IS PUBLIC INVESTMENT IN R&D VALUABLE? THE ARC PPRI WEEDS RESEARCH DIVISION

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Abstract

This study conducts an economic valuation of the ARC PPRI Weeds Research Division. The Division researches methods of biological control for invasive alien plants (IAPs). These plants pose an increasing threat to environmental integrity and ecosystem service provision. This has serious impacts on economic growth potential. A predominantly descriptive approach has been adopted to deal with the challenges associated with non-market valuation. The study found that investment into the Division’s work is highly valuable since it supports the long-term growth potential of the South African economy. The role of a well-functioning environment is highlighted as an essential base for the sustained growth of any society. It was determined that investment into the Division should be increased. The study adds to the increasing move towards a more holistic view of economic valuation, taking factors other than pure finance and econometrics into consideration.

Key Words:
Biological control
Environment
Investment
Non-market

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This study investigates the economic impact of the Agricultural Research Council (ARC) Plant Protection Research Institute's (PPRI) work into biological control (or biocontrol) of Invasive Alien Plants (IAPs). The unit under study is the Weeds Research Division, which is responsible for conducting the research necessary to select, quarantine and release biocontrol agents in South Africa (Plant Protection Research Institute, 2005). The economic valuation conducted in this study is descriptive in nature, and combines a cost analysis of biological versus conventional forms of IAP control (Gittinger, 1995) with qualitative data regarding the impacts of research and the effects of invasive alien plants (IAPs). Van Wilgen *et al* (2001) noted that although much work has been done on the history, ecology and management of IAPs, to date few studies have investigated the value created through the research of biocontrol opportunities. It is this aspect of the IAP problem in South Africa that is investigated here.

The goals of the study are to

1) Illustrate the value of the PPRI Weeds Research Division's work to the South African economy.
2) Determine whether investment into biological control research is worthwhile, and whether this investment should be increased over time.

Context of the Study

The Agricultural Research Council (ARC) is South Africa's leading agricultural research body. The organisation strives to drive research and development in the sector through the improvement of technologies and dissemination of information (Agricultural Research Council, 2012). It is the mission of the ARC to support innovation in the agricultural sector by producing relevant and new research in a range of fields. The Council is composed of a number of units, each with a focus on a specific area in the sector. The Plant Protection Research Institute is one of these units, with a mandate to provide public support services for the agricultural sector (Plant Protection Research Institute, 2006). The Institute conducts research into five main fields, namely Biosystematics, Insect Ecology, Pesticide Science, Plant Pathology and Microbiology, and Weeds Research.

The PPRI performs mainly scientific research and development (Thirtle *et al*, 1998), and has two main objectives: the development of effective management systems for plant disease, pests and invasive plants that are as minimally harmful to the environment as possible; and the promotion of the commercial use of beneficial organisms to improve the resilience, production and sustainability of the agricultural industry as a whole. These objectives are achieved through focussed research, the development of improved technologies and the transfer of these technologies to the public (Agricultural Research Council, 2010).

The Institute is classified as a public support service organisation, since the work it produces is largely scientific in nature spanning a wide range of plant related fields. The research is available for anyone to use and is done for the benefit of all people (Black *et al*, 2008). Such work includes the analysis of pesticide residues, entomology and nematology research and the custodianship of these national databases, research into pests of stored grains, and weeds research, which is the focus of this paper (Plant Protection Research Institute, 2012). Valuing these types of activities is challenging because they do not lead to easily measured changes in output levels, input costs, or other market based indicators. Instead, they tend to produce effects that are non-market in nature such as preserved biodiversity or improved knowledge (Plant Protection Research Institute, 2005). A challenge is therefore presented in terms of the estimation of the economic value of the Institute's work. This is because it is inherently difficult to place a value on a good such as a river system free from invasive water plants or a national scientific database (Tietenberg & Lewis, 2010).

The primary objective of the PPRIs Weeds Research Division is the protection of South Africa's natural resources and biodiversity from the threat posed by invasive alien plants (IAPs). This is achieved by researching the use of biological control agents to develop integrated pest management systems that are not harmful to the environment and result in long-term solutions to IAP management (Plant Protection Research Institute, 2006). The Division first began to research the use of biocontrol in 1913, to control the cactus *Opuntia vulgaris,* which was rapidly spreading across the country. Since then, 270 potential control agents have been tested with 106 of these having been deemed effective and safe for release (Klein, 2011). Of these 106 agents, 75 have become established on 48 IAP species with 21% of these IAPs having been brought under complete control and a further 38% brought under substantial control. It has previously been estimated that the use of biocontrol has thus far resulted in a 19.8% (approx. $120 million) saving in the cost of IAP control in South Africa (Plant Protection Research Institute, 2006).

The main challenge facing the PPRI Weeds Division is a lack of secure long-term funding. Due to difficulties associated with the valuation of public goods (Tietenberg & Lewis, 2010), and in this case the value of public research, the Division often finds it difficult to motivate for sufficient levels of continued investment into its projects. To better understand this problem, this study attempts to illustrate whether investment into biological control research is a valuable activity that should receive continued and increased financial support into the future. Displaying the value that the Division provides to the South African economy is essential at a time of increased financial strain in the domestic economy, and will shed light on the value of conducting publically funded basic agricultural research.

An equivalent of over 12% of total land area of South Africa (121 909 000 ha) has been claimed by invasive alien plants (Henderson, 2011. and Le Maitre *et al*, 2000). The urgent need for sustainable solutions to current and future invasions is therefore highlighted as higher levels of invasion pose a greater long run cost to the economy. Van Wilgen *et al* (2001) noted that the environmental and economic impacts of IAP invasions are not fully understood, but indications are that total costs imposed are substantial. This was supported by Le Maitre *et al* (2002) who argued that in light of the available literature regarding the range of negative impacts and rate of spread of IAPs, a failure to clear and effectively control these species will result in an exponential increase in the clearing and control costs in the future. The spread of invasive alien plant species is a problem affecting large areas of the country, and imposes a range of costs onto the local economy and environment that are set to increase into the future. Considering this, Zimmermann *et al* (2004) remarked that given a limited budget and a range of other pressing social needs, South

Africa needs to find a management solution that is able to deal with the problem at least cost and highest effectiveness.

Investment in projects such as researching biological control for invasive alien plants is almost entirely driven by the public sector, as is the case with the Weeds Research Division (Hill & Greathead, 2000). This is because biological control is largely seen as a public good, where the benefits of the research are distributed throughout communities and generally cannot be captured by private interests (Black *et al*, 2008). At a time of increased financial pressures due to turbulence in world markets and increased domestic demand for state funding, the necessity of identifying the impact that such a research institution has on the economy is increasing. This is to justify the large expenditure of public funds on the Weeds Division's work, which totals about $3 million per year (Khan, 2013). It is therefore necessary to develop a method for analysing the value of the Division's work that accounts for the non-market goods produced. Having developed this method, an understanding of the value produced must be ascertained to illustrate whether such investment is worthwhile and what future levels of investment are suitable.

The value provided by research and research institutions to an economy's development has long been recognised. Vang *et al* (2007) noted the global awareness of the value presented by universities and other publically funded research institutes as drivers of knowledge based growth and innovation. Without these research driven organisations, there is a tendency for an economy to rely on existing technologies and therefore stagnate. Wiebe *et al* (2001) supported this idea with the finding that sufficient levels of research are essential for the sustained development of economies by creating new opportunities for growth. By providing sufficient support for research organisations, a government ensures the economy is dynamic and responds to available niches that may be created. Asheim and Coenen (2005) argued that knowledge is the most strategic and important resource for growth in today's globalised economic context. Furthermore, learning was identified as the fundamental source of competitiveness. It is through new research findings, improved scientific methods and the development of skills in this sector that a range of prospects for future development are established. From this, the idea of the learning economy (Lundvall, 2010) and knowledge based economy (OECD, 1996) have arisen as key descriptive terms for contemporary development. These terms describe an economy that is geared towards exploiting incremental improvements in competitive advantage by making use of continuous research innovation and development.

Valuing research

In terms of the effect of agricultural research on consumers, Wiebe *et al* (2001) found that too little investment into agricultural research has a negative impact on food prices, productivity growth and food security. This is because increases in agricultural output are unable to keep pace with increasing demand for food. The consequence is an undersupply of food that causes prices to rise and food resources to be unevenly distributed. Ramaila *et al* (2011) backed this idea with the finding that South African research and extension services act as a constraint on agricultural productivity due to their limited nature. This points to a need for well-structured and directed research and extension. Although the work of the Weeds Division does not directly impact on food production or security, it does illustrate how research impacts on prices. This is an important aspect to consider with regards to IAP management as cost is becoming a more significant issue and therefore research to decrease cost is increasingly relevant. Relating to productivity improvements through research, Khatri *et al* (1996) used a profit function approach to obtain data on sources of productivity change in domestic agriculture. When this is combined with Vink's (2000) work in deriving the marginal internal rate of return realised through extension services, strong support for conducting publicly funded research emerges. The value of conducting research for the sake of improved productivity and cost efficiency is therefore promoted, again providing an indication that the work of the Weeds Division is valuable.

Despite the usefulness of agricultural research, Jayne *et al* (1994) found that research had little impact on the smallholder sector of Zimbabwean agriculture. In comparison, Wiebe *et al* (2001) found that the Zimbabwean commercial sector experienced a rate of return on investment into research of around 40 %. From this it was concluded that the disparity was due to the poor availability of infrastructure in the smallholder sector, and that in order for research to have a significant impact on agriculture the complementary investment into infrastructure, both physical and institutional, needs to be in place. If this is not the case then input, output and credit markets are unlikely to function efficiently and certain sectors will be unable to properly implement the new technologies made available through research (Wiebe *et al*, 2001). Again, this finding relates to the usefulness of agricultural research, pointing to the need for well-developed infrastructure and implementation procedures. In terms of the work of the PPRI Weeds Division, it could be concluded that research into biological control of invasive plants should be accompanied by mechanisms that can effectively implement the work. Should these mechanisms not exist, or be poorly developed, then the research becomes less useful.

Invasive alien plants

Moving to understand invasive alien plants in particular, Turpie and Heydenrych (2000) noted that successful invasive alien plants (IAPs) are species that have established themselves in new environments and produce large amounts of seed at frequent intervals. IAPs gain a foothold either by exploiting available niches or taking advantage of disturbances in an environment (Hobbs, 2000). An available niche for example could be a lack of tree species in a largely shrub dominated area. A disturbance on the other hand, for example, could come from overgrazing, fire or clearing (Turpie & Heydenrych, 2000). In environments that have no available niches, or are not subject to disturbances, invasive plants struggle to establish. If an invasive alien plant is however able to become established in a new environment, the plant soon begins to produce seed that is easily dispersed over large areas. The ability to produce and distribute seeds over a large area enables invasive species to spread rapidly. The example of invasive *Acacia* species such as *Acacia longifolia* (long-leaved wattle) and *Acacia salinga* (Port Jackson willow) (Impson *et al*, 2011), which are dealt with in the data chapter, provide a useful illustration of this invasive characteristic. It was noted by Impson *et al* (2011) that invasive Australian *Acacia's* produce vast amounts of very resistant seed that does well in poor soils and is easily dispersed. Many other invasive plant species display similar characteristics, for example, *Chromolaena odorata* (Zachariades *et al*, 2011) and *Campuloclinium macrocephalum* (pompom weed) (McConnachie *et al*, 2011).

Van Wilgen *et al* (2001) noted that since the early 1600s, thousands of varieties of foreign plant species have been introduced to South Africa. These were introduced for varying purposes including timber, food production, land stabilisation, hedging and ornamental usage (Joubert, 2009). Some of the introduced species are unable to persist under South African conditions, however, some have been naturalised and are able to survive and at times thrive without tending.

Van Wilgen *et al* (2001) stated that since invasive alien plants (IAPs) can survive and reproduce under local conditions, they are also able to spread without human intervention. Of the plant species that have been naturalised about 340 have become established and are now considered as invasive in South Africa (Moran *et al*, 2011). Through the use of various mapping techniques, such as SAPIA (Southern African Plant Invaders Atlas) (Henderson, 2011) and subsequent modelling of collected data, it has been estimated that over 10 million hectares of pristine South African environment has been invaded and affected by IAPs (Le Maitre *et al*, 2000). This is equivalent to 12.19% of total land area of South Africa (121 909 000 ha) (SouthAfrica.info, 2014). The scale of the IAP problem is therefore large and requires a well-structured management strategy that takes into consideration the capacity of IAPs to spread without human assistance. An example of the ability of an invasive plant to spread is illustrated in figure 1 and 2.

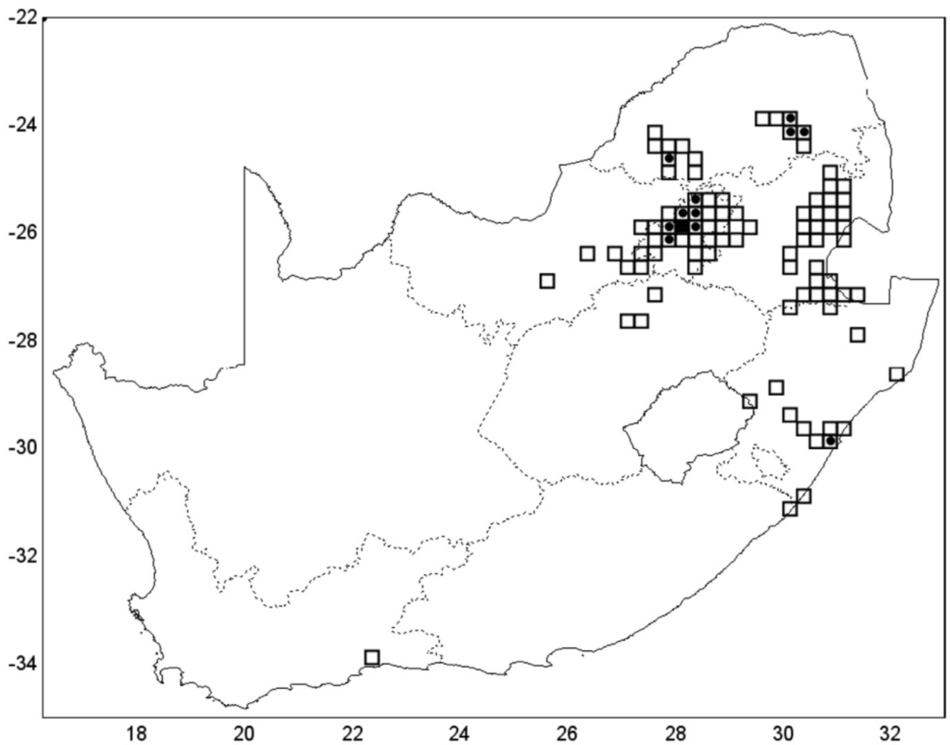

Figure 1: History of spread of *Campuloclinium macrocephalum*: 1960s (■), 1970s-1990s (●), 2000s (□).
(Source: Henderson, 2011).

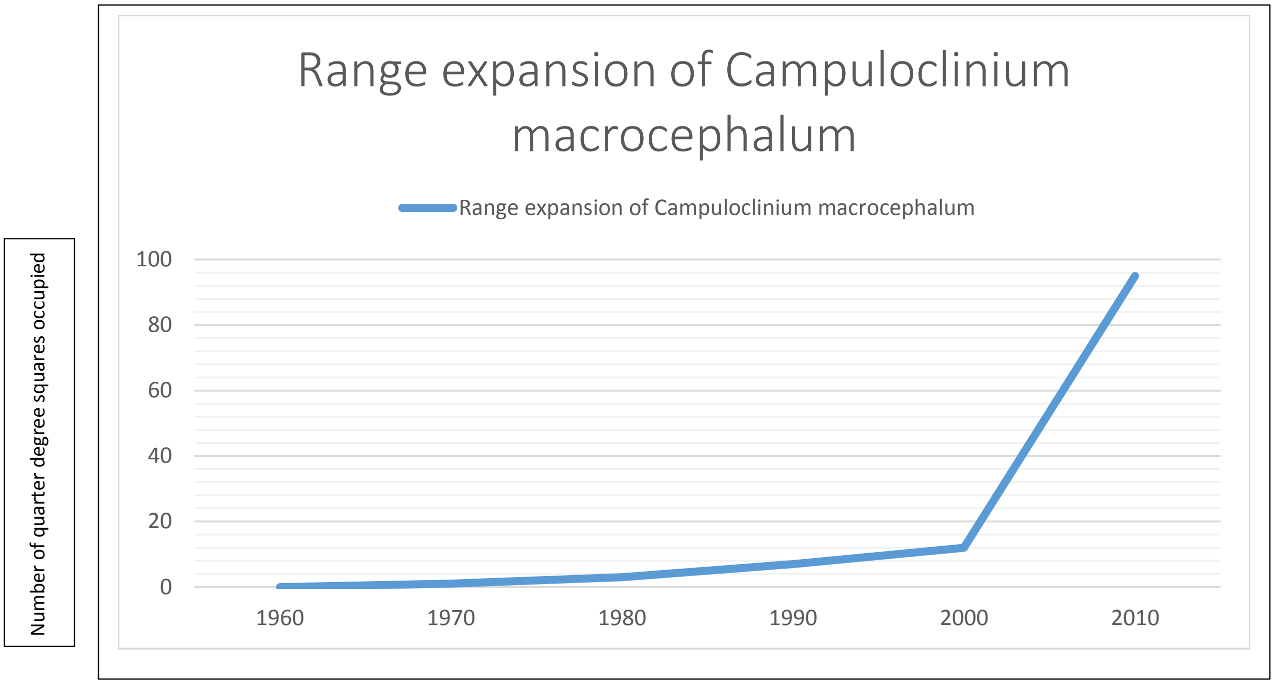

Figure 2: Range expansion in quarter-degree squares (QDS) occupied by *Campuloclinium macrocephalum* from 1960 to 2010.
(Source: Henderson, 2011).

From figures 1 and 2 it is evident that the extent of IAP invasions are expanding over time. Having become established the invasive plant displays a trend of rapid range expansion. The need for control strategies especially implemented at an early stage of the plants establishment is therefore promoted, as this allows for curtailment of the invasion before the plant is able to take a foothold in its full potential range (Henderson, 2011). As the range of the invasion increases, the related cost of control increases, since additional effort is required to clear the plant from new environments (Van Wilgen *et al*, 2001).

Turpie (2004) noted that the main challenge with invasive plant management is that mitigating the development of control strategies generally requires a quantitative assessment of why an intervention should be made. Support for IAP control needs to be shown as the financially sensible thing to do. In this regard, Van Wilgen *et al* (2001) stated that there exists no standard system for the objective quantification of the variety of impacts IAPs pose on the environment. This is because of the difficulties associated with the valuation of environmental goods and services, especially those that are of a non-market public good nature (Parker, 1999). Promoting the development of IAP management strategies therefore needs to make use of non-market valuation techniques to quantify both the damage that IAPs impose, and the relative value of available control methods.

The biological control of invasive alien plants involves the introduction of foreign species of plant-feeding insects, mites or plant pathogens to reduce the target weeds' fitness and invasiveness, therefore leading to declining populations and rate of spread of problem plants (Van Wilgen & De Lange, 2011). Joubert (2009: 219) stated that: "Biological control as a means of containing an invasive alien infestation is simple in theory: Go back to the invaders native country and find organisms that curb its growth and reproduction". The control of plants can be achieved using insects, parasites, fungus or bacteria that naturally predate on the target plant (Hill & Greathead, 2000). Depending on the effectiveness of biological agents, this form of IAP control can have either complete, partial or no impact on the target species.

There are however some wider concerns that need to be taken into account when considering biological control as a management tool for IAPs. To begin with there are the moral and ecological considerations of introducing another foreign species into an already invaded environment (White & Newton Cross, 2000). Concerns exist as to the long-term impact that such an introduction might have on the local environment (Van Wilgen *et al*, 2001). This concern is addressed below, with evidence illustrating that there are no long-term side effects experienced as a result of the release of control agents (Joubert, 2009). A further concern is who is responsible for the final decision of whether to release an agent for control or not (White & Newton Cross, 2000). This issue is also dealt with below through reference given to relevant regulation.

Van Wilgen and De Lange (2011) stated that to ensure the introduction of a biological control agent does not have unexpected and damaging impacts on the indigenous flora and fauna, stringent host specificity testing must first be conducted. Moran *et al* (2005) described host specificity as the characteristic of a control agent to target only the invasive plant in question, therefore posing no threat of feeding or attack on indigenous or other important species such as commercial crops. This is done to properly understand the full range of impacts that an agent would have on the native environment. To achieve this understanding requires thorough research and testing, and must be carried out under strict quarantine conditions to prevent an agent escaping before its host specificity has been established (Louda *et al*, 2003). As Joubert (2009) noted, the concern exists that the introduction of a biological control agent into an already destabilised environment could lead to a further invasion, which has additional detrimental impacts on the native flora or fauna. If for example an agent is introduced that does not specifically target the host plant, then it is possible that the agent could attack certain indigenous species and cause problems equivalent to or greater than those experienced as a result of the target plant. With regards to this, Louda *et al* (2003) noted that target or host specificity is one of the main areas of focus when identifying suitable control agents. Researchers must conduct stringent host specificity testing on all potential control agents to ensure that they will only target the invader in question and not any indigenous species.

Alternative options for control

In a country with an unemployment rate of 25.5% (Statistics South Africa. 2014), the argument for the use of public works programmes such as Working for Water (WfW) to create large amounts of employment opportunities is strong (McQueen *et al*, 2001). More than 20 000 jobs per annum have been created through WfW since 1995 (Working for Water, 2013). The majority of these have been targeted at the marginalised and individuals with low skill levels. The programme has social upliftment as one of its main drivers, with targets such as creating 18 000 jobs per year for previously unemployed people (60% for women and 20% for youth) and compulsory training for all staff including HIV/AIDS awareness. Employment creation is therefore at the centre of this initiative, which is the likely reason for the continued political and financial support it has received.

In terms of the value realised through public works programmes, Subbarao *et al* (1997) remarked that investment into these types of projects is a useful tool for carrying out countercyclical interventions. It was further noted that such programmes have been used throughout the world with success in aiding consumption smoothing for poor households. Adato *et al* (2005) supported this with the finding that participation in public works programmes has a positive effect on labour and employment, particularly in terms of opportunities for women. Subbarao *et al* (1997) however concluded that, while such interventions are useful as temporary safety nets for the social challenges of unemployment and poverty, these should not be viewed as permanent or sustainable solutions to said issues. McCord (2006) provided endorsement for this view by noting that available literature suggests that investment into public works programmes does not present long-term solutions for transformative social protection. Rather, this sort of investment is useful for smoothing consumption of poor households during cyclical or structural dips

The PPRI Weeds Research Division

Due to the nature of the Weeds Research Division's work, which predominantly produces non-market type goods, it is difficult to come to an accurate valuation of the Institute's research without making a number of assumptions and estimates (Scholes & Biggs, 2005). Using available techniques of valuation it is not currently possible to estimate the value of an indigenous forest free of invaders (Tietenberg & Lewis, 2010). The value of the Division's biological control research in terms of biodiversity and environmental protection is likewise not ascertainable using market analysis as it is not currently possible to place a market value on such items. The method outlined here therefore represents an attempt to conduct a non-market valuation exercise as accurately as possible using the simplest means available. The chosen method draws on some empirical aspects but predominantly assumes a descriptive nature. This is not the ideal option for displaying the value of the Weeds Division's biological control research but has been selected due to limitations in empirical data availability and reliability (Nesser, 2013). The study as a whole therefore assumes a more descriptive than empirical nature, drawing on a wide variety of literature surrounding the value of research and biological control to illustrate the value of the PPRI Weeds Research Division.

It was decided to use the cost-efficiency analysis as suggested by Gittinger (1995) and Layard and Glaister (2012) to illustrate the quantitative value of the Weeds Division. This approach will be used to consider the cost efficiency of using either biological or conventional means of IAP control. Having identified the value of biological control from this perspective, it will then be possible to draw inferences about the value of the biological control research conducted by the PPRI. Hanley and Spash (1993), noted that the use of this method allows for a comparison and choice to be made between two or more techniques available for completing the same task. This choice is based on the technique that achieves the desired result at lowest cost (Arrow *et al*, 1996). Since both biological and conventional methods of control achieve the same end of IAP management, and because cost efficiency relates directly to economic value (Layard & Glaister, 2012), it can be concluded that this method will identify the most suitable form of IAP control. Having identified this, the value of the Weeds Division can be considered.

From a decision making perspective, Donahue (1980) noted that the understanding of economic efficiency is dependent on the goals and interests involved in a project. Since any project is situated in a specific context, there exist a variety of political, social, economic and environmental objectives and preferences that place pressure on the choice of implementation technique. Depending on the various weights assigned to each of these objectives, the choice of project will be affected in differing ways (Adato *et al*, 2005). The understanding of economic efficiency is therefore affected by the context in which a decision must be made. Killick (2004) remarked that, depending on this context, there will be a tendency to choose one project over another without as much weight given to pure economic reasoning. It is therefore imperative that decision makers are aware of these demands, and make choices that are cognisant of both these and economic thought. In the context of the PPRI Weeds Division there are two main considerations that need to be remembered. These are the issues of job creation through conventional control (Working for Water, 2013) versus cost saving through biological control (Van Wilgen & De Lange, 2011). Each of these aspects persuades decision makers to opt for either conventional on biological control, and must therefore be considered when making a valuation assessment of either option. These considerations have been mentioned in chapter three and are again dealt with in chapters five and six.

The motivation for choosing this method for valuing the work of the ARC PPRI Weeds Research Division is twofold. Firstly, Van Wilgen *et al* (2001) remarked that it is inherently difficult to fully understand and quantify the benefits of biological control and the associated research. A method is therefore needed that will allow for a valuation assessment to be conducted using limited empirical data regarding the benefits of biological control research. Secondly, due to the available choice between conventional and biological methods of IAP control, a method is needed that will help determine the relative value of each of these management strategies. In identifying which of these strategies is most optimal, a conclusion can then be drawn as to the value of the biological control research conducted by the Weeds Division. This may seem like a somewhat roundabout method of valuing the work of the Institute but, due to the nature of the work and limitations in data and available valuation techniques, this method has been selected as the most appropriate for illustrating why investment into the work of the Weeds Division is worthwhile. By showing that biological control is an economically efficient choice for IAP management, the supporting research will in turn be illustrated as valuable. This method of valuation will not come to a precise figure on the value of the research work but will however provide an indication of whether the work is worth investing in. For some decision makers this may present a problem because of their desire for cut and dried financial figures. In the context of the PPRI Weeds Research Division's work however, the available non-market valuation methods are as yet unable to provide such figures (Tietenberg & Lewis, 2010). Instead, a descriptive approach must be pursued to illustrate why and in what ways this work is valuable. The following paragraphs provide additional reasoning for taking this descriptive cost analysis approach and explain how the method is used to display the value of the Weeds Division.

The approach of comparing the relative cost of conventional and biological control methods was chosen because this was taken as an indicator of the value of biological control research. If biological control is found to be more economically efficient than conventional control then the research conducted by the Weeds Division is supported as economically valuable (Hanley & Spash, 1993). This is because no biological control initiatives would be possible without the associated research carried out by the Division. The value of biological control can therefore be taken as a proxy for the value of biological control research. The use of a proxy is made because of the limitations in available empirical data concerning biological control research (Klein, 2014).

The cost efficiency approach is further deemed suitable because both conventional and biological control measures result in the same outcome of IAP management (Dlamini, 2014), which was established as essential for supporting long-term economic growth potential (Turpie & Heydenrych, 2000. and Joubert, 2009). The control of IAPs can be taken as the major benefit of the work and therefore considered as equal for both techniques of control. Using the cost efficiency approach allows a valuation exercise to be conducted using limited data on the benefits of each technique because the benefits of both techniques are considered the same. Instead, the method focusses on the relative cost of each technique as the decision making aid. The cost efficiency approach therefore allows for a choice to be made as to the optimal method, or technology, to be used in achieving IAP control (Worthington, 2000). Zimmermann *et al* (2004) specifically observed that the choice of IAP management strategy should be based on the relative costs of biological and conventional control methods. This was recommended due to the necessity of wise spending of limited state funds. By determining the relative cost efficiency of biological control it is possible to illustrate the value of biological control research. This value is demonstrated through the economy-wide savings that are achieved, both currently and in the long run, by implementing the work of the PPRI Weeds Division.

In terms of how the cost efficiency analysis has actually been carried out, a simple cost comparison has been made between biological and conventional control measures. This comparison is displayed in table 1 (provided at the end of the paper) where the budgeted expenses on biological research and implementation are compared with the budgeted expense on conventional control. These figures have been collected from the Working for Water (WfW) programme (Wannenburgh, 2014) and the Agricultural research Council (Agricultural Research Council, 2014). It must be remembered that the expenditure on biological control and comparison to conventional control has been undertaken to illustrate the relative value of biological control. Based on the finding of this analysis conclusions are then drawn as to the value of investment into biological control research, the real crux of the study. These deductions can be made based on the assumption that the benefits of either mode of control are the same. As such, the method of control that imposes the lowest cost will be taken as the option that is most economically efficient.

The data shows that approximately 2.4% of the total budget for IAP management is spent on biological control research. From this level of expenditure, Klein (2011) stated that biological control options have been investigated for 73 species of invasive alien plants. Based on the results of host specificity research, 106 control agents have been released against 48 weed species. Of the 73 investigated species, 10 have been brought under complete control meaning that no other measures are needed to control the target plant. A further 19 species have been brought under substantial control using biological methods, meaning that minimal levels of effort are required to bring the target plant under control. Of the remaining 44 species of target weed, 14 have been negligibly impacted by the release of biological control agents, and the impact on 9 species has not yet been determined. In the case of the 9 undetermined species, either there has been no post release evaluation conducted or it is still too soon after release to conduct such an evaluation. For the remaining 21 species no data exists regarding the impact of biological control agents on the weeds prevalence. For ease of reference this information is tabulated below and includes the percent of IAP species controlled at the various levels.

Table 5.3: The effectiveness of biological control research.

Degree of success of biological control (BC)	Number of IAP species	Percentage of species investigated for BC
Complete	10	14%
Substantial	19	26%
Negligible	14	19%
Not determined	9	12%
No data	21	29%
Total	**73**	**100**

If it is assumed that both complete and substantial degrees of control are considered as a success in terms of IAP management then investment into this project yields a success rate of 40%. Where a success rate refers to the percentage of instances where biological control implementation has resulted in very limited to no further need for future control (Rao *et al*, 2012). The assumption that both complete and substantial degrees of control can be considered as successful is taken as valid because under both of these circumstances the future level of investment into controlling these IAPs is very low. According to Roa *et al* (2012) a success rate of 14% and over can be considered as a valuable investment. Considering that 14% of the research of the Weeds Division has resulted in complete control and an additional 26% of the work resulted in substantial control, the investment into this work is taken as valuable. This assumption may be challenged by the point that in the cases of IAPs that have been substantially controlled a certain degree of control is still required. However, given that the degree of conventional control required is drastically reduced and the invasiveness of the IAP significantly deceased, the ability of the biological control agent to hamper the weeds spread can be taken as successful.

In comparison to the success rates of biological control, conventional control is not associated with any long-term sustained level of IAP management (Joubert, 2009). Rather, conventional control in the current period must be accompanied by control in the future since current efforts only work to manage existing infestations, which then have a chance to re-establish. Turpie and Heydenrych (2000) noted that re-establishment occurs as a result of the large seedbeds IAPs tend to produce, meaning that although the parent plants may be cleared now, seed will germinate and re-infest an area once conventional control has been ceased. In this regard, conventional control could be considered to have a very low rate of return in the long run.

Biological control research has effectively controlled 29 of the 73 weeds targeted by the ARC PPRI Weeds Research Division (Klein, 2011). Based on this, it can be determined that biological control research presents substantial value to the South African economy. This is especially the case given the low long-term success rate of conventional control measures. From a cost efficiency perspective, investment into biological control represents just over 2% of the total allocated budget for IAP control. From this 2% investment, 10 species of IAP have been brought under complete control and 19 have been brought under substantial control. In both of these cases the need for further conventional control has been drastically minimised. This represents control of 29 of the 336 species of invasive alien plants catalogued in South Africa. Although this represents only 8.6% of IAP species having been brought under control using biological methods, it is a notable success considering the focus of the Weeds Division on only 73 of these species to date. Conventional control in contrast is not responsible for the complete control of any of the 336 IAP species present in South Africa (Klein, 2011). Considering that approximately 98% of the IAP control budget is spent on conventional measures, the value of this form of control from a cost perspective is highly questionable.

Table 2 provides an analysis of the value of investment into biological control research based on four basic indicators that were identified. These indicators were chosen due to their relevance to factors considered by decision makers when deciding the most appropriate means of achieving a task.

Table 2: Set of indicators and means of assessment

Indicator	*Means of assessment*	*Biological Control Assessment (Yes/No)*	*Conventional Control Assessment (Yes/No)*
Cost efficiency	Does the work minimise cost of solving problem?	**Yes**	**No**
Long-term sustainability	Will the work result in a sustainable solution to the problem?	**Yes**	**No**
Employment creation and skills development	What is the extent and nature of employment creation opportunities produced?	**Limited** Mainly high end researchers and managers. Some low skill positions for monitoring and evaluation.	**Extensive** Mainly low skill opportunities for previously unemployed. Specifically women and youth.
Advance in scientific knowledge or capability	Does the work produce advances in national scientific knowledge database and capabilities?	**Yes** Fairly extensive advances supported	**No** Limited associated research and scientific development

Summary of recommendations

The following are the major recommendations of this study.

- Improve the post release monitoring on the impact of biological control agents,
- Improve the coordination between biological and conventional control measures,
- Improve the record keeping and data availability of the PPRI Weeds Division and Working for Water programme,
- Implement biological control measures for as many IAP species as possible and
- Increase the level of investment into biological control research through the ARC PPRI.

Final Remark

Van Wilgen *et al* (2001) stated that biological control offers substantial benefits in the control of IAPs. Although there is debate regarding the trade-off between conventional and biological control methods it appears that biocontrol offers the best, most cost effective, tool for IAP management

(Hill & Greathead, 2000). It is suggested that labour intensive control strategies are likely to prove unsustainable in the long run and that, should long-term management strategies not be put in place now, the problem of IAP invasion will increase in the future (Joubert, 2009). Zimmermann *et al* (2004) stated that any management programme should ensure that the cleared area does not become reinfested after control has been applied. This is however not the case with conventional methods of control, which require the same area to be cleared on a regular basis to prevent weeds from re-establishing. This occurs because conventional methods only target mature or adolescent plants but do not address the problem of large seed banks that develop in invaded areas, and therefore allows for continuous cycles of regermination and establishment of IAPs. Conventional methods should therefore be used as a strategy to control invasions that cannot be controlled using biological methods, but should not be viewed as a sufficient solution to the IAP problem (Van Wilgen & De Lange, 2011). The most viable solution appears to be the combined use of biological control wherever possible with conventional methods where not possible. Taking this approach would ensure that IAPs are successfully controlled at least cost to the South African economy, providing the opportunity for public investment into more holistic environmental public works programmes.

Zimmermann *et al* (2004) remarked that the opportunity that biological control presents is that once an agent has been released and established, it will remain in the environment (and will continue to control the target weed) until the target has been completely wiped out or properly controlled. No salaries need to be paid from year to year, all that is required is the initial investment to find, quarantine and release the agent. After that, the agent does all the work for free, by itself, *ad infinitum*. The strength of biological methods of IAP control is therefore its self-sustaining nature (Moran *et al*, 2005). This allows financial resources to be directed away from weed control in the long run and towards other more pressing issues that need more financial assistance – for example small farmer support. To identify and release an agent that will effectively control an invading species requires only a limited initial investment of human and financial capital – at the testing stage of the control process – after that the only costs incurred are breeding, release and monitoring costs, these generally being small and short-term in nature. Conventional control methods on the other hand require a continual investment of high levels of human and financial capital that places unnecessary economic strain where a cheaper more sustainable solution exists.

If one considers what an infestation of alien plants is, then it will be realised it is a biological invasion – the same as any infection of a host by a virus. To control the virus, a solution is needed that will not only work now but that will also build resistance and protect the host from further invasion at a later date (Van Wilgen *et al*, 2014). This is the opportunity that biological control presents. As Moran *et al* (2005) noted: "sustained long-term suppression of IAPs is not possible without biological control". Biological control offers the tool that is paid for now but from which the benefits will flow long into the future. Any plan for controlling IAPs that does not include a biological control component will prove unsustainable and expensive in the long run, as human based control will have to be continued until the invaders are completely wiped out. This will take years, and may prove impossible.

It is essential to remember that a cost to an environment or community is a cost to the economy (Naylor, 2000). This highlights the idea that the economy is broader than merely what takes place in the business sector. If considered in this way, biological control can be viewed more as acting to preserve an existing yet unaccounted for economic value than creating a new one (Hobbs, 2000). Yes, creating new economic value is highly important in today's society, however allowing the destruction of natural habitat, whether purposefully of through negligence – such as allowing the spread of IAPs – constitutes a destruction of existing value (Naylor, 2000). The value lost is exceedingly difficult to restore even if replaced by conventional business. This is a point that is difficult for many people to reconcile, given our desperate need for economic development. However, if the general perception of the natural environment as a resource to be exploited to achieve an economic end can be changed, and instead viewed as an essential base for any sustained social progress, then it is possible to create a space where millions of people can subsist and thrive. Not everyone needs to live in a city, and not all jobs need to be located there – appreciating and harnessing the value of our natural environment and the operation of the informal sector can create a space where people can solve their own problems and develop themselves, without the need for a donation.

The work of the ARC PPRI Weeds Research Division is therefore supported as an extremely valuable activity for the South African economy, society and environment. Although there exists limited quantitative evidence to support this finding, the available literature on the effects of biological invasions, biological control, and the relationship between environmental integrity and economic prosperity all point to the research of biological control methods as an exceptionally valuable activity. The study therefore recommends that the Division receives increased financial support in order to expand its research capacity and scope. This should be complemented by improved monitoring of control agents, and coordination with conventional control measures. Concurrently, it is suggested that the Working for Water begins a shift in focus away from its role as a public works programme, and more towards environmental rehabilitation and improvement. This would support the creation of employment in a more diverse range of fields, with greater upward social mobility into the environmental sector, which can become a major area of future growth in South Africa.

Table 5.2: Cost Efficiency Comparison between Biological and Conventional Invasive Alien Plant Control (All figures in 2014 $).

Period	Biological Research Budgeted Cost (x)	Biological Implementation Budgeted Cost (y)	Total Biological Budgeted Cost (x + y) = a	Conventional Budget Cost (z)	Total Control Budget Cost (x + y + z) = b	Biological as % Total Cost (a/b)*100	Biological Research as % Total Cost (x/b)*100
1 Nov 2013 – 31 Mar 2014	**602190.16**	245658.30	**847653.00**	2425801.79	25105670.96	**3.38%**	**2.4%**
1 Apr 2014 – 31 Mar 2015	**1700688.69**	563053.29	**2263084.68**	68865526.36	71128611.04	**3.18%**	**2.4%**
1 Apr 2015 – 31 Mar 2016	**1811196.81**	575230.60	**2386863.30**	69317063.82	71702802.70	**3.33%**	**2.53%**
1 Apr 2016 – 31 Mar 2017	**1790343.94**	622529.36	**2411981.35**	73060203.93	75467293.58	**3.2%**	**2.37%**

*Figures are VAT inclusive

Mean Biological control as % Total Cost = 3.27%

Mean Biological Research as % Total Cost = 2.43%

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