlife South Africa for birds (excluding marine species, or records of marginal or vagrant occurrence); J. Measey (Stellenbosch University) for reptiles and amphibians; and M.J. Samways (Stellenbosch University) for Odonata. Red data assessments have also been carried out for Butterflies (Lepidoptera), freshwater molluscs and freshwater crabs, but data are not shown. The threatened taxa (%) is the number of taxa in the categories Critically Endangered, Endangered and Vulnerable, expressed as a percentage of the number of indigenous taxa.

Taxonomic grouping	Number of indigenous taxa	Number of taxa endemic to the Cape Floristic Region	IUCN category							Threatened taxa (%)
			Extinct	Extinct in the Wild	Critically Endangered	Endangered	Vulnerable	Near Threatened	Data Deficient	
Vascular plants	9381	6407	23	3	333	575	801	233	836	18.2
Mammals	121	13	1	0	3	2	6	16	11	9.1
Birds	588	6	0	0	0	12	19	21	9	1.7
Reptiles	149	32	0	0	3	2	5	9	0	6.7
Amphibians	46	29	0	0	0	5	1	6	0	13.0
Freshwater fish	25	18	1	0	2	7	3	1	2	48.0
Dragonflies (Odonata)	83	24	0	0	1	1	7	1	2	10.8

1984). Similar patterns were subsequently also found in the Western Cape (van Wilgen & Viviers, 1985), and prescribed burning in spring was consequently discouraged. The proportion of the year during which burning could be conducted therefore became more restricted.

Capacity constraints

At the end of the 1980s, van Wilgen *et al.* (1990b) estimated that, in order to achieve a target of burning fynbos catchment areas in the Western Cape Forestry Region (~ 800 000 ha) at a return period of 15 years, 52 prescribed burns of ~1000 ha each would have to be conducted annually. This target was never achieved even when spring burning was permitted, but it declined markedly once the restrictions on spring burning were instituted (Figure 19).

Additional developments in the late 1980s also constrained the capacity of managers to conduct the necessary prescribed burning. In 1986, the catchment management functions of the Department of Forestry were transferred to provincial nature conservation agencies, with a significant reduction in operating budgets, and without many of the experienced staff necessary to carry out fire management. Louw (2006) recorded that "In 1986 one million hectares of unplanted State Forest mountain catchment area was transferred from the Department of Forestry to the Provincial Nature Conservation authorities. This brought an end to a long history of involvement of foresters in mountain catchment management during which foresters made an excellent contribution towards responsible environmental management and conservation". In addition, large tracts of un-afforested fynbos in the Outeniqua and Tsitsikamma mountains of the Garden Route areas were left without a custodian – the so-called "no-man's-land" (Cowling *et al.*, 2009) – and all management of these areas effectively ceased until the establishment of the Garden Route National Park 20 years later in 2009.

Prescribed burning also had to be integrated with the management of fire-adapted invasive alien plants, placing further constraints on prescribed burning, as pre-fire treatments of invasive plants had to be carried our prior to any burning taking place (Richardson *et al.*, 1994). Thus, despite a policy that promoted prescribed burning, only a relatively small area (on average 11% of the area of all fires in 10 fynbos

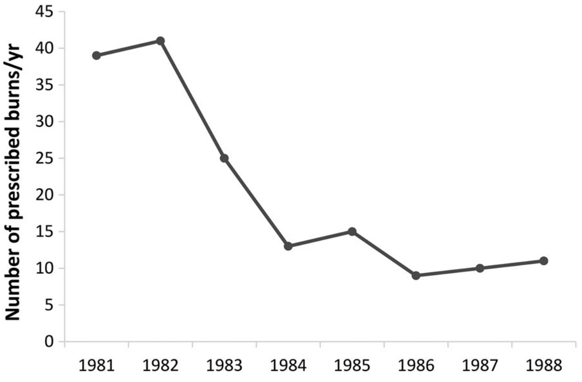


Figure 19. The number of prescribed burning operations conducted in catchment areas in the Western Cape Forestry Region between 1981 and 1988. Data are from van Wilgen *et al.* (1990a).

protected areas) burnt in prescribed burns over the past 40 years, with the rest burning in wildfires (van Wilgen *et al.*, 2010).

Current situation

In 1998, South Africa enacted new legislation to govern the management of fires (the National Veld and Forest Fire Act, Act 101 of 1998; Kruger, 2014). This Act calls for integrated fire management, recognising both the ecological role of fire for maintaining healthy ecosystems and the need to reduce the risks posed by fires. In line with South Africa's new Constitution, the Act promotes co-operative governance within a larger system of laws, including the Disaster Management Act (Act 57 of 2002), and The National Environmental Management: Biodiversity Act (Act 10 of 2004). The Act makes two important provisions designed to enable systematic, locally appropriate fire management, requiring (1) the implementation of a National Fire Danger Rating System (NFDRS) as an early-warning system, and (2) the establishment of Fire Protection Associations (FPAs) as institutions for local fire management. By 2010, 196 FPAs had been established in South Africa, but many are under-resourced, or lack the capacity to be effective (Kruger, 2014a). In addition, there has been a failure, to date, to implement the NFDRS, and as a consequence, the old regime's approach of seasonal fire prohibitions has continued (possibly *ultra vires*, Kruger, 2014a). The old system requires the issuing of hundreds or even thousands of burning permits, which is not consistent with the intent of the Act to promote ecologically-sound fire management through reasonable rules and local agreement. Almost all of the attention that fire management currently receives is focused on fire prevention, detection and suppression, leaving little or no capacity for prescribed burning. If prescribed burns are conducted, the need for ecological outcomes (such as those precipitated by high-intensity fires) is generally overridden by safety concerns, making it difficult to obtain the necessary permission to burn, and also resulting in low-intensity prescribed fires when they are implemented. The reconciliation of fire management goals that relate to safety on the one hand and to the maintenance of ecosystem health on the other remain among the most important and controversial aspects of fire management (van Wilgen, 2013).

The management of invasive alien plants

Initial response to the Wicht Committee report

The Wicht Committee's report seems to have had little or no impact on garnering support from government for the management of invasive plants in the CFR. Many publications in the 1950s and 1960s describe the worsening of the situation (e.g. Woods, 1950; Taylor, 1969). In 1959 the Control of Alien Vegetation Committee of the National Botanic Gardens of South Africa published a book entitled *The Green Cancer of South Africa: The Threat of Alien Vegetation to Our South African Veld and Forest*, which had an exclusive focus on the CFR (and mainly on Kirstenbosch) despite the national-level title. In 1961 a "hakea conference" was held in Stellenbosch (Serfontein, 1961) where "the first positive steps were taken to deal with the hakea threat" (Fenn, 1980). These "positive steps" involved the creation of an inter-departmental action committee to investigate the problem. During the 1960s the action committee investigated control methods, undertook surveys of invaded areas, and launched awareness campaigns. Some progress was made in controlling hakea in the mid-1960s (van Wilgen & Kruger, 1981) but it became clear that the problem was increasing rapidly (Fenn, 1980).

The Department of Forestry's control programmes 1970–1990

The Mountain Catchment Areas Act marked the beginning of the era of "catchment management" which involved, among other things, prescribed burning and systematic control of invasive woody plants (Fenn, 1980; van Wilgen *et al.*, 2002). In 1976 the Forestry Department decided to scale up efforts to control hakea; plans included further surveys, and linking control efforts with a programme of prescribed burning (Fugler 1983). The catchment alien plant control programme was initially deemed a success (Macdonald & Richardson, 1986) and Macdonald *et al.* (1985) estimated that 1579 km^2, or 21% of the 7592 km^2 infested by *Hakea* and *Pinus* species, had been "successfully cleared" by the end of 1984. However, despite the substantial investment by the Department of Forestry in integrated catchment management, and notwithstanding early successes, the programme could not keep up, especially as prescribed burning programmes were falling behind schedule. The situation worsened dramatically when, in 1986, the responsibility for managing mountain catchment land was transferred from the Department of Forestry to provincial conservation authorities (largely Cape Nature) who were poorly resourced and could not continue with the programme of prescribed burning and integrated invasive plant control (Cowling *et al.*, 2009).

Biological control of invasive alien plants

Research into the biological control of invasive alien plants in the CFR made a modest start in the 1970s (Annecke & Neser, 1977), but was broadened in the 1980s (as described above) with many positive results. During the early 1990s the biological control efforts were threatened with closure by declining funding. Most of the research was driven by the Plant Protection Research Institute (PPRI) within the Agricultural Research Council. When the Working for Water programme was being initiated by the Department of Water Affairs and Forestry in 1995, Dr Helmuth Zimmermann (manager of the Weeds Research Division of the PPRI) approached Working for Water's Steering Committee, outlining the available expertise in this field, and stressing the importance of the approach. As a result, the Working for Water programme funded (and continues to fund) research into biological control.

The effects of biological control on selected alien trees species in the CFR have been encouraging. Moran & Hoffmann (2011) reported that "Since 1970, ten invasive tree species in the fynbos biome have been subjected to biological control, namely: six *Acacia* species and *Paraserianthes lophantha* (Mimosaceae), *Hakea sericea* (Proteaceae) and *Leptospermum laevigatum* (Myrtaceae), all from Australia, and *Sesbania punicea* (Fabaceae) from South America. A total of 19 species have been deployed as biological control agents, including nine weevil species (eight Curculionidae and one species in the family Brentidae: Apioninae), a seed-feeding moth species (Lepidoptera: Carposinidae), two species of bud-gallers (Hymenoptera: Pteromalidae), two species of flowergallers (Diptera: Cecidomyiidae), and a gall-forming rust fungus (Uredinales: Pileolariaceae). Most of these agents primarily reduce seed production, directly or indirectly, but some also cause die-back and mortality of their host plants. The overall result, often in combination with mechanical clearing and herbicide applications, has been a substantial decline in the abundance and/or aggressiveness of most of the targeted host-plants".

Almost all of the progress post-1990 has been due to funding by the Working for Water programme. Moran *et al.* (2013) reported as follows: "A key development in WBC [weed biological control] research and implementation from 1995 has been the involvement of the Working for Water Programme, which has generously supported WBC efforts politically and financially; it has successfully integrated WBC to supplement its own substantial efforts (involving tens of thousands of people) concentrating on the mechanical and chemical control of invasive alien plants; and has enabled wider international cooperation and especially collaborative ventures into the rest of Africa".

The relative success of biological control was to a large degree due to increasing political and public credibility and support for the practice. This arose in turn from the involvement of personnel from the Council for Scientific and Industrial Research (CSIR) (Moran *et al.*, 2013). Researchers at the CSIR demonstrated that biological control was highly cost effective and that it constitutes an essential supplement to other invasive alien plant control practices (van Wilgen *et al.*, 2004; De Lange & van Wilgen, 2010).

A project aimed at the biological control of invasive pine species was initiated in the late 1990s (Moran *et al.*, 2000), but as noted previously, it was decided not to proceed with this work (Lennox *et al.*, 2009) because of concerns about the interactions between the agent and the pitch canker pathogen *Fusarium cincinatum*. However, because reasonable arguments could be presented to show that the weevils would probably not aggravate the prevalence of pitch canker under field conditions, and because biological control offers the only really effective, long-term, sustainable solution to the pine invasion problem, this decision may well be reviewed (Hoffmann *et al.*, 2011).

The establishment of the Working for Water programme

The Working for Water programme was established in 1995, with the dual goals of clearing invasive alien plants to protect water resources, while simultaneously providing employment to the rural poor. A landmark event leading to the establishment of Working for Water was a workshop on "Managing Fynbos Catchment for Water" held in Stellenbosch in November 1993 (Boucher & Marais, 1993). The presentations at the workshop provided strong arguments that prevailing approaches for managing invasive species were inadequate and that the scale of the problem was escalating rapidly. Data were presented to show that invasive trees and shrubs were reducing water production from catchments. The meeting identified two initiatives. The first was to compile a promotional "roadshow", and to present this widely to local decision-makers, stressing the impacts of invasive alien plants on water runoff rather than biodiversity benefits. Secondly, an international initiative should concentrate on the biodiversity benefits that would be gained from controlling alien plants. A presentation of this "roadshow" to Kader Asmal (Minister of Water Affairs and Forestry) in June 1995 led to the securing of funding from the government's Reconstruction and Development Programme. The "Working for Water" programme was launched in 1995 and soon became the largest invasive-plant control project in the world (van Wilgen & Wannenburgh, 2016). At the WfW launch, Asmal outlined his vision to " … create 20 000 jobs for 20 years in winning the war against invasive plants".

Working for Water's operations in the CFR have focused on a relatively small number of widespread invasive alien tree and shrub species, including *Acacia cyclops*, *A. mearnsii*, *A. saligna*, *Hakea* species, *Pinus* species and *Populus* species. Between 1995 and 2008, these control operations cost approximately R400 million, but they only reached a relatively small proportion (about 1% per annum) of the overall estimated invaded area (van Wilgen *et al.*, 2012b). While some progress has been made with *Acacia cyclops (*van Wilgen *et al.*, 2012b) and *Hakea sericea* (Esler *et al.*, 2010) through a combination of mechanical and biological control, it appears that other species (*Pinus* species and *Acacia mearnsii*) are continuing to spread. In addition, *Pinus* species are often a source of conflict, given their importance as timber trees and their highly invasive potential (Box 7).

One of the conclusions from the "Inaugural Working for Water Research Symposium" in 2003 was that " … even with the existing generous levels of funding, it is unlikely that the problem will be contained within the next half century, and clearly other solutions need to be found" (Marais *et al.*, 2004). However, funding levels have continued to increase, and Working for Water has spawned a number of related initiatives (van Wilgen & Wannenburgh, 2016). These include specialised "high altitude" teams to clear invasive alien plants from inaccessible areas; a biosecurity directorate that aims to reduce the risk of introducing potentially invasive alien species to the country; a programme that supports research and implementation of biological control; and projects aimed at the utilisation of biomass. In 2008 a unit within the South African National Biodiversity Institute (SANBI) was formed. SANBI's Invasive Species Programme focuses on (1) detecting and documenting new invasions, (2) providing reliable and transparent post-border risk assessments and (3) providing the cross-institutional coordination needed to successfully implement national eradication plans (Wilson *et al.*, 2013).

Revisions to legislation and their effectiveness

Attempts to regulate the management of invasive alien plant species have a long history in South Africa. The Weeds Act (Act 42 of 1937) made provision for the publication of the names of species which, for the purposes of the Act, were regarded as "noxious weeds", and for the compulsory eradication of those weeds by the occupier/owner of the property on which they were growing, after the required notice had been served. The Act also provided for preventing the importation of seeds and propagating material of plants that may be potentially harmful. Only three species of relevance to the CFR were proclaimed in terms of the Weeds Act: *Hakea drupacea* (proclaimed as *H. suaveolens*), *H. gibbosa* and *H. sericea* (proclaimed as *H. tenuifolia*). In practice though, this legislation was not enforced and therefore ineffective.

In 1983, the Conservation of Agricultural Resources Act (Act 43 of 1983, CARA) was passed, and this allowed for the declaration of species as weeds and invaders. In terms of CARA, declared weeds had to be either eradicated or

Box 7. Conflicts over introduced trees – amenity, forestry and invasions.

Pines escaping from a small plantation on a farm in the Koo Valley, Western Cape Province (photograph B.W. van Wilgen).

Many landscapes in the fynbos biome support introduced tree populations that simultaneously deliver benefits and have negative impacts. The management of such ecosystems for the sustainable delivery of maximum benefits requires trade-offs to be made between different stakeholders and different ecosystem services. For example, forestry plantations deliver timber, but reduce streamflow and biodiversity-related benefits. Normally, the trade-off would be straightforward in that the benefits could be easily estimated and weighed against the costs for the area converted from one form of land use to another. When the introduced species is also invasive, however, the trade-off becomes more difficult to assess, because the situation changes constantly as invasions grow. Such species may not be containable and the dynamics of invasion into adjacent areas and the nature and magnitude of the impacts of such invasions may be unpredictable.

Pine trees (*Pinus* spp.) are the key example of this type of conflict in the fynbos biome. Pines are commercially important forestry trees in South Africa, but three species cause major problems as invaders in the fynbos (Richardson & Higgins, 1998; van Wilgen & Richardson, 2012, 2014). About 6% of South Africa's forest plantations are within the fynbos biome, and 87% of this area is planted to pines. No comprehensive economic assessment has been done of the costs and benefits of these trees. Roundwood sales in the fynbos region directly generated R146 million in 2009, and the forest industry is an important employer in rural areas. De Lange & van Wilgen (2010) estimated that the loss of ecosystem services (mainly water) attributable to "fire-adapted trees" (mainly pines) in the fynbos biome was R495 million annually at current levels of infestation. These impacts will increase as invasive pines spread and become denser, leading to water shortages that will constrain development, and lead to severe degradation and loss of biodiversity. Furthermore, recurring damage from the ever-escalating frequency of fires is currently placing additional burdens on the forestry industry, raising questions of the commercial viability of the enterprise in the region. A thorough assessment of the economic and environmental sustainability of forestry with pines in the fynbos biome is clearly needed, but progress towards such an assessment has been slow (van Wilgen 2015).

effectively controlled. In addition to *Hakea* species, CARA also listed several *Acacia* species (*A. cyclops*, *A. longifolia*, *A. melanoxylon*, *A. pycnantha* and *A. saligna*), *Leptospermum laevigatum* and *Paraserianthes lophantha* as declared weeds in the CFR. Significantly, none of the weed species with commercial value were listed under these regulations.

In 2001, the CARA regulations were amended to classify weeds into three categories: (1) weeds of no value; (2) recognised weeds that also have commercial value; and (3) recognised weeds that have ornamental, but no commercial value. For weeds in the first category, control was required, and trade was banned. Landowners required permits to grow weeds in the second category, and were required to take steps to limit their spread; trade in these species and their products was permitted. Weeds in the third category (created to accommodate popular ornamental plants) could be tolerated on land where they were planted, but were also subject to permits that required steps to limit their spread, and further plantings, and sale of plants and their products, was prohibited. Species of relevance to the CFR that were added included *Acacia mearnsii* (category 2), *Eucalyptus camaldulensis* (category 2), *Eucalyptus conferruminata* (earlier listed incorrectly as *E. lehmannii*) (category 1), *Pinus halepensis*, *P. pinaster* and *P. radiata* (all category 2) and *Populus canescens* (category 2).

In 2004, the National Environmental Management: Biodiversity Act (NEM:BA, Act 10 of 2004) was promulgated. NEM:BA required the publication of a list of invasive alien species within two years, but this list was only published in 2014. In terms of the 2014 NEM:BA Regulations, invasive species are listed in four categories: category 1a species are targets for nationwide eradication (any form of trade or planting is strictly prohibited); category 1b species must be controlled and wherever possible removed and destroyed (any form or trade or planting is strictly prohibited); category 2 species require a permit for them to be traded or grown (the category was created to cater for invasive species with commercial value); and category 3 species are to remain in prescribed areas, but not planted in future, propagation or trade is prohibited (created to cater for species with existing aesthetic but no commercial value). Individuals and populations of category 2 and 3 species that are outside the permitted areas are treated as category 1b.

The NEM:BA regulations list slightly more plant taxa than CARA (379 vs 348), but the main difference is that NEM:BA lists all taxa, not just plants. For example, of the invasive animal species in the CFR, feral pigs (*Sus scrofa*) and the guttural toad (*Amietophrynus gutturalis*) are listed as category 1b, while the house crow (*Corvus splendens*) is listed as category 1a. Invasive alien fishes are also listed, with significant and complex concessions to accommodate the interests of freshwater anglers. In this respect, several species of North American bass (*Micropterus* species) were listed, but trout (*Oncorhynchus mykiss* and *Salmo trutta*) were not listed due to ongoing protestations from the fly-fishing fraternity (Weyl *et al.*, 2015).

Despite substantial problems with definitions and other aspects, NEM:BA may provide opportunities to improve the management of invasive species. For example, the definition of "restricted activities" was aimed at regulating pathways of introduction and dissemination of invasive species. Also, NEM:BA allowed for species in the highest (most invasive/problematic) category to be split into subcategories, thereby recognising that some species with a very high invasive potential need to be placed under a government-sponsored management programme, whereby landowners will be assisted with their legal obligations to deal with these species. NEM:BA also stipulated that all "organs of state" must prepare "invasive species control plans" for areas under their control, and requires management authorities of protected areas to prepare "invasive species status reports" that include details on "the efficacy of previous control and eradication measures". Despite such useful provisions, it is still too early to assess whether or not the government will be able to effectively enforce the regulations. Finally, a revised, focused set of regulations would have greater effect if envisaged as supporting stewardship programmes of different kinds, and harmonised with the provision for protected environments in NEM:BA and for Fire Protection Associations in the National Veld and Forest Fire Act.

The impact of management

Despite the fact that hundreds of millions of Rand have been spent on the control of invasive alien plants in the CFR over more than four decades, very little can be said about whether or not these interventions have slowed or reversed the spread of invasive alien plants, or whether they have protected biodiversity or ecosystem services. Most invasive alien plant control has, for the past 20 years, been dependent on funding from public works programmes supplied by Working for Water, and the performance indicators that are monitored have a focus on inputs, rather than on outputs or outcomes (van Wilgen *et al.*, 2012a). The stringent requirements to maximise employment (by minimising costs per person-day) also severely limits the programme's ability to conduct effective monitoring and evaluation, which is expensive and would further increase the costs per person-day. In addition, the funding received by Working for Water, although substantial, is clearly insufficient to address the invasion problem effectively everywhere, meaning that focus and prioritisation would be essential for making progress (Forsyth *et al.*, 2012). Successive reviews of the programme (in 1997, 2003, 2012 and 2014) have explicitly raised concerns relating to a lack of focus, poor or absent criteria to guide the selection of projects, inadequate planning, and an absence of any effective monitoring of progress or outcomes (van Wilgen & Wannenburgh, 2016).

The Working for Water programme has not been able to adequately respond to these shortcomings for a number of reasons. These include both the requirements for a focus on job creation and poverty relief, often in areas of lower ecological priority, and the fact that the development of high-level indicators of outcomes is difficult. There are not many examples of successful monitoring programmes on which to base the required indicators (Downey & Hughes, 2010). The cost of implementing effective monitoring would also arguably be prohibitive, given the imperative to maximise the levels of employment in order to ensure continued political support and ongoing funding. It thus remains an ongoing frustration that progress with invasive alien plant control cannot be adequately assessed.

The sustainable harvesting of plant resources

1945 to 1965: Protection and legislation

The first attempts to control harvesting emerged through the Cape Provincial Wildflower Protection Ordinance (No. 15 of 1937), and in 1952, the newly established Cape Provincial Nature Conservation Department was given the mandate for conservation, including the control of harvesting wildflowers. The Rooibos Tea Control Board, established in 1954, exercised strict controls over the market for tea, although it is not clear if this extended to harvest quotas. In summary, little was done about the sustainable management of plant resources during this time, mainly because the emphasis was on protection.

1966 to 1980: A focus on cultivation

With increasing emphasis on commercialisation, an indigenous wildflower industry had emerged with a focus on protea cultivation rather than wild harvest. Research input was largely descriptive, involving extensive surveys of Cape Proteaceae with the aim of identification and selection of species with economic potential for cultivation (Vogts, 1971, 1972, 1977a–c, 1980). Efforts to further control the wild-harvest resource through the Cape Provincial Ordinance (No. 19 of 1975) resulted in prohibition of the harvest of proclaimed species on state land, while on private land a permit system was put in place. Scientific input into sustainable wild-harvest remained scant.

1981 to 1993: The emergence of broad harvesting guidelines

The 1980s saw a substantial expansion of research into both cultivated and wild-harvested resources. With the Agricultural Research Council focusing on marketable products for commercial growers, a parallel interest in the ecology of the wild resource emerged. A greater ecological understanding led to the formulation of early "50% rule" recommendations, including for Proteaceae, a delay in harvesting until at least 50% of the population had commenced flowering, a harvest of up to 50% of current season flower heads after this stage, and no harvesting at least one year prior to a prescribed burn (recommended interval, 12–15 years) (van Wilgen & Lamb, 1986). Research on the fern *Rumohra adiantiformis* similarly led to the suggestion that no more than 50% of mature plants should be removed from harvest sites (Geldenhuys 1994b).

1994 to present: Policies for sustainable harvesting

Harvesting of wildflowers (and other natural products, such as buchu, honeybush and rooibos tea and thatching reeds) became widely seen as a legitimate use of fynbos ecosystems. Selected species are also harvested from protected areas, with the most successful programme being that of fern harvests in what is now the Garden Route National Park. The sevenweeks fern (*Rumohra adiantiformis*) is harvested with quotas set through strict monitoring and evaluation programmes. Other protected area programmes, such as cut-flower harvest in the Agulhas National Park have been less successful as wild-harvested flowers often fail to meet standards of quality or carry diseases, which is generally not the case with farmed fynbos species (Carly Cowell, SANParks, personal communication, 2015).

During this period, legislation was enacted that provided a framework within which harvesting practices could be implemented. As a signatory to the International Union for the Conservation of Nature (IUCN) and the international Convention on Biological Diversity (CBD), the onus is on South African government, specifically national and regional conservation agencies, to determine the status of the resource, including an understanding of supporting ecological processes and the impacts of harvesting, and to formulate appropriate management and policy actions. In contemporary post-Apartheid South Africa, the backdrop to the sustainable management of plant resources is the South African Constitution (Act 108 of 1996), which set the policy framework for social and political transformation in the environmental management sector; this period saw the parallel emergence in academic literature of the concept of co-management (Borrini-Feyerabend *et al.*, 2000; Carlsson & Berkes, 2005). The National Environmental Management: Protected Areas Act (Act 57 of 2003) and the National Environmental Management: Biodiversity Act (Act 10 of 2004) now allow for agreements on extractive use of biological resources to be formulated between national or provincial conservation agencies and stakeholders, including international companies.

The Cape Action for People and the Environment (CAPE) programme, initiated in 2001 as a 20-year partnership of government and civil society aimed at conserving and restoring the biodiversity of the Cape Floristic Region, had important spin-offs including the establishment of the Agulhas Biodiversity Initiative (ABI). ABI is a regional initiative dedicated to reconciling biodiversity objectives with other initiatives (including wildflower cultivation) at a landscape scale on the Agulhas Plain and is working with approximately 25 local government, conservation organisations and NGOs to ensure sustainability of local practices. However tensions within the industry remain, with the need for further research into the sustainable management of plant resources clearly highlighted.

Their "Policy on consumptive and commercial utilisation of biological resources from protected areas and surrounds" (CapeNature, 2007) details a number of challenges associated with these activities. They argue that Category 1 and 2 protected areas are guided by IUCN criteria to limit consumptive use of resources in these protected areas, and failure to adhere to these criteria would jeopardise the chances of sourcing international funding; that the slow-growing nutrient-limited fynbos is vulnerable to disturbance, exacerbated by changing fire regimes and climate change; and that human demographic changes in the Western Cape associated with an influx of traditional resource users has resulted in added pressure on resources. Indigenous healers and herbalists have the perception, however, that CapeNature still retains a fortress approach to separating people and nature through bureaucracy and unequal power relations (Olivier, 2013). Community-based natural resource management (CBNRM) programmes with Rastafari Bush Doctors and traditional healers have been implemented through CapeNature since 2003, but lack of capacity to undertake research into harvest policies and to monitor and audit harvesting and associated impacts has slowed progress. Attempts to mainstream biodiversity into the economy of the Western Cape have also met with resistance from landholders. Focusing on the ABI, Conradie (2010) ascribes this to a "fundamental mutual misunderstanding of what landscape initiatives could and could not do for landholders". The initiative is aimed at promoting sustainable resource use, strengthening conservation partnerships and raising conservation awareness (Lochner *et al.*, 2003), including the recruitment of some landholders into a certification programme for sustainable wildflower harvesting. A low overall participation rate in ABI's projects amongst landholders (Conradie, 2010) is likely largely due to opportunity costs which influence willingness to engage in these kinds of activities on private land (Conradie *et al.*, 2013).

The Wicht Committee stated that "a considerable amount of illegal flower picking still occurs, however, and this will always be extremely difficult to check"; clearly these concerns remain current. The Wicht Committee went on to say that "General deterioration of the veld is probably not caused by this practice, except along roads frequently used by trippers and on areas repeatedly visited for illegal gathering of flowers for sale, but rare species may become extinct as a result of it." An extensive assessment of the Red List status of all species in South Africa (Raimondo *et al.*, 2009), and subsequent analysis of medicinal plant use (Williams *et al.*, 2013) has indicated that extractive harvesting does not precipitate plant extinctions nationally. However, while there is little indication that harvesting is causing extinction risks in Cape species, expansion of rooibos plantations into the natural habitat of wild *Aspalathus linearis* subsp. *linearis* has resulted in a dramatic increase in the number of species threatened by extinction (Raimondo *et al.*, 2009).

In 1999, Flora and Fauna International purchased Flower Valley Farm and established the Flower Valley Conservation Trust – a business linking social investment with biodiversity, and a vehicle for ABI's sustainable wildflower harvesting focus area. Concentrating on knowledge, databases and techniques of governance, progress has been made through strengthening the CapeNature permit system (implemented since the Cape Provincial Ordinance No. 19 of 1974 came into effect), the development of a database to record harvest quantities and the formulation of monitoring protocols and best-practice guidelines. The knowledge and technologies informing the databases are, however, still contested; McEwan *et al.* (2014) point out that there is scope for more inclusive knowledge creation in this arena. To date, best-practice guidelines have been largely shaped by ecological knowledge produced by botanists and conservationists. This knowledge is limited by a relatively small number of studies and includes work focusing on the effects of removing seeds on seed bank and seedling ecology (Mustart & Cowling, 1992; Kilian, 1991; Rebelo & Holmes, 1988), and of harvesting on population dynamics (Maze & Bond, 1996), persistence and abundance (Cabral *et al.*, 2011; Privett *et al.*, 2014).

The best-practice guidelines are broad, and although they have not been formally published anywhere, they have been summarised by Esler *et al.* (2014) in a popular book targeting fynbos landowners and managers. They include:

- Following fire, harvesting should not take place until the obligate reseeding plant species have had an opportunity to flower and set seed, which translates to waiting at least five years after fire, and ensuring at least two successive seasons of flowering. Re-seeders are particularly vulnerable to harvesting below the first branching node, whereas re-sprouters can better tolerate harvest of this nature (Privett *et al.*, 2014);
- Populations should not be over-harvested; heavy harvesting can result in high mortality. For resprouters, it is recommended that not more than half of the above-ground biomass be harvested, and for re-seeders even less. In broad terms, the 50% harvest limits of current season flower heads, originally proposed by van Wilgen and Lamb (1986), have been supported by seed bank studies (Esler *et al.*, 1989; Mustart & Cowling, 1992), a harvest model (Maze & Bond, 1996) and experiments simulating wild flower harvesting (Privett *et al.*, 2014). These indicate that seeds (and nutrients contained therein) and populations are not likely to be depleted under conservative harvest rates (below 50%), although some species may be more sensitive than others (Rebelo & Holmes, 1988; Cabral *et al.*, 2013).

Light harvesting of re-sprouting species might well reduce mortality relative to no harvesting (Privett *et al.*, 2014);

- Populations of re-seeders should not be harvested for at least two years before a fire to allow for seed set (assuming that the date of the next fire can be predicted); and
- Several species, notably the "everlastings" (*Helychrysum* species) flower profusely following fire, and then die out, surviving until the next fire as soil-stored seeds. This needs to be recognised, and over-harvesting should be avoided; alternately, seeds should be collected and stored for re-sowing after the next fire.

Based on life-history information, CapeNature (2007) does not support the consumptive use or harvest of "key-stone" species that are long-lived, slow-maturing and which have low recruitment or survival. A more detailed vulnerability index for 150 potentially harvestable species on the Agulhas Plain has been developed to assist farmers in ranking species susceptibility to harvest based on biological, distribution and abundance data (S.D.J. Privett, personal communication, 2015), but calls for more species-specific information continue (Privett *et al.*, 2014).

Steps taken to accommodate predicted climate change

Developing management and conservation responses to climate change is a field in its infancy. International effort has focused largely on so-called "passive" approaches (Midgley & Bond, 2015), including the protection of corridors to increase connectivity, hopefully allowing species to shift their ranges in response to changing conditions. These ideas saw some of their first expression in the Western Cape (e.g. Rouget *et al.*, 2006). Initial efforts to develop these spatial approaches for climate change resilience were undertaken under the CAPE programme, which identified corridors linking uplands and lowlands as a major outcome (Cowling *et al.*, 2003).

Detailed projections of species potential range shifts have been carried out for endemic Proteaceae using information about dispersal capacities (Hannah *et al.*, 2005). However, uncertainty about future climate scenarios and non-climate determinants of range (soil type, species interactions, disturbance) makes detailed conservation planning based on anticipated range shifts unfeasible. This supports the adoption of low-risk spatial planning approaches informed by principles of maximising topographic heterogeneity and altitudinal diversity, at least for the early stages of anthropogenic climate change.

Theory developed in the CFR was expanded nationally by the National Protected Area Expansion Strategy (Box 8), in which it is stated that "protected area expansion should prioritise protection of living connected landscapes. Protected areas should be expanded to incorporate altitudinal gradients and topographic range, intact river corridors, coastal dune cordons, and a greater range of micro-habitats, in order to conserve the climatic gradients required to give us some leeway for climate change. The ability of species and systems to adapt to climate change will depend on landscapes that are sufficiently connected to allow species to move" (Department of Environmental Affairs, 2008). This has led to the prioritisation of areas of high climate and landscape variation. The PRESENCE (Participatory Restoration of Ecosystem Services and Natural Capital) learning network in the eastern Fynbos has begun to implement these insights at landscape level (Pérez *et al.*, 2010).

Box 8. The Western Cape's Protected Area Expansion Strategy.

The Western Cape's government has developed a clear Protected Area Expansion Strategy (Maree *et al.*, 2015) for the next 5 years. The strategy bases its spatial priorities on critical biodiversity areas, and then uses two factors, importance and urgency, to identify the highest priority areas for formal protection.

Important areas are those that provide one of the best remaining examples of a Critically Endangered ecosystem; that contribute to meeting biodiversity thresholds for under-protected terrestrial or freshwater ecosystems; that maintain ecological processes or climate change resilience; or that provide essential habitat for threatened and under-protected taxa.

Urgency is determined by the extent to which spatial options for meeting protected area targets still exist, which is often linked to the degree of competing land or resource uses in an area.

Thus, expansion is firmly grounded in the principles of representation, persistence, efficiency and complementarity, and is target-driven. The new Strategy sets an ambitious 5-year target of an additional 348 840 ha (2.7% of the province) to be protected. This target is informed by both ecological thresholds and (national) political commitments, and the spatial priorities for reaching these targets address five overarching themes:

(1) Critically Endangered ecosystems
(2) Under-protected ecosystems in strategic landscapes
(3) Essential habitat for selected threatened species
(4) Marine, estuarine and coastal systems
(5) Freshwater ecosystems.

To ensure the long-term viability of core biodiversity areas, targets have been set per ecosystem type for protection within some formal measures. These protection measures include formal protected areas or types of biodiversity agreements and stewardship options.

Critically Endangered vegetation types in the Western Cape, based on the percentage remaining area (extent of habitat fragmentation) and biodiversity target.

Vegetation type	Biome	Remaining area (%)	Biodiversity target (%)	Protected (%)
Piketberg Quartz Succulent Shrubland	Fynbos	0	26	0.0
Lourensford Alluvium Fynbos	Fynbos	7	30	4.2
Swartland Shale Renosterveld	Fynbos	9	26	0.5
Swartland Silcrete Renosterveld	Fynbos	10	26	0.6
Cape Vernal Pools	Wetlands	12	24	0.0
Central Ruens Shale Renosterveld	Fynbos	13	27	0.4
Western Ruens Shale Renosterveld	Fynbos	14	27	0.0
Elgin Shale Fynbos	Fynbos	18	30	5.9
Cape Flats Sand Fynbos	Fynbos	19	30	0.1

Eastern Ruens Shale Renosterveld	Fynbos	19	27	0.4
Swartland Granite Bulb Veld	Fynbos	20	26	0.6
Ruens Silcrete Renosterveld	Fynbos	22	27	0.1
Peninsula Shale Renosterveld	Fynbos	23	26	18.7
Swartland Alluvium Fynbos	Fynbos	25	30	1.7
Cape Lowland Alluvial Vegetation	Fynbos	31	31	0.7

The strategy also highlights the transfer of forest plantation "exit" lands into the custodianship of CapeNature or SANParks. These include properties vested with the Department of Agriculture Forestry and Fisheries, but which were leased for production forestry. Owing to their unprofitability as plantations, they are now in the process of being withdrawn from tree production, with the goal of rehabilitating them to their pre-planting state or other natural vegetation cover. CapeNature has indicated a willingness to accept a set of properties – totalling about 11 200 ha – that fit in with their biodiversity objectives and for which sufficient management funding will be available.

Apart from these "passive" planning-based strategies, disturbance-driven ecosystems offer the opportunity for active management responses via manipulation of the disturbance regime (Nel *et al.*, 2014, Midgley & Bond, 2015). There are clear indications that wildfire regimes are changing in response to climate change, and a significant effort is underway to plan for and adapt to this eventuality via a UNFCCC Special Climate Change Fund supported project under the Global Environment Facility (GEF project ID 3934). Interventions underway include the expansion of fire management capacity, improved landowner awareness of high risk practices such as neglect of invasive alien control, promotion of lower risk management burning, and improved early warning of high fire risk conditions.

PART 6: CONCLUSIONS

Conclusions of the Wicht Committee

This review provided an opportunity for researchers from a range of backgrounds to focus their attention on the broad issue of the management and conservation of a globally important ecosystem, by examining the events that led up to, and followed, the production of a similar report 70 years ago. As we noted in our introduction, we believe that research in support of conservation in the CFR constitutes the longest history of any concerted effort to develop a basis for conserving an entire region. It is therefore useful to reflect on the conclusions reached by the Wicht Committee, and to assess whether, and if so how, the work that followed the publication of their report has changed these views.

The Wicht Committee's primary conclusion was that "an objective study of the vegetation of the south-western Cape Province leads inevitably to the conclusion that it is deteriorating rapidly and that measures to preserve it should immediately be applied". The committee also noted that complete protection everywhere would not be affordable, nor would it be in the interests of economic development. However, they also introduced a moral argument, stating that "the people of South Africa would, however, be disgraced if they did not make a supreme effort to prevent the total loss of the extraordinary rich and beautiful Cape vegetation". In this final part, we revisit the conclusions of the Wicht Committee, and we examine both the degree to which they remain valid, as well as the new issues we will face in the 21st century.

Fire and the burning of vegetation

The first specific conclusion reached by the Wicht Committee related to the role and use of fire. Researchers and managers in the 1940s were confronted with significant challenges when it came to developing a robust fire management policy. Understanding was extremely limited, and opinions on the way forward were divided. In fact, it was "a letter from Dr Henkel on grass-burning" that ultimately led to the Wicht Committee's report. Henkel's "letter on grass burning" included an analysis of the differences between fynbos, a fire-dependent ecosystem, and forest, an ecosystem vulnerable to fire, as well the wildfire problems that had arisen from a policy of fire exclusion in the fynbos. The committee extended this kind of analysis, and recognised that total protection from fire would not be achievable, recommending that, outside of established nature reserves, "the standard practice should meanwhile be the deliberate, rotational burning of prescribed areas – controlled burning". They also warned that "such burning should never be followed by sustained pasturing", because the practice of pasturing was "barely profitable, and invariably leads to destruction of vegetation and serious erosion". The concerns about erosion linked to browsing have not been realised, mainly because the rise of modern mechanised agriculture has been accompanied by a marked decrease in reliance on subsistence agriculture in natural areas. Following the work that demonstrated the positive role of fire, prescribed burning was practised widely for at least two decades in the 1970s and 1980s. Its use has more recently declined markedly, and we conclude that fires are currently not well managed in the CFR. The governance of fire management is bedevilled by a lack of capacity, and a failure to fully implement the Veld and Forest Fire Act, leading to outdated approaches of fire bans in the absence of a National Fire Danger Rating System (Kruger, 2014a,b). Contemporary fire regimes are overwhelmingly driven by unplanned fires, and people continue to intrude their homes, business premises, vineyards and orchards into the mountains. Consequently, the need to ensure the safety of people and infrastructure often overrides ecological considerations, preventing the implementation of an effective programme of prescribed burns. While most wildfires are ecologically beneficial (occurring as they do at appropriate return intervals, seasons and intensities, van Wilgen *et al.*, 2010), the widespread presence of fire-adapted invasive alien plants is a cause for concern. Although the use of fire should be integrated into alien plant control programmes, this is currently not done, and unplanned wildfires continue to promote the proliferation and spread of invasive alien plants. There are also concerns that fires are becoming more frequent, driven by growing human populations, and increased access to previously remote areas, which leads in turn to an increased risk of ignitions. In addition, the effect of climate change is uncertain, but it seems that it will exert changes to future fire regimes, as reflected in the observed increase in frequency of extensive large fires occurring during extreme weather events (Wilson *et al.,* 2010; Southey, 2009). The achievement of an effective system of fire management that will simultaneously promote conservation and ensure adequate levels of safety therefore remains elusive. This situation demands a new approach to research. It will require researchers from disciplines in the natural and social sciences, as well as the humanities, to actively collaborate with local agents in developing the contextual knowledge that encompasses meaningful local responses to wildfire risk and the requirements for ecological fire management.

Invasive alien plants

The Wicht Committee noted in their conclusions that "the natural character of the vegetation is being changed by intruding exotic species", and that "in many localities foreign species are dominating and replacing the indigenous ones". This view has not changed, and in fact the situation has worsened substantially. Currently, there are several important concerns about the way in which this problem is managed. The National Strategy on Biological Invasions in South Africa (https://sites.google.com/site/wfwplanning/strategy) currently relies very heavily on funding from public works programmes to support invasive alien plant management. This practice, however, largely bypasses the organisations that have been established with the express goal of promoting the collective management of resources locally, such as conservancies, Fire Protection Associations and Catchment Management Agencies, to the detriment of such organisations. The practice also diverts funds that should arguably flow directly to conservation management agencies, such as CapeNature and South African National Parks. These agencies are therefore unable to build embedded capacity to manage the problem and to develop local expertise; they are essentially rendered bystanders. This situation will not lead to sustainable management, as funding from public works programmes almost certainly cannot persist at current levels in the longer term. Direct funding to management agencies, with the express purpose of controlling plant invasions (and thus protecting vital water resources that will be needed to underpin economic development in the longer term) would avoid the problems of dual goals and increase efficiencies (van Wilgen & Wannenburgh, 2016). We have also noted the recommendation of the Wicht Committee that "it seems, at present, that unless enormous sums of money are expended on their [invasive alien plant] eradication or control they will become dominant everywhere except in nature reserves and other selected areas where they will constantly be destroyed". The assessment that we need to focus on particular areas if we are to make progress remains valid today (van Wilgen *et al.*, 2016b), despite "enormous sums of money" having been spent over the past two decades (van Wilgen *et al.*, 2012).

The situation clearly demands a re-appraisal of current management approaches. First, it needs to be accepted that invasive alien plants are now permanent features of many landscapes of the CFR, even some within protected areas. In many cases, the only realistic goal would be to achieve a "maintenance level" of invasion. This level needs to be set according to deliberated agreement on the desired state of any given catchment or ecosystem. It may therefore be necessary to implement management policies that tolerate some limited biodiversity loss in exchange for reducing alien plant invasions to a level at which they would be less problematic. For example, burning prescriptions for fynbos shrublands call for the use of fire to be restricted to certain seasons and frequencies, but deviations from these prescriptions in some areas might be the only sustainable way to bring invasions under control. Fire prescriptions that allow for burning in spring, for example, would facilitate the much more widespread integration of fire and alien plant control operations. The alternative to relaxing burning prescriptions, which would be to insist on strictly promoting a fire regime that would best suit pristine fynbos, would result in fewer opportunities to burn, and consequently a greater area burnt in wildfires. Ultimately, a wildfire-driven fire regime would result in greater levels of invasion, and a greater loss of biodiversity. Secondly, it may be necessary to practise conservation triage, in which available funding is directed towards priority areas, leaving others unmanaged. The alternative of spreading available funds evenly across many areas will likely lead to ineffective control everywhere, as currently appears to be the case.

Current legislation, notably the Regulations in terms of the National Environmental Management: Biodiversity Act, is ineffective and new legal instruments need to be developed. Consideration must be given to the special problems that exist in different parts of the CFR. For example, experience shows that management of invasions in urban areas requires a fundamentally different approach to that followed in protected areas and rural landscapes (Gaertner *et al.,* 2016). More attention also needs to be given to the development of voluntary codes of conduct in partnership with key stakeholders, such as in the plantation forestry industry.

Flower harvesting and resource use

The Wicht Committee noted in their conclusions that "rare species are being exterminated by illegal flower picking". Although there is no evidence that this has happened (i.e. no species have become extinct due to over-harvesting), there have been occasional causes for alarm (for example, when a local population of *Orothamnus zeyheri* was eliminated by a single enthusiastic picker for a local flower show, A.G. Rebelo, personal communication) There have, however, been developments that were not foreseen by the committee. These include a switch from harvesting of wild populations to formal cultivation (with accompanying habitat destruction), and the practice of planting or sowing "desirable" species into natural areas (augmentation), which can change relative species composition, and possibly result in hybridisation, with possible long-term implications for conservation. In addition, there has been an increase in the illegal harvesting of plant resources to support the rapidly-growing demand for traditional medicines, in turn precipitated by human population growth and marked changes in cultural demographics in the CFR. While much has been done to develop guidelines to support sustainable harvesting from wild populations, the growing trend towards formal cultivation, and the rapidly increasing (but difficult to quantify) harvesting of a range of plant products for traditional medicine are re-emerging as significant threats to conservation.

Protected areas

The Wicht Committee recommended in its conclusions that "large representative national reserves, as well as local reserves, should be established on which all efforts to maintain the vegetation in an unaltered natural state should be concentrated". At the time, most of the protected area was in Crown Forest, i.e. inalienable protected areas in today's terms. The committee sought to build on these, through the idea of "national reserves", and this led over the next 70 years to a situation in which nearly 19% of the CFR became formally protected. The land thus protected is biased towards areas characterised by steep slopes, high altitudes, and infertile geological substrata, leaving others inadequately protected (especially in the lowland areas, Table 5), but the protected area network nonetheless now far exceeds the modest targets set by the Wicht Committee. However, and as reviewed above, changing fire regimes, ongoing and increasing invasion by alien plants, fragmentation and illegal harvesting of resources are serious challenges to achieving the goal of maintaining the vegetation in these reserves in an unaltered state. One of the main problems in this regard is that the funding provided to the conservation agencies tasked with managing these areas has declined substantially in real terms. This started with the transfer of management responsibility for State Forests from the Department of Forestry to provincial conservation agencies, with a loss of capacity and funding which continues to decline, despite considerable increases in the area that has to be managed. Conservation agencies are increasingly expected to generate their own funding, largely from tourism and in some cases the legal harvesting of natural products from protected areas, which potentially further compromises the achievement of optimal conservation outcomes. Essentially, protected areas now exist in a radically different socio-political context to the one that prevailed when they were set up, and the expectations of how these areas should be used, and managed, will have to take this into account in future. In addition, as noted above, protected areas in many cases are already substantially and irreversibly altered, and need to be increasingly viewed and managed with these realities in mind.

Coping with climate change

The issue of human-induced climate change was understandably not foreseen by the Wicht Committee. Efforts to mitigate climate change, while critically important, have to be co-ordinated and implemented at a global scale, and are not considered further here. Adaptation to unavoidable climate change, on the other hand, will be very important for conserving biodiversity at the scale of the CFR. Changes to local climate are very likely to exceed the ability of species with restricted ranges and low dispersal capacity to adapt via migration or *in situ* evolution. Research on species range shifts suggests that there will be four geographic range response types under likely future climate scenarios – "persisters" (species that will be able to maintain sufficient range despite climate changes), "partial dispersers" (species that will be able to survive in some proportion of their current range but will require some dispersal to new areas to maintain viability), "obligate dispersers" (species that will become extinct if they fail to disperse to a new range), and "range losers" (species that retain very little to no suitable range under climate change scenarios). Amongst the Proteaceae, early indications are that the proportions of these categories will be roughly 60:25:5:10 by mid-century (Williams *et al.*, 2005). This suggests that managed relocation might be necessary for about a third of CFR plant species (partial and obligate dispersers), and *ex situ* approaches would be needed to conserve about a tenth, the range losers (von Maltitz *et al.*, 2008).

Given the uncertainties inherent in these projections, it would be important to monitor such species for early signs of adverse impact as the climate changes, and if these do emerge, to adopt targeted interventions to prevent local and global extinction if these are feasible and affordable. Preventing all climate-induced extinctions in the event of significant warming will probably not be feasible, given capacity constraints, and the fact that the CFR is home to 9381 indigenous plant species, and that potentially one third (>3000 species) may require managed relocation if they are to survive in the wild. In addition to the impracticality, this form of management is highly contentious, especially given the likelihood of hybridisation between closely-related species that may occur in the novel relocation range. The *ex situ* conservation of the genetic diversity of threatened taxa will increase in importance under this scenario. Fundamental work is also needed to understand adaptation options, and must include ecological and landscape genetics, knowledge fields that will allow effective "prescriptive evolution", or "evolutionary conservation", in addition to, or instead of, measures such as assisted migration (Barker & Odling-Smee 2014; Smith *et al.*, 2014).

The role of research

The Wicht Committee concluded that "there is, at this stage, no final answer to the question: what must be done to preserve the Cape vegetation?" They noted further that "research should in time provide the basic data for preparing a final conservation policy". There can be no doubt that research has resulted in huge increases in our levels of understanding regarding the ecology of vegetation types in the CFR, and the threats that they face. Much of this understanding arose from long-term research at a few intensively-studied sites (mainly in the west of the CFR), and was supplemented by widespread observations and studies across the CFR that allowed for the robust extrapolation of research findings. Research was also considerably bolstered by the National Co-operative Programmes, notably the Fynbos Biome Project, which led to high levels of collaboration between government departments and academic institutions, and to transdisciplinary exchanges. However, many questions remain, some of them arising from increased levels of understanding, and others from issues related to recent phenomena such as global climate change (Box 9). The research environment has also shifted away from long-term research conducted by scientists embedded in management agencies to short-term studies conducted largely by academic institutions. It is clear from the experience that followed the publication of the Wicht Committee's report that much benefit was gained from the long-term partnership between research and management that characterised the *modus operandus* of the Department of Forestry, but such models are unlikely to be re-instated.

Box 9. Challenges to conservation as seen by the new generation of fynbos ecologists.

At the colloquium that was held to mark the 70th anniversary of the Wicht Committee's report, the RSSAf invited seven post-graduate students to identify the major challenges to conservation in the CFR, from their perspective as young professionals about to embark on a career in this field. The students (Adriaan Grobler, Andrea Beyers, Bongani Mnisi, Joy Mangachena, Jurene Kemp, Petra de Abreu and Stuart Hall) were selected by their academic supervisors at universities based in the CFR (Nelson Mandela Metropolitan University, University of Cape Town, Cape Peninsula University of Technology and Stellenbosch University). Their ideas are summarised here.

The four **major threats** to the sustainable conservation of the CFR were identified as habitat loss, biological invasions, ecosystem mismanagement and climate change.

Six **primary challenges** that will need to be faced when dealing with these threats are:

- *Restoring and managing novel ecosystems:* Defining restoration goals and prioritising areas for restoration is a complex issue. It is likely that global change will rapidly alter systems to completely new states. Integrating the concepts of "novel ecosystems" and social-ecological "resilience" into the theory and practice of restoration in the CFR could assist in developing practical and implementable restoration options.
- *Conserving beyond the boundaries of protected areas:* With only 19% of the CFR represented in protected areas, we can no longer aim to rely on these alone to achieve conservation targets. The 1980s brought us systematic conservation planning and awareness of the importance of reserve networks. Thirty years on, we now recognise that off-reserve conservation is indispensable in any holistic conservation plan. Land stewardship in conservancy networks may be the only remaining option for effective conservation, but they will have to bring social and economic benefits to be viable.
- *Considering taxa of conservation concern:* Over the past few decades, the conservation paradigm has shifted away from conserving species to conserving ecosystems. However, with large proportions of the known flora in the CFR being of conservation concern or under threat of extinction, it is will be difficult to disregard individual taxa.
- *Moving towards sustainable cities:* The CFR hosts two major cities and several other large towns that are situated in areas of irreplaceable biodiversity. These centres are set to grow, and we cannot afford to develop our cities in an unsustainable manner. Sustainable urban development can be promoted by raising awareness and improving education, leading to constructive debate and the identification of innovative approaches to conservation.
- *Managing fire in a changing environment:* The CFR is fire-prone and fire-dependent, and trade-offs will be needed in future to meet the dual goals of ensuring safety from wildfires and protecting biodiversity. Fynbos relies on a variable regime of relatively high-intensity fires of moderate frequency. Increasing fire frequency due to growing sources of ignition, measures to prevent or contain high-intensity fires, the alteration of fuel beds by alien plants and climate change all need to be carefully considered when trying to influence future fire regimes.
- *Controlling invasive alien species:* The control of invasive alien species will require awareness campaigns, drawing from scientific research, not only to raise awareness of the problem, but also to persuade landowners, the public, and policy makers of the need to act against this significant threat. The inclusion of all stakeholders would be needed to ensure a coherent and effective approach to the problem.

Finally, three **pathways to sustainability** were identified as essential for achieving sustainable management:

- *Communication, collaboration and participatory learning:* Scientific findings need to be communicated regularly to conservation practitioners. In return, conservation and management requirements should be communicated to academics to ensure relevant and directed research. Public engagement should be strongly encouraged, rewarded or required for researchers to ensure a better public understanding and trust of the scientific process. Unfilled career niches should be identified (e.g. consulting, science journalism, environmental law) and scholars should be encouraged to pursue these as career paths. Environmental education should continue to take priority to raise a generation of environmentally-responsible citizens, ensuring large-scale support of science and conservation.
- *Implementing research and policy:* Government policy-makers should ideally be more strongly influenced by scientists. The majority of current policy-makers do not have a scientific background and often make decisions based on political or financial considerations rather than on rigorous environmental principles. Furthermore, environmental policy should not only be sound, but it should be enforced across all levels of management.

Funding the biodiversity sector: Biodiversity and natural resource management is an underfunded sector. Terminology and frameworks should be standardised and used to promote cross-sector funding, especially for preventative, educational and capacity-building programmes, but also for implementation of activities for protecting ecosystem services and enhancing conservation. There is a need to bring together interdisciplinary and multidisciplinary research teams linked to transdisciplinary forums for developing ground-level actions and for recognising cross-sector funding opportunities. These can be initiated and developed by using available research and knowledge.

Final thoughts

We may ask in conclusion, what of this history deserves the attention of today's custodians of the long-term programme? Three lines of thought seem obvious.

A sense of purpose:

Research conducted after the publication of the Wicht Committee's report was characterised by an overarching sense of purpose, and was deliberately designed to properly inform the management of mountain catchment areas (or, the management of their ecological infrastructure, in contemporary terms). Today, the obvious questions relate, first, to the problem of global change – climate change as well as the marked increase in atmospheric CO_2 concentrations, and invasion by alien species – but the research purpose, for a long-term programme, would need greater definition. Second, a defining sense of purpose should recognise the consequences of a newly-urbanised and diverse society, and the unmet needs of such urban communities, especially regarding the ecosystem services they distinctly require, such as educational and other cultural services.

An enduring science–policy interface:

A second requirement would be a sound and enduring arm's-length relationship between the science and the making of policy. By "arm's-length" is meant a relationship of mutual respect and recognition of each other's autonomy, together with a deep appreciation of the challenges both of the science (and its need for time) and of the making of policy (and of its need for timeliness). The thinking and literature on the desirable form and nature of this science–policy interface is now well developed (e.g. Jasanoff, 1998, 2010). This is an intense challenge in South Africa today, with quick turnover of personnel among the policy-making community, and short funding lines for science, aggravated by performance measures based upon the number of published papers. Special qualities of leadership will be required. Lessons may be learned from the embedding of the scientist in the policy or management milieu, as Wicht found in his experience of managing the Jonkershoek State Forest, and which has recently been re-emphasised for South African National Parks (van Wilgen *et al.*, 2016a).

Strategic, long-term study sites:

The third would be a programme anchored in a strategic set of intensive, long-term study sites. The set of sites and the network would need to take account of today's "hybrid ecosystems" (Marris, 2011, cited in Hulme, 2014) and not seek to represent the research agenda as a study of the pristine. The set of sites, which necessarily would be limited, would serve several purposes: the findings there would be the "unimpeachable" baseline for interpolation between sites and for the validation for complementary studies; the sites would have a deep history of observation, of slow-onset processes as well as events; and ideally, the sites would be the locales at which scientists have the opportunity to immerse themselves and enjoy the process of discovery, as well as to acquire the enduring field experience that builds the tacit knowledge (of both the natural environment and management institutions) required for proper interpretation of research findings. Special difficulties arise in the hosting of such sites: Jonkershoek worked well for 50 years while it enjoyed a single, committed host, but since then its management has been divided, and its future appears insecure.

Returning finally to the Wicht Committee, we recognise perhaps a fourth prerequisite for success in a long-term programme in ecology – a common and deep understanding of the history of the science, and of the people and locales that produced it.

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