

Global forest research, science education and community service positively impacted by a unique Centre of Excellence in Tree Health Biotechnology

Emma T Steenkamp and Michael J Wingfield*

Department of Microbiology and Plant Pathology, DST–NRF Centre of Excellence in Tree Health Biotechnology, Forestry and Agricultural Biotechnology Institute, University of Pretoria, Pretoria 0002, South Africa

* Corresponding author, e-mail: mike.wingfield@fab.up.ac.za

Despite their importance in ecosystems and biodiversity, very little is known about the health of trees in the native environments of South Africa. The vision and primary goal of the Centre of Excellence in Tree Health Biotechnology (CTHB) is therefore to promote the health of native trees by making use of biotechnology. In this paper, we use the CTHB as an example to explore the positive impacts of the Department of Science and Technology's Centre of Excellence programme on the science system of South Africa and, furthermore, to consider the programme's overall contribution to the strategic priorities set out in the South African Government's Medium Term Strategic Framework that guides the national mandate. We also discuss briefly how the outputs of the CTHB are put into practice in the form of tangible services provided to stakeholders from all sectors ranging from academia, the forestry industry and the general public through to government. Finally, we consider the various factors that have contributed to the success of the CTHB and conclude with a reflection on the far-reaching effects that a relatively small investment by the Department of Science and Technology has had on research and development in South Africa. This is not only in terms of human capacity development, but also overall research excellence. For the CTHB specifically, this initiative also has facilitated a deep appreciation of the factors threatening the health of native trees. Such knowledge provides a crucial foundation towards our understanding of the challenges associated with trees in native woody ecosystems and those propagated commercially, which have emerged and will continue to emerge as a result of trade, transport and tourism, as well as climate change.

Keywords: long-term funding, multidisciplinary research, pests and pathogens, postgraduate education, tree health

Introduction

About one-third of the total land area of South Africa is occupied by woodlands (wooded grasslands and dense thickets) and forests (0.5% natural forests and 1.1% forestry plantations) (DAFF 2013a). These areas play important roles in the South African bioeconomy (e.g. Nambiar 1999, Shackleton et al. 2001). For example, commercial forestry annually contributes to about 1% of the national gross domestic product and 1.4% of the total formal employment (DAFF 2013a), and the various products associated with natural forests and woodlands have significant impacts on rural livelihoods (Shackleton and Shackleton 2004). In addition to these products and outputs, forests and woodlands also provide diverse ecosystem services ranging from soil and water resource conservation through to carbon sequestration and climate change mitigation (e.g. Shvidenko et al. 2005, Brockerhoff et al. 2008). Although declines in the quantity and quality of these services and products, especially in native ecosystems, have been linked to human activity (e.g. Le Maitre et al. 2007), little is known regarding the health of woody species in natural forests and woodlands.

The research of the Centre of Excellence in Tree Health Biotechnology (CTHB; <http://www.fabinet.up.ac.za/cthb>) focuses on the application of biotechnology to promote the health of trees indigenous to South Africa. Despite the fact that tree diseases and pests are responsible for dramatic losses to native ecosystems in many parts of the world (Wingfield et al. 2010, 2011), virtually no previous research has attempted to understand how these factors might impact on South African biodiversity. Focus on the latter reflects the main area of activity during the first half of the CTHB's existence. The Centre recently further expanded its research scope to include questions regarding the possible effects that factors such as plant genetics and physiology, climate change, and human needs in terms of food, medicine, fibre and fuel may have on the health of native trees. With its unique research focus, the CTHB thus represents the first concerted effort to understand the health of plants in native South African woody ecosystems.

The CTHB is one of the nine Centres of Excellence (CoEs) supported by the South African Department of Science

and Technology (DST) and National Research Foundation (NRF) (NRF 2013). Overall, the CoEs seek to concentrate existing resources in order to facilitate long-term multidisciplinary research that is both locally relevant and internationally competitive. Here, the ultimate objective is to enhance the pursuit of research excellence and capacity development. These core values have been actively pursued subsequent to the establishment of the CTHB in 2004 and its formal launch early in 2005.

The CTHB has been developed as one of the research platforms in the Forestry and Agricultural Biotechnology Institute (FABI; <http://www.fabinet.up.ac.za>), which is a postgraduate research institute that was established in 1998 at the University of Pretoria (UP). FABI also houses the internationally recognised Tree Protection Co-operative Programme (TPCP; <http://www.fabinet.up.ac.za/TPCP>), now a 24-year-old research initiative established and part funded by the South African forestry industry to conduct research on pests and diseases threatening the long-term sustainability of plantation forestry in South Africa. It was, therefore, fitting that the CTHB was chosen to function alongside this programme, which already had a substantial international footprint in the field of tree health. In fact, the relationship between the two research programmes (CTHB and TPCP) is highly synergistic because of the human and intellectual resources available to the combined programmes.

The cooperative interaction between the CTHB and TPCP also extends to their complementary research objectives and activities. This is because their partnership allows for the exploration of research questions that would not have been feasible without their distinct, but interlocking, areas (native ecosystems and plantations) of interest. An example that clearly illustrates the impact of the CTHB–TPCP collaboration comes from the work done on *Chrysosporthe austroafricana*. This fungus is native to South Africa and capable of affecting hosts in the order Myrtales, which also includes non-native plantation-grown *Eucalyptus* species, and on which it causes the debilitating disease *Chrysosporthe* canker (Gryzenhout et al. 2009) (Figure 1).

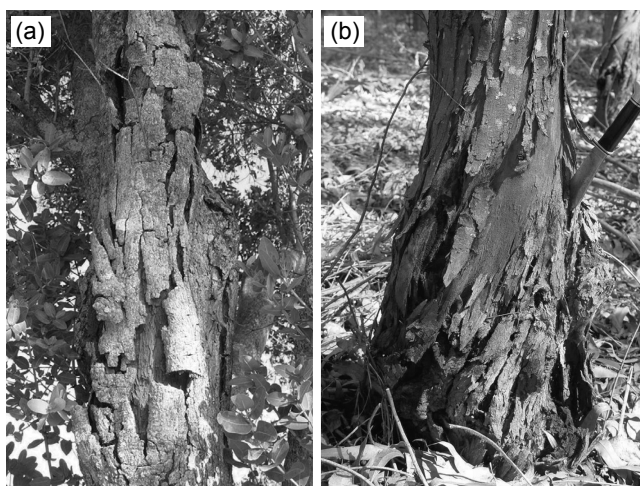


Figure 1: The characteristic cankers caused by the fungus *Chrysosporthe austroafricana* on native *Syzigium cordatum* (a) and non-native plantation-grown *Eucalyptus* (b)

Through their synergistic research, the TPCP and CTHB have not only promoted an understanding of the potential impacts of this pathogen on native trees in the Myrtales, but they have also contributed substantially to the development and implementation of strategies to avoid the effects of *Chrysosporthe* canker in commercial plantations (Gryzenhout et al. 2009). Even in cases where a specific pathogen or insect pest is relevant exclusively to the TPCP or CTHB, the knowledge produced from the respective research activities has invariably been used to promote the health of both native and non-native trees. Thus, the lessons learned during the pursuit of plantation tree health provide substantial value towards ensuring the health of trees in native ecosystems and vice versa.

The CTHB represents a cooperative programme that is both multidisciplinary and inter-institutional, which is consistent with the vision of the broader CoE programme. The Centre's 10 initial core team members included authorities in the fields of microbiology, entomology, plant pathology, molecular biology and genetics at UP, as well as a forestry scientist from the University of KwaZulu-Natal, and established researchers at the Medical Research Council's Programme on Mycotoxins and Experimental Carcinogenesis (PROMEC), the Council for Scientific and Industrial Research (CSIR) and the Centraalbureau voor Schimmelcultures (CBS) in The Netherlands. As a result of the increase in its funding base in 2009 and the subsequent expansion of the CTHB's research scope, the Centre now includes 27 PhD-level research scientists specialising in the additional fields of botany, forest ecology, ecosystem ecology, conservation ecology, resource ecology, plant physiology and wood science. The 2012 core team is made up of 13 members of staff from UP and the CBS, as well as 14 researchers from the Agricultural Research Council (ARC) and other higher education institutions (HEIs) in South Africa (i.e. Rhodes University, University of Cape Town, University of Stellenbosch, University of the Free State and University of the Witwatersrand). The CTHB is, therefore, structured as a virtual CoE that conducts scientific research via a collaborative network with its node at FABI.

Alignment of the CTHB's vision with the South African National Challenges

Like most initiatives supported by public funds, the objectives of the DST/NRF CoE programme are tightly linked to government's Medium Term Strategic Framework (MTSF) that guides the national mandate (South African Government 2009). This is also true for individual CoEs, no less the CTHB, where performance is measured against the envisaged outcomes or deliverables (South African Government 2010) reflected in the MTSF. Understandably, there are important intrinsic differences in the research focus of the various CoEs, and this clearly implies that their expected outputs are subtly different.

With its research focus on the health of native woody plants, the CTHB's objectives are well aligned with the national challenges involving sustainable livelihoods and resource management (MTSF strategic priority 1: *Speeding up growth and transforming the economy to create decent work and sustainable livelihoods* and MTSF strategic

priority 9: *Sustainable resource management and use*). For example, a number of the Centre's ongoing research projects explore the link between woody resource utilisation and tree/ecosystem health, which is important to protect and maintain native ecosystems and biodiversity. The current and past research of the CTHB has also facilitated a deep appreciation of the insect and microbial diversity associated with South Africa's native environments (e.g. Cruywagen et al. 2010, Roets et al. 2010, van der Linde et al. 2011). This has revealed considerable movement of insect pests and microbial pathogens between and among native and non-native tree hosts (e.g. Slippers et al. 2005, Heath et al. 2006, Perez et al. 2010). Apart from emphasising the apparent threats to our native ecosystems (e.g. Roux et al. 2007, Mehl et al. 2010), this research has also highlighted the links between the health of native species and those commercially cultivated. This is primarily due to the ability of certain native pests and pathogens to infest/infect commercially important species, resulting in significant economic losses (e.g. Pavlic et al. 2007, Heath et al. 2010, Wingfield et al. 2010). The CTHB and its partner programme, the TPCP, are also actively involved in studying and identifying non-native pests and pathogens, the introduction of which represent a huge threat to South Africa's naturally occurring and planted trees species (Wingfield et al. 2010, 2011).

Together with the TPCP, the research activities of the CTHB are strongly focused on developing strategies to limit the threats that pathogens and insect pests pose to the South African woody resource base. These programmes have produced and continue to build bases of information central to the development of effective pest and disease management strategies, as well as quarantine measures to prevent their introduction and spread in South Africa (Richardson et al. 2007, Lu et al. 2011, Garnas et al. 2012). At a global level, members of the team have also engaged in various initiatives such as the development of the Montesclaros Declaration (IUFRO 2012) that seeks to reduce the dangerous practice of moving plant material globally. The joint CTHB-TPCP research outputs thus contribute meaningfully to the sustainability of the South African industries and livelihoods that are dependent on the woody resources of the country.

Plant pathogens and insect pests do not recognise national borders and the tree health problems experienced in one country are not necessarily restricted to that region (Perrings 2010, Slippers and Kassen 2012). This is even more so for African countries, where borders are known to be relatively 'porous' and raw plant material is easily transported from one country to another. Because of the high probability of pest or pathogen introductions into South Africa from other African countries, the CTHB and the TPCP have developed a strong collaborative network with scientists at HEIs and research institutes in African countries with similar types of woody resources. They include Zimbabwe, Mozambique and Malawi in the Southern African Development Community (SADC), as well as Uganda and Cameroon. Given the dynamic nature of these collaborations, which involve interaction at all levels of research and postgraduate education, numerous tree health threats have been identified and strategies have been or are

being developed to deal with their imminent arrival. A key example is found in the participation of CTHB in the Forest Invasive Species Network for Africa (FISNA; <http://www.fao.org/forestry/fisna/en/>), a hugely important African initiative to monitor the movement of tree pests and pathogens on the continent. The CTHB and its collaborators thus participate actively in pursuing economic and environmental sustainability in the host countries involved and in Africa as a whole (MTSF strategic priority 8: *Pursuing African advancement and enhanced international cooperation*).

The broad and multidisciplinary research focus of the CTHB makes the Centre ideally situated for participation in the national challenges involving human resource development (MTSF strategic priority 4: *Strengthen the skills and human resource base*). This is mainly because the activities of the CTHB, as for most other CoEs, primarily function at research-intensive HEIs. This allows for the efficient use of scientific research as a primary educational tool for postgraduate learning. For example, the CTHB annually supports the research activities and/or bursaries for a large number of postgraduate students (Figure 2), and by the end of 2012 has produced 40 MSc and 31 PhD graduates since its launch in 2005. In addition, the close linkage with the TPCP also affords opportunities for students in the CTHB programme to expand their knowledge base to the commercial and industrial sectors.

Like other CoEs, the CTHB has needed to work intensively to improve the demographic profile of its student body (Figure 2). In this regard, it has pursued various initiatives to attract South African students from traditionally

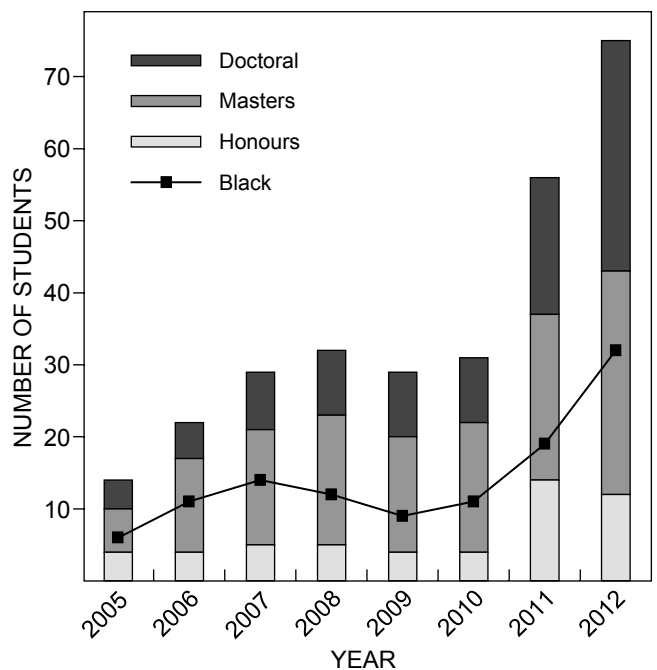


Figure 2: Students supported through bursaries by the CTHB from 2005 to 2012. These numbers do not include students with bursaries from other sources, but that have research projects funded by the CTHB. The proportion of students from previously disadvantaged backgrounds that are supported through CTHB bursaries are indicated by the black line

disadvantaged backgrounds into the programme. Although all CoEs have reported reasonable levels of success in improving their demographic composition, the overall situation must still be improved considerably. Perhaps the issues in need of most attention are the working environment and the associated benefits in South African HEIs and research institutes. To prospective students from poor backgrounds, these are generally perceived to be less attractive than those in, for example, the private sector (Herman 2011, Wingfield 2011). Nevertheless, together with all the other CoEs, the CTHB has strongly supported the 'PhD as a driver' policy of the NRF, which in turn contributes significantly to the knowledge economy of South Africa.

The importance of mentorship in the continuum of science learning is well recognised (Phillips and Pugh 2000), especially when 'developmental relationships' among undergraduate and postgraduate students are considered (Barker and Pitts 1997, Reddick et al. 2012). Following this view, the CTHB initiated an undergraduate mentorship programme in 2005, which annually targets approximately 20 second- and third-year BSc students that have potential to follow long-term careers in science (Figure 3). Because undergraduate students are mentored by CTHB postgraduates or postdoctoral fellows, the initiative

promotes learning at both the undergraduate and postgraduate levels. On the one hand, the mentees are introduced to postgraduate studies and the culture of science, while on the other hand, mentors are provided with the opportunity to refine their teaching and mentorship skills. Also, mentees invariably communicate their experiences in the programme to their peers, with the effect that the broader student body becomes better informed regarding careers in science and the opportunities associated with this field. Based on the success of this CTHB initiative (i.e. the majority of the mentees in the programme have continued with postgraduate studies), the Faculty of Natural and Agricultural Science at UP has established an identical mentorship programme, which is likewise showing a similar positive impact. Clearly, similar initiatives at other institutions should be strongly promoted to increase national postgraduate student numbers and to advance throughput rates.

Apart from promoting postgraduate learning, the CTHB has placed a strong emphasis on providing high-school learners with information regarding their post-secondary education opportunities (Figure 3). In order to achieve this goal, the CTHB participates extensively in two student outreach programmes: 'UP with Science' and MRYE (Mpepu Rural Youth Encouragement). 'UP with Science'



Figure 3: Education and outreach activities of the CTHB. (a) A group of postgraduate mentors and undergraduate mentees who participated in the CTHB mentorship programme. (b) Members of the CTHB-sponsored and -mentored MRYE group, which promotes tertiary-level education among high-school learners in rural areas. (c) Primary-school learners participating in the CTHB exhibition during the Department of Science and Technology's National Science Week. (d) High-school learners participating in an 'Up with Science' laboratory-based project together with their postgraduate mentor

is a science enrichment programme designed to actively engage students in the City of Tshwane Municipality and runs out of UP's Science Centre (<http://www.upwithscience.up.ac.za/>), while high schools in rural areas mostly outside the borders of Gauteng represent the main audience of the MRYE programme (<http://www.mrye.org>). Again, based on the successes reported for both outreach programmes, as well as those for other smaller outreach projects with CTHB involvement, this Centre contributes significantly to the national objective of broadening access to post-secondary education. Without doubt, improvements in the national higher-education throughput targets to ultimately strengthen the human resource base of South Africa, would only be possible through concerted efforts involving initiatives aimed at learners in both secondary and tertiary educational institutions.

Research outputs – impact and implementation

All CoEs have, as one of the basic requirements of the DST/NRF CoE programme, the obligation to provide services to stakeholders in government, industry and/or civil society. The key component of these services is the knowledge that has been produced, while service delivery or provision is intrinsically dependent on research excellence. From scientific and academic points of view, the knowledge produced by the Centre has considerable impact. This is clearly illustrated by the numbers of citations in scientific journals that have been accumulated by the Centre's published articles (Figure 4). It is further emphasised by a value of 29 (according to the Thomson Reuters Web of Knowledge™) for the so-called h-index (Hirsch 2005), which is used to capture productivity and quality of research (i.e. 29 of the articles published since the Centre's launch have been cited 29 times or more). With this track record, and its focus on native tree health, the CTHB is well positioned to render services to stakeholders in the academic, government, public and private sectors.

As part of the programme's role to render service, CTHB researchers serve on expert committees, advisory panels and editorial boards. These committees and panels include working groups dealing with issues pertaining to native and non-native tree health, as well as various scientific associations and societies aimed at promoting specific disciplines or science in general. Through their service on advisory boards, members of the CTHB provide leadership and guidance for various professional organisations and institutions in South Africa. In this abbreviated document, it is not possible to provide details of the many examples of service rendering by individuals to research institutions and organisations, but these are well illustrated on the web site of the CTHB.

From an applied or practical perspective, the knowledge produced by the CTHB has numerous spinoffs in terms of pest and pathogen diagnostics and surveillance (Figure 5). The joint CTHB–TPCP programmes maintain a world-class disease Diagnostic Clinic in FABI. This facility provides an important service to the South African forestry industry, institutions working with native trees and to the general public. Various members of the CTHB also undertake routine surveys to monitor, detect and diagnose tree health problems in native forests and woody ecosystems, which

also extend to other African countries that are part of the CTHB's collaborative network. The information collected by the Diagnostic Clinic and during surveys allows for a better understanding of existing pests and pathogens and is also a crucially important component of pest/pathogen risk analyses (Anderson et al. 2004, Sturrock et al. 2010). Access to this knowledge makes it possible to assist government in developing initiatives and legislation to safeguard South African woody resources against invasive insect pests and microbial pathogens. However, such protective strategies can only succeed when information regarding pests and pathogens is efficiently disseminated among key stakeholders (Miller et al. 2009). As a result, the joint CTHB and TPCP programmes have a strong field extension focus (Figure 5), which involves the presentation of talks at field days and research meetings, popular science articles in newsletters and newspapers, and radio interviews that are all aimed at educating stakeholders on tree health. Importantly, the maintenance of the internet list server 'TreeHealthNet' includes more than 500 South Africans that receive regular updates on key issues relating to tree health in the country.

The use of scientific knowledge to inform government policy graphically illustrates how research outputs are put into practice. In this regard, the newly developed National Forest Protection Strategy for South Africa is an excellent example. Prior to its publication (DAFF 2013b), South Africa

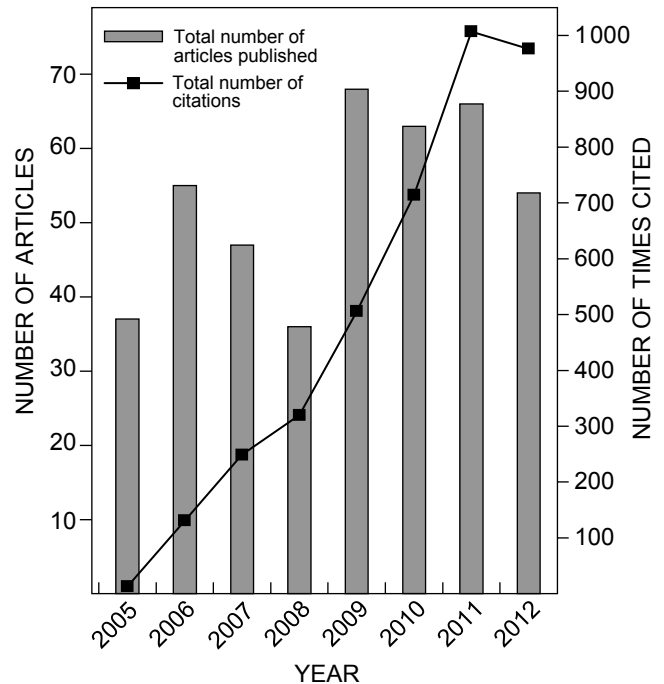


Figure 4: Citation report for articles published in international peer-reviewed journals by researchers of the CTHB from 2005 to 2012. The data for this report were obtained using the Thomson Reuters Web of Knowledge™ (accessed 25 January 2013), which was also used to generate the citation statistics. Note that these data only include the papers produced by the members of the CTHB at University of Pretoria, and not those produced by members of the extended programme at other HEIs and the ARC

lacked a defined strategy to deal with the impact of pests, pathogens and fire on forests. Members of the CTHB team played a pivotal role in developing this strategy, significantly drawing from the research and knowledge generated by the CoE. Likewise, members of the team have participated in the development of the regulations for the National Environmental Management: Biodiversity Act for South Africa (DEAT 2004).

A value-for-money investment

The DST/NRF CoE programme has been hugely successful and all Centres have performed superbly across all of the key performance indicators defined for them (NRF 2009). The view that the CTHB represents a 'good-value-for-money' investment was emphasised by the 2009 expert Review Panel (NRF 2009) who concluded that *Given the exceptional productivity of the Centre to date, there is little doubt that further NRF/DST funding of this important work would be well spent.* From the CTHB's perspective,

the successes of the programme can be attributed to four main factors. Firstly, as a formally constituted CoE, the CTHB has concentrated the resources and research activities of a large number of scientists within a common broad research focus – the health of native woody plants. There are two key issues here: *focus*, which is critical to research excellence, and *critical mass*, which has catalysed energy and a common goal among the participants. Secondly, the funding model of the programme has made it possible to pursue long-term multidisciplinary research initiatives, which are uncommon in the academic environment. Thirdly, the CTHB's alliance with the TPCP has stimulated research into areas at the intersection of native and plantation tree health. Not surprisingly, the pursuit of questions at the intersection of these research areas (i.e. the so-called Medici Effect; Johannson 2004) has allowed for significant paradigm changes in the promotion of tree health. A fourth and equally important factor that has contributed to the success of the CTHB is a spinoff of the first three factors, which represents what might be termed a Leverage Effect. This



Figure 5: Field research and extension work conducted by the CTHB. (a) CTHB scientists searching for *Ceratocystis* species and their insect vectors on elephant-damaged trees in the Kruger National Park. (b) Students of the CTHB examining fungal fruiting bodies on a felled log in Mozambique. (c) Members of the CTHB conducting an on-site diagnosis of a diseased camel thorn tree in the Northern Cape province. (d) The CTHB participates in a tree health information session in the field, which is attended by members of the general public, farmers and foresters

has captured tremendous advantages for the academics, students and stakeholders of the CTHB.

There is no question that the CoE status of the CTHB and the funding linked to it have allowed for significant leveraging of new research funding. This primarily arises from the synergy between the CTHB and the TPCP that draw considerably from and complement one another. The ultimate outcome is not only a positive impact on the health of native woody ecosystems, but also sustainability of commercial forestry. Through the outcomes of the CTHB, it has become patently clear that research efforts on both native trees and plantation forestry depend crucially on each other, which is further reflected by the new industry funding that has been leveraged after the establishment of the CTHB. The research of the CTHB and TPCP programmes also has led to new research questions that compliment tree health research, but that fall outside the core focus areas of these two programmes independently. Pursuit of these new research questions would not have been possible without the existing research framework of the collective CTHB and TPCP programmes and the synergies between them. Similar arguments can also be made for the CTHB research conducted at other HEIs, where access to CTHB resources and capacity has enabled individual researchers to secure additional funding and to explore new research questions.

The CTHB's leveraging power is also evident in its human resource base. Because of the Centre's reputation of research excellence and its stable funding model, the CTHB has, for example, successfully leveraged five academic positions from its host institution. The dynamic nature of CTHB research has also attracted numerous postgraduate students and postdoctoral fellows, and to accommodate them bursaries have been and continue to be leveraged from various national and international funding agencies. Likewise, based on the positive outcomes of the field extension work conducted by the CTHB and TPCP, a number of technical positions have been leveraged from the South African forestry industry to promote knowledge brokerage and to expand field extension activities. Although the human resources gained through this Leverage Effect are difficult to quantify precisely in terms of monetary value, they represent tangible by-products of the CTHB's reputation of research excellence and the stable funding from the DST.

From a financial point of view, it is perhaps easiest to quantify the leveraging power of the CTHB where research infrastructure and facilities are considered. For example, the joint CTHB–TPCP programmes have leveraged or contributed to the leveraging of various large research equipment or facilities (e.g. high-throughput next-generation sequencing facilities, automated DNA sequencers, real-time PCR machines and phytotron/incubation facilities). Another notable example is the leverage that has made it possible to build a R6 million facility on the UP Experimental Farm to undertake research on the biological control of forest pests threatening commercial forestry in South Africa (Roux et al. 2012). Biological control represents the most effective and environmentally safe means to deal with problems that are and will continue to threaten industrial development, woody resource sustainability and job creation in South Africa. In addition, capacity

in developing biological control agents is equally important for native woody ecosystems as they are challenged by invasive alien pests, which could include those affecting plantation trees. Undeniably, the success of the CTHB and the many students involved in this Centre provided the core motivation that led to the funding becoming available to establish the FABI Biological Control Centre.

Amongst the many positive impacts of the CTHB, this CoE has also contributed significantly to the development of inter- and intra-institutional collaboration, which in turn has promoted substantial synergy and critical mass to deal with tree health issues. At the time that the CoE was awarded in 2004, FABI was a newly formed research institute and the CTHB provided it with considerable impetus that had not been anticipated when FABI was established in 1998. The CTHB also has had a substantially positive impact on the development of other research programmes in FABI, which competes well with many similar institutes internationally. In addition, by being hosted in FABI, the CTHB has been able to build strong linkages with other departments in UP's Faculty of Natural and Agricultural Sciences. Likewise, at the inter-institutional level, the CTHB has established a highly dynamic collaborative network of research scientists, both locally and abroad. The CTHB further maintains dynamic collaborations with the South African National Parks Board, the Department of Agriculture, Forestry and Fisheries, the ARC, the Department of Trade and Industry, and virtually the entire forestry industry of South Africa. No less important, the CTHB connects researchers in other African countries, which is important for the development of science, technology and education broadly on the African continent.

Conclusions

The rationale behind the establishment of the DST/NRF CoE programme was to stimulate sustained distinction in research while at the same time developing highly qualified human resource capacity. If the CTHB is used as an example against which to measure the success of this initiative (Figure 6), the DST/NRF CoE programme has accomplished exactly what it set out to do, and more. From the brief overview presented here of the activities and outputs of the CTHB, it is obvious that this Centre has established a distinctive niche in South Africa's science system. It uses its resources and infrastructure to conduct research, participate in human resource development and provide services to stakeholders from all sectors. The outputs of these activities, in turn, allow the Centre to contribute meaningfully to at least four of the 10 National strategic priorities. Similar contributions are also made by most of the other CoEs, which illustrates clearly how a relatively small investment by DST (R50 million in 2010/2011; NRF 2011) can be used to contribute to the ultimate enhancement of economic growth and development and the welfare of the people of South Africa.

Across the board, the DST/NRF CoEs have had a remarkably positive impact on research, science education and community service in South Africa and the CTHB provides one example of this accomplishment. As illustrated in this document, the success of the CTHB (and surely

A South Africa with the human and physical resources needed to withstand the tree health challenges brought about by globalisation (trade, transport and tourism) and climate change

- Improved and sustainable health of native trees and woody ecosystems
- Sustainable forestry and woody ecosystem management
- Improved research skills and increased human resources
- Employment opportunities across many disciplines
- Dynamic research partnerships (globally including Africa)

- Peer-reviewed scientific papers and position papers
- BSc Honours, MSc and PhD graduates
- Efficient and effective tree health surveillance
- Advice to government and other institutions
- Students pursuing careers in science
- Research collaboration nationally and internationally

- Research on the health of native trees and woody ecosystems
- Disease and insect pest diagnostics/monitoring
- Undergraduate and postgraduate education
- Field extension and knowledge brokerage
- Mentorship of high-school learners regarding careers in science

CTHB human capacity, resources and infrastructure at six South African higher-education or research institutions

IMPACTS

WHAT DO WE AIM TO CHANGE?

OUTCOMES

WHAT DO WE WISH TO ACHIEVE?

OUTPUTS

WHAT DO WE PRODUCE OR DELIVER?

ACTIVITIES

WHAT DO WE DO?

INPUTS

WHAT DO WE USE TO DO THE WORK?

Figure 6: Framework linking the various components (inputs, activities, outputs, outcomes and impacts) of the CTHB's research value chain. The framework is based on the model proposed for the Outcomes Approach, which is used by government for alignment to the MTSF (South African Government 2009, 2010)

other CoEs) can be attributed to many interacting factors including a multidisciplinary approach, which is typically not possible in more focused research programmes. Of all these factors, however, the two most important ones are (1) the critical mass of scientists working collectively and passionately on a common research theme, and (2) the fact that the CoE funding has provided substantial leverage to access new collaborations, novel multidisciplinary research activities, facilities and funding. In our view, these key issues have driven the growth and success of the CTHB, which would not have been possible without the establishment of the Centre.

Consistent with DST's 10-year (2008–2018) innovation plan for South Africa (DST 2007), the CoE programme brings numerous benefits to the knowledge economy of the country. However, unlike countries in the developed world, the large majority of the basic research conducted in South Africa is funded or part-funded with public money. Therefore, should funding through the CoE programme be down-scaled or terminated, most of the CoEs would

continue to attract research funding to sustain their work, but this would certainly not be near the same level. This is also true for the CTHB, which will undeniably continue to function, but the consequence of limited funding in South Africa would clearly result in a programme significantly different and less effective than the one that is currently in place. Assuming that a high level of performance is maintained by the CoEs, we believe that it is essential that the NRF and DST seek to support the CoE programme beyond the current funding cycle of 15 years. In fact, the notion that government expenditure on research and development represents a key driver in the knowledge-based economy of South Africa and Africa, in general, is widely recognised (e.g. Teng-Zeng 2009, Blankley and Booyens 2010, Pouris 2012).

While strong research programmes will always find new opportunities, it would be naïve to believe that any of the CoEs, no less the CTHB, would be able to continue at near the same levels of achievement without the core funding on which they rely. These CoEs might be analogous to

newly developed aircraft that have been carefully designed, built, launched and that have reached 'cruising altitude'. They are flying high and providing them with the required fuel enables them to continue to do so profitably for long periods of time. Moreover, they provide superb models for new vehicles with similar and even more impressive objectives that might be developed in the future. Much like the statement of the late-nineteenth century poet Ralph Waldo Emerson, *life is a journey, not a destination*, we see the activities of the CoEs as a long-term journey to promote excellence in research, Science education and community engagement. In the case of the CTHB, this is in the field of tree health where the journey has already established many important milestones. Given continued support, it will continue to do so increasingly effectively.

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