Systems for identifying invasive threats to New Zealand flora by using overseas plantings of New Zealand native plants

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Abstract

Monitoring pests and diseases of New Zealand native plants grown overseas could be a useful guide in predicting the possible effects of such pests if they were to reach New Zealand. The aim of the monitoring system is to improve the predictive power of biological invasions into natural ecosystems. An “expatriate” plant monitoring system would observe and characterise pests and diseases on overseas New Zealand flora. Four possible scenarios describing how monitoring plants grown overseas could be achieved were identified and the advantages and disadvantages of each scenario compared against selected criteria, such as quality of data, diagnostic capability, management of information, provision of short and long-term data and suitability. The relative importance of these criteria depends on the monitoring approach taken, which determines the final operating structure. In our view, a team of New Zealand researchers monitoring sites would provide the best operational structure for implementing an expatriate plant monitoring system. However, end users are encouraged to make their own recommendation and select an operating scenario which best serves their own biosecurity needs.

Keywords: expatriate plant communities, invasive species, risk prediction, pathways.

Introduction

In New Zealand about 80% of indigenous plant species are endemic (McGlone et al. 2001) and have largely evolved in isolation from herbivores and pathogens from other biogeographic regions. Due to this isolated development our endemic species are at greater risk than other native plants from harmful organisms. Pests or pathogens of plants related to New Zealand endemic plant species may pose a high risk (Ridley et al. 2000). A classic overseas example of an invasive pathogen severely affecting a highly susceptible native plant species was that of chestnut blight (*Cryphonectria parasitica*). The fungus did little damage to its natural host, an Asian chestnut species, but when introduced from Japan to North America in the 19th century it infected and killed most American chestnut (*Castanea dentata*) trees (Hepting 1974; Parker & Gilbert 2004). A more recent example is that of the Emerald ash borer (*Agrilus planipennis*), which entered the US from Asia in 2002 and is destroying most of their native ash species (e.g. *Fraxinus* spp.). It is not an important pest in its native range. However, pests with broad host ranges are also a threat to native plant species. For example, the polyphagous painted apple moth (*Teia anartoides* Walker) was identified as a threat to New Zealand's native vegetation, and following an incursion in New Zealand was recorded on New Zealand native host plants unrelated to hosts found in the pest's native range (Stephens et al. 2007). Because of similar and as yet unknown threats a worthwhile biosecurity goal is to undertake surveillance for invasive pest species that threaten native plants in natural and modified ecosystems The scale and inaccessibility of natural ecosystems puts constraints on what surveillance and eradication tools can be practically and economically deployed. Therefore novel approaches for determining which species represent a significant pest risk before they reach the border may be a more effective strategy.

In 2002, the US National Research Council proposed that plants native to the United States growing in other countries, such as in botanic gardens and arboretums, could be monitored in order to better predict which non-native pest and pathogen species might be a potential risk should they arrive in the United States (Anon. 2002). The term "expatriate plant communities" is used to describe this concept. The concept includes a measurement of the severity of the damage caused by the pest or disease species, as well as a summary of the factors that contribute to the damage in order to provide quantitative and qualitative information for constructing risk assessments. Overseas plantings of native species have been surveyed to inform the country of origin of potential risk organisms (Wylie & Floyd 1999), but the "expatriate plant communities" concept expands the development of an ongoing monitoring system across multiple sites.

This is the first attempt to design and begin testing the "expatriate plant communities" concept, which seeks to detect potential high-risk pests and diseases before they arrive in New Zealand by monitoring New Zealand plantings at multiple international sites on a long-term basis. The main objectives were to:

- identify where New Zealand plant collections are growing overseas,
- locate optimal sites by identifying regions of the world where temperatures and climatic conditions closely match those typically experienced by native plants growing in New Zealand,
- develop monitoring protocols and logistics of setting up a preliminary diagnostic system for identifying possible risk species,
- compare the nature and range of pest species associated with New Zealand plants growing overseas with records in New Zealand,
- assist with the long-term goal of building a database resource for predicting which exotic pests or diseases might damage New Zealand's natural estate, should they establish in New Zealand and,
- assess the value and suitability of running an expatriate plant monitoring system by identifying possible operational models.

The value of the concept has not previously been tested. Some limitations of the concept may include: the small area and number of specimens available in overseas plantings; the effects of intervention to maintain plant health by garden managers; the choice of 'robust' species or commercially developed varieties for amenity gardens; and the reliability of risk extrapolation based on novel overseas plant and pest associations. Potential limitations will be investigated in later publications. This paper outlines the development of monitoring protocols and then focuses on assessing the value and suitability of four operational scenarios capable of delivering a successful expatriate plant monitoring system.

Methods

Overseas collections of New Zealand plant

Overseas collections of New Zealand plants were located using printed literature, books, journals and news articles; personal knowledge and contacts of research members; and the internet. An emphasis was placed on well-managed sites such as botanic gardens, arboreta, research organisations and nurseries holding long-established collections of New Zealand plant species. A questionnaire was used to collate information on: the size of the New Zealand collection; number of species; origin of the plants; environmental conditions of the site; access to lists of plant species; areas of specialisation; collection databases; plant pests and diseases observed, damage caused, and any diagnoses.

Suitable locations were selected for monitoring based on climate matching and site criteria. Appropriate plant species to monitor were chosen based on the selection of indicator species using a climate matching procedure and species lists provided by overseas collaborators.

Sampling protocols and management of information

Sampling protocols for use by non-experts were developed and tested using informal visits to 14 overseas sites. Protocols contained guidelines for planning a site visit, examining plants, collecting specimens, delivering samples to overseas diagnostic collaborators and importing non-viable materials into New Zealand for identification and reporting results.

The project team constructed a database of overseas New Zealand plant collections that included pest and pathogen records. The database will eventually allow collaborators to add their own data, compare data between sites, and send alerts when new data are added in the future.

Evaluation of operational models

The data, logistics, economics and organisational details of implementing an operational expatriate incursion risk monitoring system were considered and four operational scenarios were identified. The annual cost for each operating scenario was estimated based on a number of assumptions, including: an annual inspection of one site each located in the UK, USA and Australia; all activities associated with a single survey would take between 5 and 16 days depending on the operational scenario; estimated costs for staff were based on a moderate daily rate of $800 NZD/day, including overheads; the cost for identifying samples from a single site were based on collecting 12 herbivore and 12 plant pathogen samples; and where costs were unknown an informed estimate was made. The estimates were calculated on travel and labour costings at January 2008 prices; future costings may differ. Annual inspections are not necessarily the best option in this case as viruses are often more evident in spring, fungal diseases are more obvious in autumn and insect populations more abundant in summer. The final number of inspections will depend on the chosen scenario.

The advantages and disadvantages of each scenario were compared against selected criteria such as, the delivery of high quality data on organisms of biosecurity risk to New Zealand's native estate, accurate and rapid diagnostic capabilities (including the identification of viable fungal or viral isolates which cannot be imported into New Zealand), simple and effective management of information, flexibility to provide accessible short-term and long-term data, and overall suitability.

For each criterion a subjective ranking was made from 1 to 4 (1 = poor and 4 = best), and added together to provide an overall score for each scenario. The relative suitability of each scenario was determined by comparing the total scores. The operating scenario with the highest total score was recommended.

Results and discussion

Collection sites and preliminary visits

Of the 110 overseas gardens approached 33 completed the survey form. From the information provided a short list (Table 1) of suitable locations was prepared. Indigenous plant species chosen for monitoring are listed in Table 2.

The sites visited during the development of sampling protocols are listed in Table 1. The number of NZ indigenous plant species in these gardens ranged from 12 to >300 and surveyors spent an average of 6 hours (ranging from 2 to 20 hours) examining the plants. Sampling protocols developed prior to the visits were found to be appropriate.

A total of 91 attacks were observed on expatriate New Zealand plants from the 14 site visits. Of these 32 pest taxa were identified. Mealy bugs, scale insects, nematodes and fungal pathogens were amongst the most commonly observed organisms. The majority of specimens needing further diagnosis had symptoms of infection by a plant pathogen. Given that there were relatively few site visits, with a correspondingly small dataset of diagnosed conditions, it would be premature to provide full species risk assessments or undertake predictive analyses until more detailed data are compiled.

Monitoring scenarios

The four possible scenarios describing how an expatriate system could operate were identified and the estimated annual costs (at January 2008), including overheads associated with each scenario for monitoring three overseas expatriate plant communities are outlined in Table 3. Costs include salaries, travel and accommodation, identification charges, report writing, database entry and database management.

Table 1. Recommended overseas New Zealand plant collection sites for future monitoring. Sites were ranked based on climate match index (CMI) and site selection criteria (e.g. level of damage, frequency of pest species, association with phlyogenetically related plants, long-term accessibility, site logistics, historical records, willingness to collaborate, etc.).

Overseas New Zealand plant collections	Country	CMI	Ranking
Royal Tasmanian Botanic Gardens[1]	Australia	0.93	1
Wakehurst Place, Kew gardens	UK	0.91	2
Royal Botanic Garden Edinburgh	UK	0.89	3
Royal Botanic Gardens Melbourne[1]	Australia	0.85	4
Ventnor Botanic Garden[1]	UK	0.86	5
Santa Cruz Arboretum	USA	0.77	6
Strybing Arboretum	USA	0.75	7
University of California, Berkeley Gardens	USA	0.75	8
Earlscliffe Garden Baily	UK	0.91	9
Washington Park Arboretum	USA	0.88	10
University of British Columbia Botanic Gardens[1]	Canada	0.80	11
Adelaide Botanic Garden[1]	Australia	0.75	-
Arktisch-Alpiner-Garten, Walter-Meusel-Stiftung[1]	Germany	0.86	-
Berlin-Dahlem Botanisch Garten and Museum[1]	Germany	0.85	-
Martin Luther University, Halle Wittenberg[1]	Germany	-	-
Mt Lofty Botanic Garden[1]	Australia	0.75	-
Brisbane Botanic Gardens - Mt Coot-tha[1]	Australia	0.80	-
Estação Agronómica Nacional (INRB) [1]	Spain	-	-
Harold L. Lyon Arboretum[1]	USA	-	-
Rennsteiggarten Oberhof[1]	Germany	-	-

[1]Sites visited (some more than once) during the development of sampling protocols discussed in this paper.

The advantages and disadvantages of each operational scenario were:

Scenario 1 – New Zealand expatriate team

The main advantage of this scenario is that New Zealand researchers may be more motivated to undertake detailed evaluations, especially if staff had time dedicated to this project for repeated visits to sites by the same individuals. One disadvantage is that it requires more international travel. Where relationships have been established with local diagnostic experts, samples could be passed to these local experts following each site visit. Where local experts are not available, samples would be brought back to New Zealand for analysis, resulting in additional permit costs and length of time to identify the pest or pathogen. This could be a problem because New Zealand workers may be identifying species that do not occur in New Zealand. However, New Zealand workers who diagnose organisms on a daily basis also have access to extensive international reference collections from different countries to support them. Despite this, more time may be required to validate the species from an overseas expert and check references due to unfamiliarity with the fauna of the country of origin if its flora and fauna are poorly described (e.g. Asia).

Table 2. Indigenous plant species chosen for monitoring. Species were selected based on (a) presence at each overseas garden, (b) reported insect pests overseas, (c) reported pathogens overseas, (d) culturally significant to Maori and (e) whether the plant species was threatened in New Zealand. Note: species names are based on records held by the overseas collection and are not necessarily the currently accepted scientific name.

Acaena novae-zealandiae	*Dacrydium cupressinum*	*Melicytus ramiflorus*
Agathis australis	*Dianella nigra*	*Metrosideros excelsa*
Alectryon excelsus	*Dicksonia lanata*	*Muehlenbeckia axillaris*
Aristostelia serrata	*Dicksonia squarrosa*	*Myostidium hortensia*
Asplenium oblongifolium/bulbiferum	*Dodonaea viscosa*	*Myrsine australis*
Astelia nervosa	*Entelea arborescens*	*Nothofagus* sp.
Beilschmiedia tarairi	*Gaultheria antipoda*	*Olearia paniculata*
Blechnum minus	*Gaultheria depressa*	*Pellaea rotundifolia*
Carex flagellifera	*Griselinia littoralis*	*Phormium cookianum*
Carmichaelia spp.	*Halocarpus kirkii*	*Phormium tenax*
Carpodetus serratus	*Hebe* sp.	*Phyllocladus trichomanoides*
Celmisia spp.	*Hebe buchananii*	*Pittosporum crassifolium*
Chionochloa spp.	*Hebe cupressoides*	*Pittosporum eugeniodes*
Clianthus puniceus	*Hebe salicifolia*	*Pittosporum tenuifolium*
Coprosma propinqua	*Hebe speciosa*	*Podocarpus nivalis*
Coprosma rhamnoides	*Kunzea ericoides*	*Podocarpus totara*
Coprosma robusta	*Leptospermum scoparium*	*Pseudopanax arboreus*
Cordyline australis	*Libertia ixioides*	*Pseudopanax crassifolium*
Corokia cotoneaster	*Libertia peregrinans*	*Pseudopanax ferox*
Corokia macrocarpa	*Libocedrus bidwillii*	*Rhopalostylis sapida*
Cortaderia spp.	*Libocedrus plumosa*	*Solanum laciniatum*
Corynocarpus laevigatus	*Lophomyrtus obcordata*	*Sophora microphylla*
Cyathea dealbata	*Macropiper excelsum*	*Tecomanthe speciosa*
Dacrycarpus dacrydioides	*Melicope ternata*	*Todea barbara*
		Xeronema callistemon

Scenario 2 – Overseas surveyors and diagnosticians

Overseas surveyors and diagnosticians may have limited knowledge of New Zealand plants, but may have better expertise for identifying local pests and pathogens. This familiarity could provide some time and cost savings. However, quality of diagnostic services vary between countries. An additional cost may also be an initial visit to the site by a New Zealand coordinator to establish contact with surveyors and diagnosticians, and in particular operate training sessions to standardise sampling protocols across sites. Regular visits by a coordinator may also help to encourage the collection of high quality data and maintain communication. The disadvantages of this option may include: a lack of commitment from non-New Zealand surveyors; a loss of control of the process and possibly limited knowledge of New Zealand plant species.

Table 3. Overview and estimated annual costs of four operational scenarios for the monitoring of selected expatriate plant communities in Australia, the UK and the USA, including the identification of pests and diseases from symptoms and the reporting of results.

Scenario	Estimated costs (NZD)	Role
1 – NZ expatriate team	\$91,000 – 106,000	A team of B3, MAFBNZ and/or DoC staff are employed to undertake the monitoring, including all identification and reporting.
2 – Overseas surveyors and diagnosticians	\$123,000 – 127,000	Contractors living near the overseas sites are employed to undertake the monitoring, including all identification and reporting.
3 – Reciprocal QUADs team	\$94,000	Each country from the QUADs partnership (Quadrilateral Scientific Collaborations) funds their own team to monitor selected sites within their own country in exchange for data collected from research teams undertaking similar monitoring overseas. Identifications and reporting of the results are undertaken by each team from each country and exchanged via a coordinated database. Note that the UK is not part of QUADs.
4 – Informal visits	\$67,000 – 70,000	Scientists, volunteers, MAF BNZ and DoC staff visit expatriate sites as side trips during other international travel (e.g. attending conferences, other business or during annual leave). Selected sites may not be monitored every year but a variety of other expatriate sites would be monitored.

Scenario 3 – Reciprocal QUADs team

Further collaborative development with Quadrilateral Scientific Collaboration (QUADs) partners (e.g. USA, Australia, Canada and New Zealand) has a number of advantages. Firstly, teams involved from reciprocal countries would expect a shared investment in terms of rigour and biosecurity focus. This ‘joint sense of purpose’ may counter the perceived lack of commitment from non-New Zealand surveyors identified in Scenario 2. Secondly, this scenario may provide stronger opportunities to develop a long term programme for risk assessment and predictive systems (Anon. 2002). Finally, local diagnostic expertise may be less costly as specimens could be identified locally, and include the advantages outlined in Scenario 2. The disadvantages of this scenario (as outlined for Scenario 2) are: a possible lack of commitment from overseas researchers, some loss of control of the process, limited knowledge of New Zealand plants. In particular, this collaboration would provide a limited geographic focus on North American and Australian sources of introductions thus excluding other potential geographic sources of pests and pathogens (e.g. Asia, UK). However, this scenario differs in that it is probable that the links established, and the ongoing communication that will ensue, would overcome the potential drawbacks. This scenario presents complex challenges in terms of management due to the involvement of multiple agencies from different countries, the amount of pre-planning required to standardise all the process and protocols, plus the development of a long-term funding strategy to continue existing work.

Scenario 4 – Informal visits
This scenario appears to be of lowest cost because international travel is incurred by other business funding. Subsequent costs, i.e. the processing and identification of samples, will be similar to those incurred for a targeted visit. An additional advantage of this approach would be that visits may not be restricted to the selected sites. This would provide additional data from a wider geographic and climatic range, which is an advantage for testing invasions due to climate change. Some disadvantages of this scenario are that: single visits to a site are unlikely to provide any depth of knowledge regarding the pest or pathogen's effects on a New Zealand native host. In addition, if particular sites were monitored each year this scenario may not be useful unless the gardens were close to common international ports, e.g. Sydney and London. This scenario is the least likely of the four to result in repeated visits to gain quality spatio-temporal data for addressing hypotheses about why and how invasions occur.

Deciding on which operational scenario to choose, in order to implement an expatriate plant monitoring system, depends on what information the end users value the most. For example,

1. If locating where invasions might originate (e.g. in order to block pathways or assess differences due to changes in climate) then sampling numerous high-risk sites less intensively would be of most value.
2. If predicting where an invasion may originate, why it occurs and how to avoid further incursions then a combination of the two approaches with a moderate number of high-risk sites selected (e.g. by defined risk criteria such as climate matching) and monitored reasonably intensively would be of most value.

An effective expatriate plant monitoring system should meet the expectations of biosecurity end users. The operating structures compared above consider criteria relevant mainly to the research outputs. Other criteria that are important to biosecurity endusers may also need to be considered.

Appropriate criteria for an effective expatriate plant monitoring system are: the quality of data, diagnostic capability, simple and effective management of information, flexibility to provide accessible short and long-term data, and costeffectiveness, although the relative importance of these criteria will ultimately depend on the end user's monitoring preferences (e.g. 1 or 2 above).

Quality of data
Scenarios 1 (New Zealand expatriate team), 2 (Overseas surveyors and diagnosticians) and 3 (Reciprocal QUADs team) are more likely to provide detailed spatio-temporal pest and disease data than Scenario 4 (Informal visits). Scenarios 1-3 would be given priority if intensive, repeated surveys by trained staff at high-risk sites is important to end users. Climate matching and candidate species work also identified the importance of targeted monitoring both in terms of site selection and New Zealand plant species composition. Informal visits are the least likely to provide detailed pest and disease data because individuals may lack strong observational skills, and brief surveys on a sporadic basis limit the opportunities to make repeated measures. Overall, scenario 1 is expected to provide the best data, but the variable quality of data collected using operational scenarios 2 and 3 could be addressed by using standardised processes and protocols.

Accurate and rapid diagnostic capabilities
The identification of pests and pathogens is of central importance to the expatriate plant monitoring system, thus having overseas collaborators identify samples on a casual basis is not optimal. For a successful long-term plant monitoring system, fixed overseas relationships may need to be established. Currently there is no formal international diagnostic network of laboratories. The establishment of a standardised approach (e.g. ISO certification or NATA) for the identification of overseas samples is particularly necessary for organisms such as fungi, which may require detailed isolation and morphological identification of living cultures. Pathogenicity testing including re-infection and re-isolation from the host plant may also be required in order to establish a causal relationship. Opportunities to carry out such procedures in New Zealand are limited due to import and ERMA requirements. Overall, scenarios 2 (Overseas surveyors and diagnosticians) and 3 (Reciprocal QUADs team) provided advantages for the rapid and accurate identification of specimens compared with scenarios 1 (NZ expatriate team) and 4 (Informal visits) because local diagnostic expertise would probably be better at identifying local pests and pathogens than New Zealand staff. Diagnostic capabilities would also be improved if agreements with accredited overseas diagnostic labs for the identification of specimens were made official and a formal international diagnostic network was established.

Simple and effective management of information
Each scenario requires a coordinator to manage and communicate the information collected by the expatriate plant monitoring system. The simplest operational structures to administer and retain quality control would probably be scenario 1 (NZ expatriate team) and scenario 4 (Informal visits) since only New Zealand staff are involved, aside from expert diagnosticians likely to assist with identifying specimens. Scenario 2 (Overseas surveyors and diagnosticians) and scenario 3 (Reciprocal QUADs team) would probably require a more complex organisational structure with greater input from a coordinator via workshops or training sessions to

establish standardised protocols across all sites, to control data variability, provide updates and act as the central contact point for the entire monitoring system. Scenario 2 (Overseas surveyors and diagnosticians) would require a coordinator in each country, in addition to a New Zealand coordinator, while scenario 3 (Reciprocal QUADs team) would require a coordinator for the whole QUADs programme in addition to each participating country having their own coordinator.

Flexibility to provide easily accessible short- and long-term data
The expatriate NZ plant database would be an important long-term component of the plant monitoring system. It may also be a valuable resource to a range of other programmes. Scenarios 2 (Overseas surveyors and diagnosticians) and 3 (Reciprocal QUADs team) would require the expatriate NZ plant database to be linked between national and international agencies. However, the data collected by multiple agencies would be more valuable than a database containing only references focused on New Zealand. Formal agreements between participating organisations from other countries would also ensure a greater commitment to share the monitoring information collected thus increasing access to both short- and long-term datasets that normally would not be available. Scenario 3 may provide a better system for maintaining the best long-term flexibility in accessing useful data sources.

Overall cost
The most inexpensive operating structure appeared to be scenario 4 (Informal visits), followed by scenario 3 (Reciprocal QUADs team) and scenario 1 (NZ expatriate team) (Table 3). The most expensive operational scenario to implement would probably be scenario 2 (Overseas surveyors and diagnosticians). The difference in costs between operating scenarios was not as large as expected, for example, the costs of scenarios 1 and 3 (NZ expatriate team and Reciprocal QUADs team) appeared to overlap.

However, an inexpensive operating structure may not cover all the criteria that an expatriate plant monitoring system is expected to deliver and a more expensive operating structure may not necessarily be more effective. The costs of each operating scenario were compared against the other selection criteria to identify their overall suitability (Table 4).

When the rankings were added together and the total scores compared, scenarios 2 (Overseas surveyors and diagnosticians) and 4 (Informal visits) were the least cost effective, Scenario 3 (Reciprocal QUADs team) was relatively cost-effective and scenario 1 (NZ expatriate team) appeared to be the most cost-effective operating scenario.

The four operating scenarios were presented as separate options, but they are not mutually exclusive. Selecting combinations of scenarios may also be considered. For example, scenario 4 (Informal visits) could be operated in conjunction with scenarios 1, 2 or 3 (NZ expatriate team, Overseas surveyors and diagnosticians, Reciprocal QUADs team).

Table 4. Rankings from 1 to 4 (1=poorest, 4=best) and total score of each of the four operational scenarios identified (Scenario 1–New Zealand expatriate team, Scenario 2–Overseas surveyors and diagnosticians, Scenario 3–Reciprocal QUADs team, Scenario 4–Informal visits).

Selected criteria	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Quality of data	4	2	3	1
Accurate and rapid diagnostic capabilities	2	3	4	1
Simple and effective management of information	4	2	1	3
Flexibility to provide easily accessible short and long-term data	4	2	3	1
Overall cost	3	1	3	4
Total score (overall suitability)	17	10	14	10

Recommendation

The most suitable operating scenario was scenario 1 (NZ expatriate team). This operating scenario is the most likely to succeed because it fulfils most of the selected criteria to successfully implement an expatriate plant monitoring system. Advantages of using this scenario included: higher quality of data because New Zealand staff have a vested interest in protecting their natural ecosystems and would be experts in pests and diseases of New Zealand plants; the ability to make repeated surveys over time using the same individuals, which would allow for greater detection of new organisms and the ability to monitor long term impacts on native plants; the flexibility to provide access to a range of data sources operated by national organisations willing to share resources; and moderately low costs to administrate. One of the limiting factors for this scenario was that of sample identification, but diagnostic capabilities would be improved if agreements with accredited overseas diagnostic labs for the identification of specimens were made official and a formal international diagnostic network was established.

Conclusion

The expatriate plant monitoring system has the ability to improve our knowledge of biosecurity risks to native plants and ecosystems in New Zealand by studying the pests and diseases occurring on New Zealand plants overseas. A comparison of four possible operational scenarios identified a New Zealand expatriate team as best meeting the criteria for an expatriate plant monitoring system to deliver good quality data at reasonable cost without being too complex to manage.

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