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The adequacy of alien plant species distribution data: implications for implementing efficient control programmes

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Melodie, Pls add to the above. Thx

ABSTRACT

Successful long-term invasive alien plant control programmes rely on alien plant distribution and abundance data to assess, prioritise, implement and monitor the efficacy of the programme. Here we assess the impact of data accuracy using the alien plant programme in Table Mountain National Park, South Africa. A systematic plot-based survey method was carried out to assess the distribution of alien plants in the park at a fine scale (systematic sampling). Alien plant richness, total area invaded and the degree of spatial overlap in species' presence was compared between the systematic sample and a protected area (PA) managers' dataset (collated from collective observations by park visitors, rangers and managers) and Working for Water (WfW) project data (data collected for the planning and implementation of the alien plant clearing programme) using a range of confusion matrix-based statistics to assess similarity and error rates between the datasets. A total of 106 alien plant taxa were detected across the three datasets, 12 in PA manager's data, 23 in WfW data and 101 in the systematic survey. Overall, there was substantive disagreement between the datasets on the distribution of alien plants. For example both management datasets estimated species' hectare coverage at orders of magnitude greater than indicated by systematic sampling. The inaccuracy of manager data has direct negative implications for funding allocation, which currently appears to be in excess of what is required. We recommend that contrary to perception, fine-scale surveys are a cost-effective way to inform long-term monitoring programmes and improve programme effectiveness.

Keywords: control programme, confusion matrix, invasive species, protected area management, systematic distribution sampling

INTRODUCTION

Protected areas (PAs) have been established as part of a core approach to biodiversity conservation and maintenance of functional ecosystem processes (Barr et al. 2016; Dudley and Parish 2006; Watson et al. 2014). PAs are complex ecological systems and PA managers require high quality and up-to-date information to effectively manage these areas for their intended conservation mandates and objectives (Biggs et al. 2003; Pressey et al. 2015). One of the primary threats to biodiversity in PAs is the invasion and persistence of invasive alien plants (Foxcroft et al. 2013a; Foxcroft et al. 2013b; Spear et al. 2011). For example, invasive alien plants can change community structure (Holmes and Cowling 1997), alter energy, nutrient and water flows (Ehrenfeld 2010; Le Maitre et al. 2002) and modify disturbance regimes, especially fire (Alba et al. 2015; Brooks et al. 2004). In most cases, once an invasive alien plant has established, it cannot be removed unless through large control efforts or only at substantial cost (Foxcroft et al. 2013a; McConnachie et al. 2012; van Wilgen et al. 2012b), resulting in permanent effects on native biodiversity (Kettenring and Adams 2011).

There are many potential pathways by which alien and potentially invasive alien plants can be introduced into PAs (Foxcroft et al. 2008). Some PAs have to contend with a legacy of deliberate alien species introductions prior to PA proclamation or as part of the current management practices of a PA in the form of forestry plantation or at tourism facilities (Kueffer et al. 2013). Protected area managers are therefore required to continually detect, control or eradicate a range of existing alien plants, and develop strategies to prevent or appropriately respond to the arrival of new alien species that could exacerbate current threats (Pyšek and Richardson 2010).

An invasive alien plant control programme typically comprises a set of actions to achieve objectives that are guided by the strategic aims or goals of the programme (Foxcroft 2009; Tu 2009; Wittenberg and Cock 2001). To implement an effective control programme, PA managers need to consider the achievability of specific objectives, goals and outcomes. Often compromises and prioritization of objectives and goals are required due to constraints on time, financial and other resources, lost opportunity costs and conflicting priorities (Donlan et al. 2015; Roura-Pascual et al. 2011; Roura-Pascual et al. 2009). However, the type and quality of information used to guide prioritization, decision-making and monitoring is an integral, yet often overlooked, component of control programmes (Foxcroft 2009; Gardener et al. 2010; McConnachie et al. 2012; van Wilgen et al. 2012b).

South Africa has a long history of invasion by alien plant species, driven by a range of complex global, local, social and ecological interactions (Le Maitre et al. 2004). Many introduced species are well-established and substantial negative impacts on biodiversity and ecosystem services have been documented (Kotzé et al. 2010; Nel et al. 2004). 'Working for Water' (WfW) is a nationally funded invasive alien control programme that aims to restore and maintain habitat structure and function to mitigate the loss of ecosystem services, especially water production (van Wilgen et al. 2012a) through creating employment opportunities and facilitating skills development that contribute to poverty alleviation.

WfW has historically invested (1995 – 2015) approximately ZAR 564 million (1 US$ ~ 15 ZAR in 2015) in South Africa's PA's (van Wilgen et al. 2012a; van Wilgen et al. 2016). Despite the substantive investment in the programme, annual estimates of the clearing work required remain high, necessitating sustained large or increasing budgets. The WfW programme is implemented through projects at the PA level, undertaken as partnerships between PA managers and WfW project teams. For PA clearing projects to be efficient, data on alien plant species richness (McGeoch et al. 2012), the distribution of target species across the entire treatment area (Gardener et al. 2010; Pyšek and Richardson 2010; Wittenberg and Cock 2001), and a measure of the abundance of the populations are required (Dewey and Andersen 2004). Given the fundamental importance of spatial data for alien plant management, there are a variety of methods of data collection that have been developed and are currently being implemented in the WfW alien control programme. However, there has been no assessment of the best approach for data collection or the effects the various collection methods have. Given the large monetary investment, it is important to determine the role and effectiveness of various types of data in informing alien plant management programme efficacy.

In this study, the Table Mountain National Park (TMNP) is used as a case study to quantify the adequacy of datasets used in PAs for the management of invasive alien plants. Alien plant species richness, distribution and abundance data from three sources, (i) WfW project managers, (ii) invasions recorded by PA managers and (iii) a fine-scale, in-field systematic survey of alien plant species, were assessed. The assessment aimed to determine the relative error in estimates of the extent of invasion across TMNP from each of the different data sources and the possible role of this information in misinforming management plans and reducing clearing efficiency. The implications of discrepancies between the datasets are discussed and recommendations provided to improve data collection methods and the evidence base used for alien plant species management.

MATERIALS AND METHODS

A. Study Area

The Cape Peninsula, on the south western tip of South Africa, is a mountainous, topographically diverse area comprising a range of nutrient poor soils with high levels of species endemism of both plants and invertebrates (Cowling et al. 1996). About 2,285 plant species have been recorded, with 158 species being endemic (Helme and Trinder-Smith 2006). The Cape Peninsula has experienced a long history of human settlement with the establishment of the City of Cape Town, which has a population of over 3.7 million people (Statistics South Africa 2011). The TMNP was established within the urban matrix in 1998 to consolidate the management of remaining conservation-worthy land on the Cape Peninsula and currently covers about 250 km^2. For over a century the historical land-use and proximity to urbanization has facilitated the introduction and spread of numerous alien plant species into TMNP (Alston and Richardson 2006; Macdonald et al. 1985; Shaughnessy 1980; Spear et al. 2013).

The TMNP has an intensive long-term alien plant clearing programme in place that is currently implemented through the WfW Programme, and was previously implemented as part of the management function of the PA, employing semi-skilled labour, skilled private contractors and civil society volunteer groups (Macdonald et al. 1985). The current alien plant clearing programme is divided into three operational projects covering the northern, central and southern sections of TMNP. This study focused on the southern section of the PA which is the largest in both area, covering approximately 130 km^2, and also in funding allocated for alien plant control, which was ZAR R8.7 million for the 2013 financial year (Working for Water 2013). This section of TMNP has a history of woody alien plant species invasion spanning at least 70 years and has had management control programmes in place since the late 1980s (Macdonald et al. 1985; Taylor and Macdonald 1985; Taylor et al. 1985). Despite these programmes, annual estimates of the clearing work required remain high, necessitating sustained large budgets.

B. Alien Plant Management Datasets

The implementation of the TMNP alien plant management programme is based on data from two main sources: data collated by the PA managers who maintain records of alien species reported by park rangers and park visitors (hereafter the 'Management' data) and WfW project information, which includes a database of spatially linked historic clearing information (hereafter 'WfW' data). We generated a third dataset using a fine-scale systematic sampling approach to map the richness, distribution and density of all alien species in TMNP (hereafter the 'Systematic' data).

1. PA Managers Dataset – 'Management dataset'

Protected area managers are collectively responsible for implementing the daily operations of the park. At a group workshop in 2013, 11 managers from the park, were asked to consolidate current distribution records from SANParks' management datasets and add expert knowledge to distribution maps for all alien plant species that were common, or considered important for direct control or monitoring. The distribution of the alien plant species was delineated on a colour aerial map (scale 1:20,000) divided into the 0.70 km^2 polygons used for conservation management purposes. Where required, these management units were sub-divided to allow for finer-scale delineation per alien plant species or abundance variations. Protected area managers used three measures to estimate alien species abundance, resulting in a combination of percentage cover, density per hectare and descriptive measures (Appendix: Table 1). This resulted in the map being divided into 297 polygons that ranged in size from a relatively fine grain of 0.02 km^2 to a coarse grain of 0.71 km^2 (mean of 0.44 km^2), covering a total area of 130.75 km^2. The data were then captured in ArcGIS 10.x (ESRI).

2. Working for Water Dataset – 'WfW dataset'

Working for Water managers rely on a database of alien distribution information known as WIMS (Working for Water Information Management System) to guide the programmes' implementation. A key component of the WIMS system is the development of an annual plan of operations (APO). These APO's contain a detailed list of all alien plant species and their percentage cover that occur within a project area for a particular year. The project area is further divided into management clearing units known as nBals (National Biological Alien data). The alien species composition and cover for each nBal is updated annually through a combination of in-field visual assessments and rapid plot-based assessments. The WfW dataset for the area comprised 182 nBals which ranged from a relatively fine grain of 0.02 km^2 to a very coarse grain of 12.57 km^2 (mean of 0.71 km^2) and covered a total area of 125.50 km^2. Alien species distribution data (species presence and percentage cover; Appendix: Table 1) were obtained for each of these nBals for the 2013 project year.

3. Systematic Survey Dataset - 'Systematic dataset'

A dedicated survey team systematically sampled the southern section of the PA between April and November 2013. The survey was designed by overlaying the study area with a fine grain (0.02 km^2) sampling grid. A 500 m^2 circular sampling plot was placed at the centre of each grid cell. Within each plot all alien plant species were identified, and richness and abundance quantified. Where the number of individuals for a given species was less than 100, all individuals were counted; where the number of individuals was likely to exceed 100, three randomly placed sub-plots totalling 10 m^2 were sampled. All individuals within the sub-plots were counted and extrapolated by multiplying the mean to a full plot estimate. Where the growth form of the plants did not allow for individual counts (e.g. grasses and creepers), a percentage cover of the full plot was determined using six cover classes (Appendix: Table 1). All counts and cover estimates from the sample plot were extrapolated to the size of the full 0.02 km^2 grid cell for analysis.

Where a plot could not be established, for example where the centre of a grid cell was positioned on infrastructure or inaccessible terrain, the sample plot was located as close to the intended point as possible and the new Geographic co-ordinates recorded with a hand-held GPS unit (Garmin e-Trex) within an accuracy of 3 meters. A total of 5,276 plots covering a combined area of 126.40 km^2 were surveyed.

C. Dataset Comparisons

The three datasets had slightly different spatial extents and only the overlapping areas, which covered 125.15 km^2, were included in analyses. These included 295 of the 297 Management polygons and 176 of the 182 WfW nBals. The Management and WfW datasets were compared to the Systematic data in terms of (i) the alien plant species richness, (ii) the degree of spatial overlap in alien plant species presence and (iii) the recorded abundance and area invaded by selected alien plant species.

1. Species Richness within datasets

Species listed within each dataset were checked and verified for taxonomic accuracy and known presence (Spear et al. 2011). While most records contained species level information, some records were only identified to genus level (e.g. *Eucalyptus* spp.). For these cases, the records were grouped and treated as a single taxon (e.g. *Eucalyptus* spp.). The Systematic dataset included 12 extralimital species (e.g. *Afrocarpus falcatus* and *Aloe arborescens*) that were excluded from the analysis as they were not specifically recorded in the other datasets. To determine the accumulation rates of alien plants within the three datasets, the mean species accumulation curves, with 95% confidence limits, were plotted based on 100 randomisations using Estimate-S v 9.1 (Colwell 2013). Although not directly comparable due to the different sizes of the individual sample units, the mean, minimum and maximum species richness was calculated for each dataset to allow for overall comparison of the data for the study area.

2. Selection of taxa for comparison

The datasets were checked for species that were common to all three datasets. All records belonging to *Hakea* spp., *Pinus* spp. and *Eucalyptus* spp. in the Management and the WfW datasets were not consistently identified to the species level within these genera and as such were analysed at genus level. The datasets had five species in common identified to species level (*Acacia cyclops*, *Acacia longifolia*, *Acacia saligna*, *Leptospermum laevigatum* and *Paraserianthes lophantha*) which together provided eight taxa (species or genera) for comparative analysis. This selection included the taxa that are the primary focus of the alien plant control programme.

3. Degree of spatial agreement in taxa presence/absence between datasets

Taxa within each sampling unit were scored as present or absent. The degree of spatial matching in taxa presence was then assessed between the Systematic data and (i) Management and (ii) WfW datasets. As the PA managers and WfW data are captured in large polygons, the data from the small plots of the Systematic data that fell within the each polygon were pooled for analysis. To determine which plots from the Systematic dataset fell within each polygon, a standard spatial query in ArcGIS (10x) was performed.

The data were summarised as cross-tabulates where the Systematic data are regarded as the observed class and either the WfW or Management data the predicted class (Appendix: Table 2). The cross- tabulates were treated as a the confusion-matrix (Fielding and Bell 1997) where *a* is the number of sampling units in which the taxa were recorded in both datasets (*true presence*), *b* where only the Management data or WfW dataset recorded the taxa (*false presence*), *c* where only the Systematic dataset recorded the taxa (*false absence*) and *d* where the taxa was not recorded in either dataset (*true absence*). A range of confusion matrix-based statistics (Accuracy, Prevalence, Sensitivity Specificity and Odds Ratio; Appendix: Table 3 for definition and formulas) were used to assess the degree of similarity and error rates between the datasets (Fielding 2007; Fielding and Bell 1997). In addition two measures of classification accuracy, Kappa (K), and the True Skill Statistic (TSS) (Allouche et al. 2006) were calculated to determine the proportion of specific agreement between the Systematic data and WfW data, and the Systematic data and Management data.

4. Total area invaded by taxa and baseline clearing costs

For each dataset the total condensed area covered was calculated by multiplying the taxon percentage cover in each base mapping unit by the area of that mapped unit (Marais and Wannenburgh 2008), which then expresses the area invaded as an equivalent of a 100% cover. Where Management data were expressed using a descriptive value, these abundance classes were converted to cover estimates by using the mid-value of the cover class (Appendix: Table 1). These mid-point cover estimates have the potential to over or under estimate the cover values and thus the total condensed area. The effect of this was minimised by having a narrow range of cover values available within a class (e.g. 1-10% for low density classes while for higher density sites the over or under estimate is limited by the small size of sample units (0.02 – 0.03 km^2).

The WfW data are recorded as percentage cover per taxon and therefore these values were used as recorded. The Systematic data density counts were converted to cover values using the WfW Norms and Standards tables (Le Maitre and Versfeld 1994). Each sample unit from the Management dataset and WfW dataset was paired with the Systematic dataset and the total condensed area calculated for the Systematic dataset. The differences between the datasets were tested using a Wilcoxon Signed-Rank Test for paired samples, with the pairs being the sample units.

For each dataset the condensed areas were calculated for each taxon and for all taxa together to compare the estimated clearing costs that would be derived from each dataset. Estimations were based on current 2016 WfW norms and standards of 24.65 person days per hectare (0.01 km^2) required to clear adult alien plants at 100% cover

(Neethling and Shuttleworth 2013) multiplied by the daily WfW programme's person-day cost of R250 per person per day.

RESULTS

1. Alien plant species richness

A total of 106 alien plant taxa from 71 genera were recorded from all three datasets (Figure 1, Supplementary data: Table 1). The most taxa (101 taxa, 95% of the total) were recorded through systematic sampling, followed by the WfW dataset (23 taxa, 22%). The Management dataset had the fewest taxa (12 taxa, 11%). The Management and WfW datasets comprised mainly woody species (9 out of 12, and 15 out of 23 taxa respectively), while woody species accounted for only 38 of the 101 taxa in the Systematic dataset. Only nine taxa (8% of the total) were recorded in all three datasets (Figure 1).

The Systematic dataset had more species in common with the WfW data than the Management data, with 19 (including 14 woody species) of the 106 species in common, but 81 (76%) of the alien plant taxa in the systematic sampling dataset were not recorded in either the WfW or the Management data. The five species recorded in the WfW and Management datasets, but not in the Systematic dataset, comprised taxa only identified to genus level or species that only had a single location record.

The rate that taxa were recorded within the datasets was greatest in the Systematic dataset (Figure 2). After reaching a cumulative area of 2.5 km^2 there was no overlap in taxa richness between the Systematic dataset and either the WfW or Management datasets. The alien plant taxa accumulation curve approached an asymptote at approximately 10 km^2 (12% of the total study area) for the Management data, while the WfW dataset continued to accumulate taxa until 120 km^2 (95% of the study area) and the Systematic dataset did not reach an asymptote for the study area.

2. Degree of spatial agreement in taxa presence/absences between datasets

2.1. Management and Systematic dataset

In the Management dataset, at least one alien taxon was recorded in each of the 295 polygons while the Systematic dataset recorded at least one alien taxon in 266 of the 295 polygons (90%, Table 1 and Table 2). According to the Management dataset, *Acacia cyclops* and *Acacia saligna* were widespread in the study area (recorded in 282 and 285 of the 295 polygons respectively), while the Systematic dataset recorded these two species as being scattered in the study area (recorded in 195 and 198 of the 295 polygons respectively).

The overall agreement on alien plant spatial distribution for seven of the eight taxa was poor between the Systematic and Management datasets (Table 2), with the Kappa and TSS statistics less than 0.4, which is considered to be a minimum threshold designating good agreement (Landis and Koch 1977). Although there was agreement on spatial presence (sensitivity scores >0.9; Table 2) for widespread taxa (e.g. *A. cyclops* and *A. saligna*), there was low agreement on absence (specificity scores = 0.06) for these taxa. Localised taxa (e.g. *Acacia longifolia, Leptospermum laevigatum*) showed opposite trends with high agreement of absence (specificity scores >0.8; Table 2) and fair agreement of presence (sensitivity scores >0.4; Table 2).

2.2. WfW and Systematic dataset

When comparing the WfW and Systematic datasets, at least one alien taxa was recorded in each of the 176 WfW sample units compared to 174 of the 176 WfW nBals for systematic data (Table 1 and Table 3). In the WfW dataset, only *A. saligna* was recorded as widespread, with *A. cyclops* and *A. longifolia* recorded as scattered within the study area and the remaining five taxa having localised distributions.

Overall, the agreement between the Systematic and WfW datasets for all eight taxa was very poor (Table 3), with the kappa and TSS statistics for all eight taxa lower than 0.4. The WfW dataset was similar to the Management dataset, where widespread species had agreement on presence (sensitivity scores >0.9; Table 3), while the agreement on absence was variable (specificity scores 0.37-0.69; Table 3). For localised taxa, the WfW dataset recorded generally good agreement of absence (specificity scores >0.8) while the agreement of presences was generally low (sensitivity scores <0.25). Overall the dataset recorded a mismatch in the distribution of the taxa analysed.

3. Total invaded area by taxon and baseline clearing costs

In the Management dataset the total condensed area invaded by all alien plant taxa was 28.44 km^2 (equivalent to 22.7% of the study area; Table 4). This was significantly more than the total condensed area of 2.43 km^2 in the Systematic dataset (equivalent to 1.9% of the study area; Table 4: Z=-14.711, p<0.001, r=0.606). All taxa, both widespread species such as *A. cyclops*, *A. saligna*, and localised species such as *A. longifolia* and *Pinus* spp., showed marked, highly significant differences (Table 4; p<0.001) in total condensed area invaded, with the Management dataset consistently reporting higher condensed area across all taxa (Figure 3).

The condensed area of all alien plants in the WfW data totalled 15.84 km^2 (equivalent to 12.6% of the study area), which despite being 45% less than the Management dataset, was still significantly greater than the condensed area recorded in the Systematic dataset (Z=-9.622, p<0.001, r=0.513, Table 5). Like the Management dataset, the WfW data recorded widespread taxa such as *A. cyclops* and *A. saligna* as having significantly greater condensed areas (p<0.001, Table 5) compared to the Systematic data. The majority of localised taxa (e.g. *A. longifolia*, *L. laevigatum* and *Paraserianthes lophantha*) had similar condensed density estimates in the two datasets (Table 5; Figure 3), but their spatial locations were poorly matched.

Overall there was a large discrepancy between the Systematic and WfW data in the estimated budget required to control all invasive alien plants. The Systematic data estimated a requirement of ZAR1.5 million while the WfW data produced a budget estimate of ZAR9.8 million (Figure 4). The discrepancy in required budget to treat alien invasive plants was similar for individual taxa. For example, *A. saligna* in the Management dataset had a total condensed area of 10.78 km^2 and the WfW dataset had a total condensed area 12.85 km^2, while the Systematic dataset recorded only 1.36 km^2 total condensed area (Tables 4 & 5). Cost estimates to treat *A. saligna* derived from the Management data would be ZAR6.64 million and ZAR7.92 million from the WfW data (Figure 4). A costing based on the Systematic data indicates that a reduced budget of R0.84 million would be adequate to treat this species.

DISCUSSION

Understanding the inherent strengths and weaknesses in data that are used to inform decision making will influence the long-term outcomes and sustainability of invasive alien plant management programmes (Cook et al. 2009) as the accuracy of the data has a direct effect on the quality of management decisions made for control programmes. Although the accuracy of data collection is consistently emphasised in invasive alien plant control programmes globally (McNaught et al. 2008; Rew and Pokorny 2006), these data do not often meet the specific needs for which they are collected (Cook et al. 2009) or inappropriately applied to multiple objectives due to budget and time constraints. However there are seldom multiple datasets available for PA managers to assess the extent to which data types and sources impact on achieving the desired outcome. In this study, the data compiled from three sources in TMNP allow for such detailed analysis.

The positive relationship between grain (size of the minimum mapping unit) and resultant species distribution (area of occupancy) (Foxcroft et al. 2009; McGeoch and Gaston 2002) was not properly considered in the Management and WfW datasets. While the datasets agreed on the occurrence of the most common invasive species at a landscape or PA scale (course grain) at a finer grain, the systematic sampling approach listed significantly more alien species, smaller distribution ranges of species and lower abundance of the common, wide-spread species. Not accounting for coarse grain of mapping when estimating area occupied by alien species has significant consequences for the management of alien species in terms of resource allocation and budget and can lead to the failure or delayed success of a control programme (Rejmánek and Pitcairn 2002; Wilson et al. 2013).

The similarity in the species and their abundance collected by PA managers and WfW project managers is not unexpected. The WfW programme prioritises the control of the most abundant, widespread and thus visible species in the PA, which would also be known to the PA managers. However, the long-term success in controlling or eradicating invasive plant species requires an integrated approach (Foxcroft and McGeoch 2011). This includes prevention, early detection and rapid response being implemented in conjunction with on-going control efforts to enable a cost-effective and long-term viable approach (Hulme 2006; Simberloff 2009; Tu 2009; van Wilgen et al. 2011). Investing in fine scale and accurate data on alien species within PA's would inform all of these objectives. However, PA managers often prefer experience-based information for decision making (Cook et al. 2009; Pullin et al. 2004), and even when presented with evidence-based data are reluctant to alter their decisions (McConnachie and Cowling 2013). The inherently social context of the PA decision making environment (including PA's policies, management structure, stakeholder base, priorities and capacity) is one of the main reasons given for not implementing evidence-based actions (Ntshotsho et al. 2015). In addition, the over-prediction of species presence in control programme plans may appear inconsequential to a manager with a risk averse mind-set, who perceives inclusion of false presences as preferable to missing invasion sites (false absences), though we show the latter also has risks associated. Shortfalls in the current PA manager and WfW datasets and their consequences for effective and efficient alien management are discussed below.

1. Incomplete species lists

Large scale alien control programmes typically target common species due to information available to inform programme development and control plans. Incomplete alien plant species lists however may result in less common species being undetected within a PA (McGeoch et al. 2012), losing opportunities for eradication of small populations before they become widespread (Leung et al. 2002; Rejmánek and Pitcairn 2002). For example, the systematic sampling found *Callistemon salignus* (white bottlebrush) and *Centranthus ruber* (red valerian) occupying a few sites, totalling around 0.01 km^2 that could be targeted for eradication. As urban development and human populations increase around parks, adding to the pathways for alien species, the importance of accurate alien species listing is heightened (Alston and Richardson 2006; Spear et al. 2013). The systematic sampling recorded nine species of ornamental garden plants occurring in the PA, along its urban boundary, that were not listed in the WfW or PA mangers datasets (Supplementary material: S1).

Complete species lists are also important to enable prioritisation and risk assessment (McGeoch et al. 2012). Currently the data from the PA managers or WfW cannot be scaled up to the organisational level to accurately inform national and international indicators relating to species richness and rates of new species arrival1. This results in a missed opportunity that the WfW project can play in the global management of alien species and responses to global targets (McGeoch et al. 2010). Due to the strength of the systematic sampling approach, the Systematic data can readily be integrated with existing alien species lists at a national and international level (Foxcroft et al. 2017; Spear et al. 2011).

2. Species distribution and grain of data collection

Common pitfalls of control programmes include the ability to adequately detect target species prior to treatment and the lack of detection when re-infestation of the treated area from adjacent non-treated areas occurs (Rejmánek and Pitcairn 2002). The course grain of the Management and WfW data that are currently used in the PA's alien plant control programme suffer from both these deficiencies. Inadequate detection of the spread of a species across the PA in these management datasets means that new or expanding populations will go undetected. For example, the systematic sampling recorded 41 additional sites for *A. longifolia* where the species had historically not been recorded Coarse (large) grained data overestimated the occupancy of taxa in this study. Consistent over-estimation of occurrence of widespread species such as *A. cyclops* and *A. saligna* in the management datasets can result in overstating the core invaded area while inadequately delineating outlying satellite areas (He and Gaston 2000; McGeoch and Gaston 2002). Data used by WfW and PA managers to direct the control of alien invasive plants therefore cannot be used to monitor and evaluate of the effectiveness of control within monitoring frameworks, for example the Thresholds of Potential Concern Adaptive Management framework (Foxcroft 2009).

3. Inaccuracy in estimation of species abundance

Measures of abundance (number of individual plants per unit area) are important for developing and monitoring the strategic goals of invasive plant control programmes through understanding the nature and scope of management interventions relative to the impact that the species will have (Latombe et al. 2016). Key actions recommended for alien plant control programmes include (1) reducing the residency time of new invaders, (2) identifying, and focusing on areas of high propagule pressure and (3) maintaining or locally eradicating invaders from lightly invaded areas (Tu 2009). Due to the incorrect abundance estimates in the WfW and Management data, inefficient application of control methods, improper prioritisation of target areas, and misallocation of resources can be expected. The substantial overestimate of costs resulting from WfW data, when compared to systematic sampling data, illustrates the potential extent of the problem. One might expect that a risk adverse approach of overestimating the workload would ensure that areas are completely cleared of alien species. However, the project area still has a wide occurrence of alien species present which means that the currently inflated budget maybe obscuring the appropriate or more effective control methodologies. The misalignment of resource allocation can have long-term negative implications for a control programme where budgets and resources are often limited (Krug et al. 2010; Moore et al. 2011).

Benefits of Systematic Sampling

In managing alien control programmes there is often a budget trade-off between funds available for field sampling and control operations, with intensive sampling being avoided due to the time constraints, costs, and resources required (Hauser and McCarthy 2009). While a variety of invasive alien plant survey are warranted depending on the management objectives (Dewey and Andersen 2004), survey approaches for alien plant programmes covering large areas should emphasise accurate, consistent and repeatable methodologies (McNaught et al. 2008). Currently both the WfW and PA managers approaches fall short of these requirements and produce a skewed picture of the effort and resources required. The poor distribution and abundance from the WfW and PA manager data results in the continued motivation for project budgets ZAR7.2 million per annum in excess of what would likely be appropriate if more targeted management could be effected.

In addition to the systematic sampling addressing shortfalls in accuracy, this approach enables comparisons to be made across time and as needed through repeated data collection. This will allow for better understanding and management of alien plant species, as the systematic sampling accurately determines where alien plant species are not present in the PA, either though successful control over time or that these areas have not yet been invaded. The systematic mapping exercise cost approximately ZAR100,000 (<0.1% of the control budget at the time). We propose that when viewed in comparison with the potential budget savings enabled by more accurate plans, the systematic sampling approach is a very cost effective addition to the current management approach that provides data from that can readily feed into local, national and international monitoring programmes.

CONCLUSION

Differences in alien species datasets are expected due to differences in the purpose for and scales at which data are collected. However, as we illustrate here, the urgency of required management actions often results in implementation prior to gaining a full understanding of the problem. Our systematic sampling provided estimates of species richness and abundance that differed by orders of magnitude from the data that are used to make management decisions. While managers may perceive the time and cost required to undertake detailed landscape-scale surveys as wasteful when something could be done about the problem in the interim, we argue that properly assessing the true scope of the problem is critical to optimizing the impact of control work and outputs for budgets spent. Fine-scale alien plant surveys can be used to establish baseline alien plant species information that is suitable for implementing long-term monitoring programmes to assess change as a result of management interventions and environmental factors. This would overcome the current situation where existing management datasets do not allow for the determination of the source, extent, dynamics and realistic clearing costs of alien plants.

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Tables and Figures

List of Tables

Table 1. Dataset summary for the Management, Working for Water (WfW) and the Systematic datasets.

	Management	**WfW**	**Systematic**
Total extent of survey area	130.75 km^2	125.50 km^2	126.40 km^2
Number of polygons	297	182	5,276
Polygon size range	0.02 km^2 - 0.71 km^2 (mean 0.44 km^2)	0.02 km^2 - 12.57 km^2 (mean of 0.71 km^2)	0.02 km^2
Species per sampling unit	Total: 12 Min: 1 Max: 7 Mean: 3.0 (SD=1.40)	Total: 23 Min: 1 Max: 6 Mean: 2.2 (SD=1.37)	Total: 101 Min: 0 Max: 16 Mean: 0.79 (SD=1.51)
Number of polygons occupied by alien plants out of the total polygons for that dataset	297 (100%)	182 (100%)	2,151 (41%)
Range occupied (all species)	130.75 km^2	125.50 km^2	43.02 km^2
Time period collected	All records known by PA managers as at July 2013	January – March 2013	April to November 2013

Table 2: Presence and absence of selected taxa recorded in the Systematic and Management datasets (n= 295). S+ indicates presence in the Systematic data; S- indicates absence in the Systematic data; M+ denotes presence in the Management data and M- denotes an absence from the Management data, with the resulting confusion matrix measures (defined in Appendix: Table 3).

Taxa	M+ S+ (a)	M+ S- (b)	M- S+ (c)	M- S- (d)	Accuracy	Prevalence	Sensitivity	Specificity	Odds Ratio	Kappa (K)	TSS
All taxa	266 90%	29 10%	0 0%	0 0%	0.90	0.90	1.00	0.00	NS	0.00	0.00
Acacia cyclops	188 64%	94 32%	7 2%	6 2%	0.66	0.66	0.96	0.06	1.71	0.03	0.02
Acacia longifolia	43 15%	38 13%	41 14%	173 58%	0.73	0.28	0.51	0.82	4.77	0.34	0.33
Acacia saligna	194 66%	91 31%	4 1%	6 2%	0.68	0.67	0.98	0.06	3.20	0.05	0.04
Eucalyptus spp.	9 3%	19 6%	21 7%	246 84%	0.86	0.10	0.30	0.93	5.55	0.24	0.23
Hakea spp.	0 0%	2 1%	37 12%	256 87%	0.87	0.13	0.00	0.99	0.00	-0.01	-0.01
Leptospermum laevigatum	15 5%	32 11%	20 7%	228 77%	0.82	0.12	0.43	0.88	5.34	0.27	0.31
Paraserianthes lophantha	19 6%	47 16%	27 9%	202 69%	0.75	0.16	0.41	0.81	3.02	0.19	0.22
Pinus spp.	55 19%	31 11%	30 10%	179 60%	0.79	0.29	0.65	0.85	10.59	0.50	0.50

Table 3: Presence and absence of selected taxa recorded in the Systematic and WfW datasets (n = 176). S+ is presence in the Systematic data; S- is absence in the Systematic data; W+ is presence in the WfW dataset and W- is the absence in the WfW dataset with the resulting confusion matrix measures (defined in Appendix: Table 3).

Taxa	W+ S+ (a)	W+ S- (b)	W- S+ (c)	W- S- (d)	Accuracy	Prevalence	Sensitivity	Specificity	Odds Ratio	Kappa (K)	TSS
All taxa	174 99%	2 1%	0 0%	0 0%	0.99	0.99	1.00	0.00	NS	0.00	0.00
Acacia cyclops	61 35%	19 11%	54 30%	42 24%	0.59	0.65	0.53	0.69	2.50	0.19	0.22
Acacia longifolia	24 13%	12 7%	61 35%	79 45%	0.59	0.48	0.28	0.87	2.59	0.15	0.15
Acacia saligna	142 81%	17 10%	7 4%	10 5%	0.86	0.85	0.95	0.37	11.93	0.38	0.32
Eucalyptus spp.	7 4%	10 5%	29 17%	130 74%	0.78	0.20	0.19	0.93	3.14	0.15	0.12
Hakea spp.	6 3%	5 3%	34 19%	131 75%	0.78	0.23	0.15	0.96	4.62	0.15	0.11
Leptospermum laevigatum	6 3%	8 5%	31 17%	131 75%	0.78	0.21	0.16	0.94	3.17	0.14	0.10
Paraserianthes lophantha	12 7%	16 9%	46 26%	102 58%	0.65	0.33	0.21	0.86	1.66	0.08	0.07
Pinus spp.	15 8%	7 4%	48 28%	106 60%	0.69	0.36	0.24	0.94	4.73	0.21	0.18

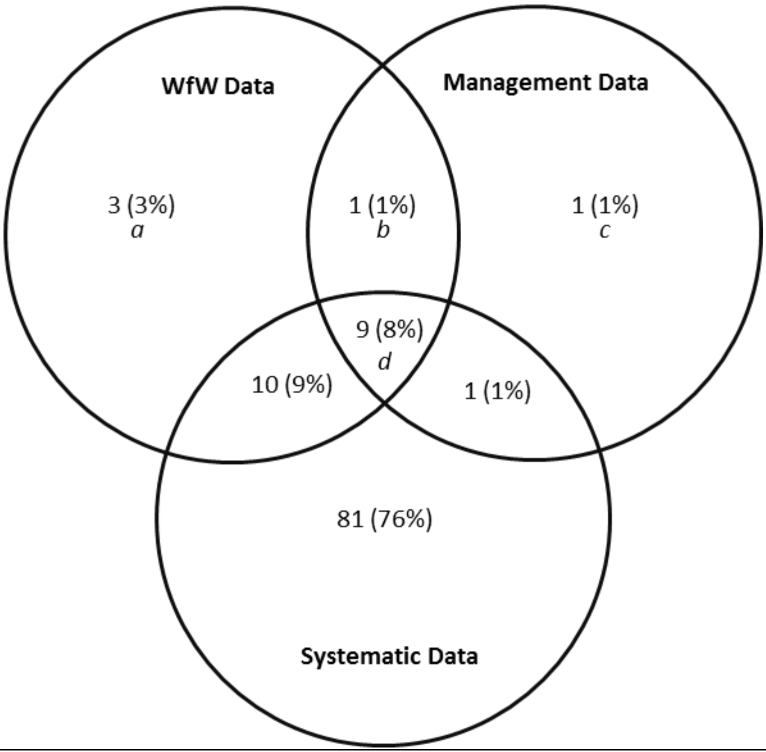
Table 4: Comparison of the total condensed area for selected taxa in the Management data (MD) and the Systematic data (SD).

Taxa	Mapping units (n)	Data-set	Total Condensed Area (km^2)	Mean (km^2)	Median (km^2)	*z*	*p*	*r*
All taxa	295	MD	28.44	9.64	4.26	-14.711	<0.001	0.606
		SD	2.43	0.82	0.13			
Acacia cyclops	295	MD	8.94	3.03	1.78	-14.504	<0.001	0.597
		SD	0.32	0.11	0.02			
Acacia longifolia	295	MD	3.19	1.08	0.00	-6.964	<0.001	0.287
		SD	0.52	0.17	0.00			
Acacia saligna	295	MD	10.78	3.65	0.71	-13.204	<0.001	0.544
		SD	1.36	0.46	0.02			
Eucalyptus spp.	295	MD	1.06	0.36	0.00	-3.437	<0.001	0.141
		SD	0.02	0.01	0.00			
Hakea spp.	295	MD	<0.01	<0.01	0.00	-4.521	<0.001	0.186
		SD	0.02	0.01	0.00			
Leptospermum laevigatum	295	MD	0.44	0.15	0.00	-4.616	<0.001	0.190
		SD	0.07	0.02	0.00			
Paraserianthes lophantha	295	MD	0.80	0.27	0.00	-6.228	<0.001	0.256
		SD	0.08	0.03	0.00			
Pinus spp.	295	MD	3.24	1.10	0.00	-7.962	<0.001	0.328
		SD	0.06	0.02	0.00			

Table 5: Comparison of the total condensed area for selected taxa in the WfW dataset (WfW) and Systematic data (SD).

Taxa	Mapping units (n)	Data-set	Total Condensed Area (km^2)	Mean (km^2)	Median (km^2)	*z*	*p*	*r*
All taxa	176	WfW	15.83	9.00	3.80	-9.622	<0.001	0.513
		SD	2.43	1.38	0.56			
Acacia cyclops	176	WfW	2.00	1.14	0.00	-4.882	<0.001	0.260
		SD	0.32	0.18	0.02			
Acacia longifolia	176	WfW	0.54	0.30	0.00	-0.822	0.411 (NS)	0.044
		SD	0.52	0.29	0.00			
Acacia saligna	176	WfW	12.85	7.30	2.24	-9.495	<0.001	0.506
		SD	1.36	0.77	0.10			
Eucalyptus spp.	176	WfW	0.18	0.10	0.00	-0.191	0.848 (NS)	0.010
		SD	0.02	0.01	0.00			
Hakea spp.	176	WfW	0.03	0.02	0.00	-2.940	<0.01	0.157
		SD	0.02	0.01	0.00			
Leptospermum laevigatum	176	WfW	0.11	0.06	0.00	-1.213	0.225 (NS)	0.065
		SD	0.07	0.04	0.00			
Paraserianthes lophantha	176	WfW	0.08	0.04	0.00	-1.344	0.179 (NS)	0.072
		SD	0.08	0.04	0.00			
Pinus spp.	176	WfW	0.05	0.03	0.00	-3.643	<0.001	0.194
		SD	0.06	0.03	0.00			

Figures



a:
Cortaderia jubata
Metrosideros excelsa
Opuntia spp.

b:
Pinus spp.

c:
Hakea spp.

d:
Acacia cyclops
Acacia longifolia
Acacia saligna
Arundo donax
Eucalyptus spp.
Lantana camara
Leptospermum laevigatum
Paraserianthes lophantha
Pennisetum setaceum

Figure 1. The number of alien taxa unique to and shared between the three datasets; Systematic (101 taxa in total), WfW Dataset (23 taxa) and Management Dataset (12 taxa) with a total of 106 taxa across all data sets. See Appendix 1 for full species list.

(See Pdf)

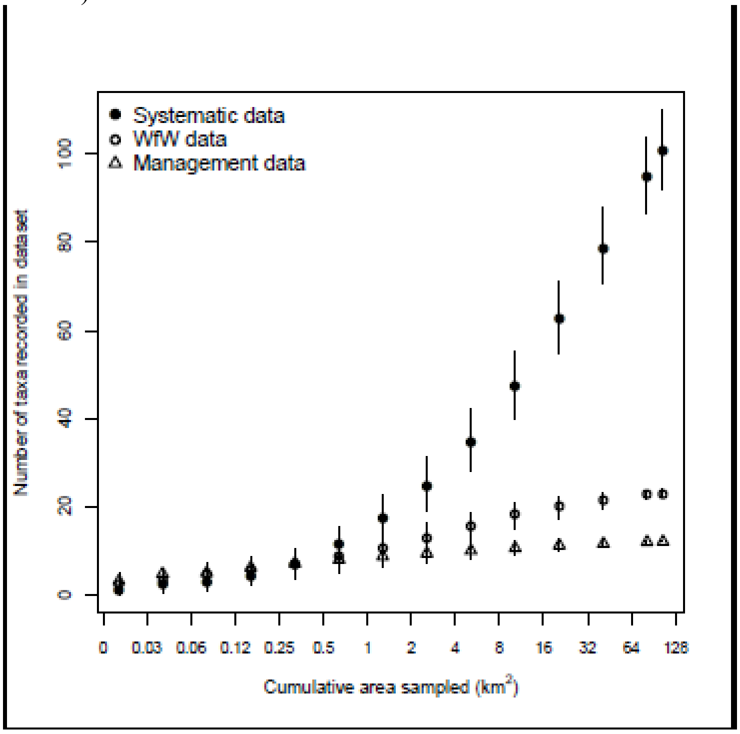


Figure 2. Mean alien plant taxa accumulation curves (100 randomisations) for the Management, Working for Water (WfW) and Systematic datasets plotted log (base 2; *x*-axis), with error bars indicating 95% confidence intervals as calculated with EstimateS (Colwell R.K., 2013).

31

(See pdf)

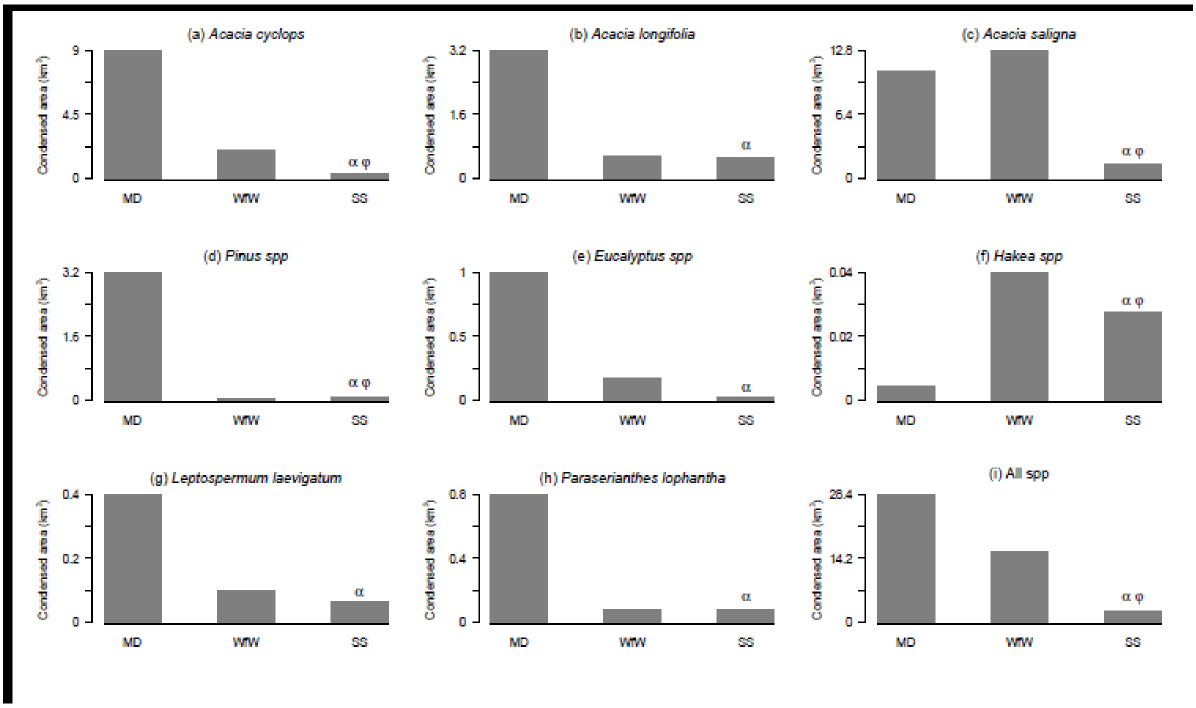


Figure 3. Total condensed area (km^2) for taxa in the Management (MD), Working for Water (WfW) and Systematic (SD) datasets where (α) indicates a significant difference between the Systematic data and the Management data (p<0.01; Table 4) and (φ) a significant difference between the Systematic data and the WfW data (p<0.01; Table 5).

32 (See pdf)

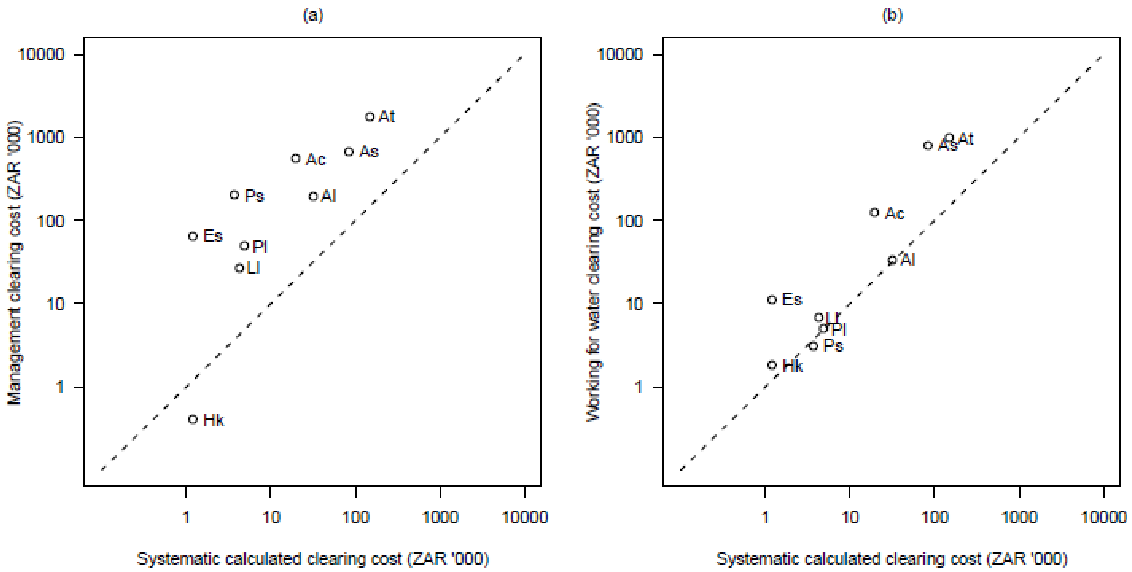


Figure 4.Calculated total clearing cost form the Systematic data and (a) the Management data and (b) the Working for Water (WfW) data. At-All selected taxa (combined); Ac-Acacia cyclops; Al-Acacia longifolia; As-Acacia saligna; Es-Eucalyptus spp.; Hs-Hakea spp.; Ll-Leptospermum laevigatum; Pl-Paraserianthes lophantha; Ps-Pinus spp.

Appendix Data

Table 1. Standardised classes used to group the relative measures of abundance (percentage cover, density and descriptive) for invasive alien plants invasions from the Management, Working for Water (WfW) and Systematic datasets

Standardized Abundance Class	Management: Descriptive	Management, WfW and Systematic: species cover (%)	Management: density (plants/ha)
0	Un-invaded	0	0
1	Rare	> 1%	<6
2	Occasional	1-10%	6 - 800
3	Scattered	11-25%	800 - 2,200
4	Medium	26-50%	2,200 – 7,600
5	Dense	51-75%	7,600 – 10,000
6	Closed	> 75%	> 10,000

Table 2: Confusion matrix (sensu – Fielding & Bell 1997) for comparing presence and absence data from the Management or WfW datasets to the Systematic dataset.

Taxa x		Systematic Dataset	
		Presence	Absence
Management or WfW dataset	Presence	*a*	*b*
	Absence	*c*	*d*

a, is the number of polygons where both datasets recorded a presence value (true presence);
b, is the number of polygons where the Management or WfW datasets did record a presence value (false presence);
c, is the number of polygons where the Management or WfW datasets did not record a presence value (false absence);
d, is the number of polygons where both datasets did not record a presence value (true absence); and
n = a + b + c + d

Table 3: Confusion matrix measures derived from the confusion matrix for the presence and absence data from the Management or WfW datasets and the Systematic dataset. Notation as per Table 2.

Measures	Formula	Description
Accuracy	(a+d)/n	proportion of correctly predicted polygons
Prevalence	(a+c)/n	proportion of presence records
Sensitivity	a/(a+c)	probability that the Management or WfW datasets will correctly classify a presence
Specificity	d/(b+d)	probability that the Management or WfW datasets will correctly classify an absence
Odds Ratio	ad/cb	ratio of correctly assigned polygons to incorrectly assigned polygons
Kappa (K)	$\frac{(a+d)-\{[(a+c)(a+b)+(b+d)(c+d)]/N\}}{N-\{[(a+c)(a+b)+(b+d)(c+d)]/N\}}$	specific agreement greater that chance (Fielding 2007)
True Skill Statistic (TSS)	(sensitivity + specificity) – 1	specific agreement greater that chance (Allouche 2006)