Invasive Plant Science and Management 2016 9:55–59

In the Footsteps of Cows: Using Livestock Tracing Technology to Trace and Predict New Weed Incursions of Tropical Soda Apple (*Solanum viarum*) in Australia

Scott Charlton, Robyn Henderson, Ian McGowen, Bernie Dominiak, and Michael Michelmore*

Tropical soda apple is an aggressive prickly perennial shrub growing up to 2 m high. It invades open to semishaded areas, including pastures, forests, riparian zones, roadsides, recreational areas, and horticultural and cropping areas. In Australia during August 2010, the weed was identified on the New South Wales Mid North Coast. It is believed that tropical soda apple has been present in this area for a number of years and both systematic and ad hoc surveys have found the weed in other satellite locations. The discovery of tropical soda apple at several cattle handling facilities indicated that cattle are a significant vector for the weed. The aim of this project was to use the National Livestock Identification System (NLIS) data to trace cattle movements from affected properties throughout New South Wales and into other Australian states. This has proved advantageous, as there are few other nonecological mechanisms to systematically trace significant weed movement. We have been able to conduct a pathway analysis of where this weed is likely to occur across New South Wales through the use of NLIS. Importantly, we can use this information to pinpoint surveillance activities for local managers, thus ensuring better use of resources. We have also been able to create a stochastic model for incursions at these sites using information gleaned from the NLIS data.

Nomenclature: Tropical soda apple, *Solanum viarum* Dunal.

Key words: Data warehousing, national livestock identification system, NLIS, pathway analysis, tracing.

Weeds are recognized as a major economic problem in Australian agricultural systems and have a broad impact on society, the environment, and the economy. The economic impacts are measured as costs of control, decreases in yield, and reductions in economic surplus (Sinden et al. 2005). The total annual cost of weeds in Australia was estimated at US$1.8 billion or about 10% of the gross value of the rural production in 2000 to 2001 (Pimentel et al. 2001). It was estimated that the effect of weeds on annual winter cropping is approximately A$1,182 million alone (Jones et al. 2005). It has been calculated that 80 and 20% of these costs fall on the farmer and the consumer, respectively (Sinden et al. 2005). Additionally weeds attract at least A $116.4 million of government expenditure on control, surveillance, and other management activities, including protocols to exclude exotic weeds.

Tropical soda apple, *Solanum viarum* Dunal (Solanaceae), is a native of northeastern Argentina, southeastern Brazil, Paraguay, and Uruguay. It was first recorded in Florida in 1987 and was known to infest 10,000 ha (24,711 ac) by 1990 and half a million hectares by 1995. By 2007 it had spread to nine other states in the southeastern United States (Mullahey et al. 1998). In the United States it is a Federal Noxious Weed aptly named "the plant from hell" due to its inherent management challenges. Tropical soda apple has also naturalized in Africa, India, Nepal, West Indies, Honduras, Mexico, and outside its native range in South America. There are few successful biological controls (Diaz et al. 2008).

Tropical soda apple is an aggressive, prickly perennial weed growing up to 2 m (6.6 ft) tall. The leaves are unpalatable to stock due to prickles. Domestic stock, feral animals, and birds are attracted to the sweet smell of mature fruit and seeds are passed in dung or droppings. Other transport vectors are via water and contaminated produce (such as hay),

DOI: 10.1614/IPSM-D-14-00079.1

* First, second, third, and fourth authors: Manager Invasive Plant Programs, Invasive Species Officer, Geographic Information Officer, and Leader Regional Pest Management, respectively, New South Wales Department of Primary Industries, Locked Bag 21, Orange, NSW 2800, Australia; fifth author: Invasive Species Officer, New South Wales Department of Primary Industries, P.O. Box 389, Goulburn NSW, 2580, Australia. Corresponding author's E-mail: scott.charlton@dpi.nsw.gov.au

equipment, pasture seed, compost, and soil. In the United States tropical soda apple plants produce an average of 45,000 to 50,000 seeds per plant with germination rates of 70 to 90% (Mullahey et al. 1998). Approximately 20% of seeds may have dormancy (Akanda et al. 1997).

Tropical soda apple reduces carrying capacity and dense stands may limit access to water or shade, possibly causing heat stress in summer (Mullahey et al. 1998). In cropping areas, tropical soda apple harbors a range of plant viruses and insect pests that may move into nearby solanaceous crops (McGovern et al. 1994; Medal et al. 1996).

Tropical soda apple was first identified during general surveillance in Australia in the Kempsey area, south of Coffs Harbour, on the New South Wales Mid North Coast in August 2010 (Figure 1; for a full map of Australia, see Figure 2). However, the weed is believed to have been present in this area for a number of years. The extent of the core infestation was about 50 ha. Subsequent surveys have identified other smaller infestations in surrounding riparian areas. Risk assessments conducted for the plant indicate that tropical soda apple has potential to spread to coastal and subtropical regions in New South Wales and Queensland. Modified environments such as irrigated agriculture are also potentially threatened by its establishment. Although tropical soda apple was first observed on the New South Wales Mid North Coast, the exact introduction location is difficult to determine. Anecdotal reports suggest a particular cattle property located within the region may be the source; however, a clear link to the importation of the plant has not been established. The source of the original introduction is likely to remain unknown.

Regulation

On May 12, 2011, tropical soda apple was listed as a Class 2 noxious weed under the New South Wales *Noxious Weeds Act 1993* across all of New South Wales, meaning that the weed must be eradicated from the land and the land must be kept free from it. Within the core infestation area, tropical soda apple is also managed as a Class 3 weed, where control measures require that the plant, including all fruiting material, must be fully and continuously suppressed and destroyed.

Evidence from the United States and landowner observations both indicate that distribution by animals is likely to be a major vector for this weed (Mullahey et al. 1998). The occurrence of the weed at sale yards and other cattle handling facilities supports this theory. There was initial evidence that stock from one particular property infested by the weed were dispersed across New South Wales. It is likely that other producers in the area have also contributed to the problem by transferring stock to other locations in New South Wales and interstate. This dispersal mechanism indicates that a statewide management approach is required to coordinate efforts with neighboring states.

Although the nearby Macleay River may be a significant pathway for the incursion, the distribution pattern of the weed along the river suggests that animal movement along the river corridor is the more likely dispersal mechanism, rather than the actual stream. Although native and feral animals can act as a similar mechanism for the plants movement, this distribution is localized and less significant compared to the potential long-distance spread via human-facilitated livestock movements. If no attempt was made to trace and eradicate tropical soda apple, the weed was likely to become another exotic weed that adapted to Australian conditions and became established (Downey et al. 2010; Hosking et al. 2011).

In Australia, pest management agencies often rely on "passive" or "general" surveillance reports from members of the public to assist in surveillance. This strategy reduces the need for costly active surveillance for invading species over large areas (Cacho and Hester 2011). Due to its rarity and relative unfamiliarity to land managers, passive surveillance alone was not considered appropriate for determining the distribution and location of tropical soda apple. In a novel approach, the National Livestock Identification System (NLIS) was used to trace subsequent movements of the weed throughout New South Wales. Not only were individual and often isolated incursions of tropical soda apple located, broader patterns of dispersal were determined, which consequently informed the feasibility of control programs. This strategy allowed resources for specific surveillance programs to be allocated efficiently to quickly delineate the infestations and therefore increase the likelihood of eradication

National Livestock Identification System

The NLIS is Australia's scheme for the identification and tracing of livestock. The NLIS for cattle was introduced in New South Wales on July 1, 2004, and involves electronic identification of cattle and centralized recording of movements on a national database. Since 2005, all cattle must be tagged and registered. Sheep were included in 2006. This system is a whole-of-life identification system that enables individual animals to be tracked from the property of birth to slaughter for food safety and market access purposes (Trevarthen 2007).

NLIS uses approved ear devices or rumen boluses to track and report all movements of cattle between properties with different property identification codes (PICs). Historically, NLIS has been used to manage livestock threats such as disease prevalence or pesticide residues (Pearse et al. 2010; Tonsor and Schroeder 2006). As discussed above, information from NLIS was used specifically to target weed surveillance and enhance the delivery of extension materials. In particular, cattle movements from tropical soda apple–affected properties have been a significant focus

https://doi.org/10.1614/IPSM-D-14-00079.1 Published online by Cambridge University Press

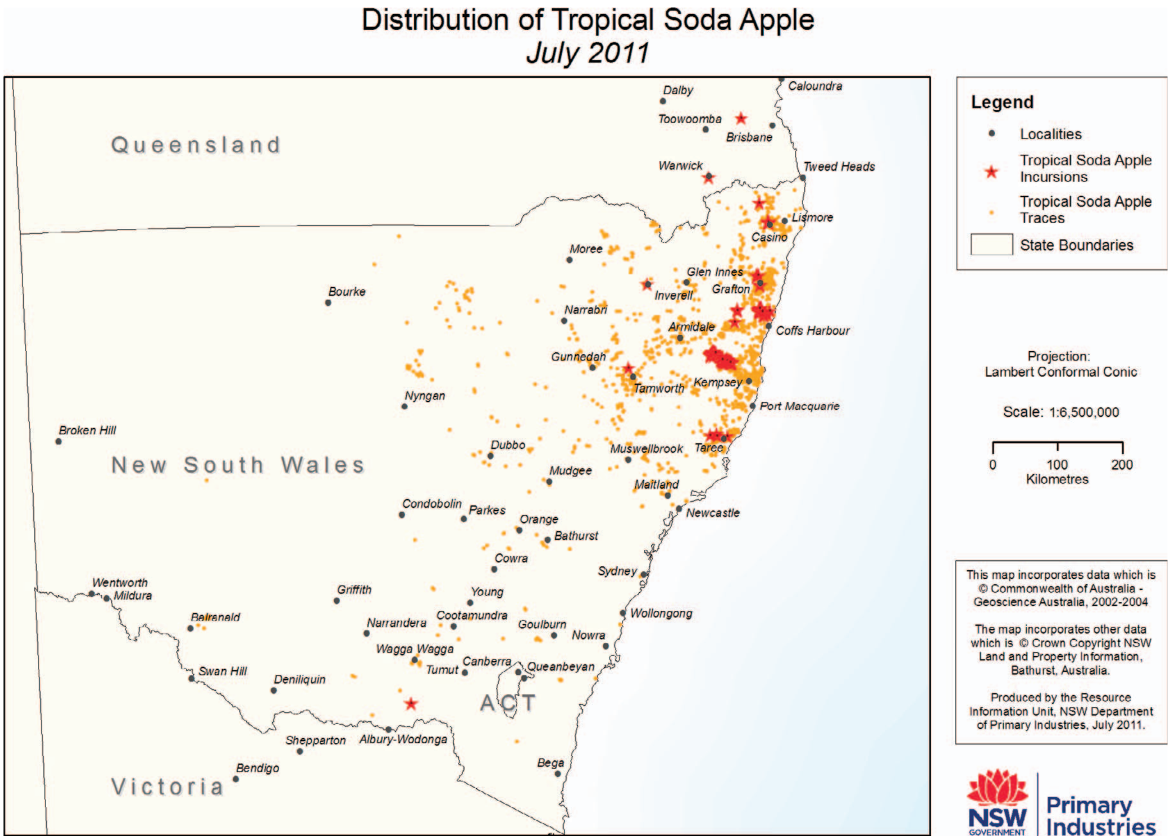

Figure 1. Map of New South Wales showing sites where tropical soda apple was detected and "properties of interest" associated with tracing activities from the National Livestock Identification System. (Color for this figure is available in the online version of this article.)

of trace-forward activities. To abide with privacy requirements covering NLIS, property data was sanitized to ensure that unnecessary information was not freely disseminated.

Pathway Analysis

In November 2010, a pathway analysis was conducted to model the distribution of tropical soda apple based on cattle movements across New South Wales. The centroids of all properties with tropical soda apple present were collated. This process resulted in a list of geographic coordinates of 756 infested properties. This list was then given to the Livestock Health and Pest Authority (LHPA) who provided a NLIS PIC for each coordinate. The resulting list of PICs was then used to identify 26,762 cattle movements from potential infested properties.

Available cattle movement data were analyzed for the 2004 to 2010 period in the belief that the initial incursion took place during that period. Consideration was given as to whether the movements should be prioritized based on how long ago the movement took place. It was decided that it would be difficult to get an objective ranking of risk based on this method. Ultimately, the risk of the spread was quantitatively based entirely on the number of and quantity of cattle movement events.

The NLIS database was interrogated to determine the first movement of individual cattle from each infested property. Where cattle were transferred to a cattle handling facility, the subsequent movements were also determined. The trace forward ended when an animal went from an infested property to a slaughterhouse. Slaughterhouses and other cattle handling facilities have been the focus of local government surveillance activities outside of this process. The resulting list of 1,048 PICs in receipt of cattle from infested properties was submitted to the LHPA for conversion into Lot/Deposited Plan numbers. The conversion of PICs increased this number again as an individual property can have multiple lot numbers attached to it. Consequently, over 7,440 lots or "properties of interest" (Figure 1) across 57 weed Local Control Authorities were mapped. This process also identified properties of interest in the neighboring states of Victoria and Queensland—9 and 25 properties respectively. The appropriate interstate authorities were promptly alerted to the possible weed presence.

The New South Wales Department of Primary Industries wrote to 57 weed Local Control Authorities requesting they inspect the properties of interest in their area and report the results back to New South Wales Department of Primary

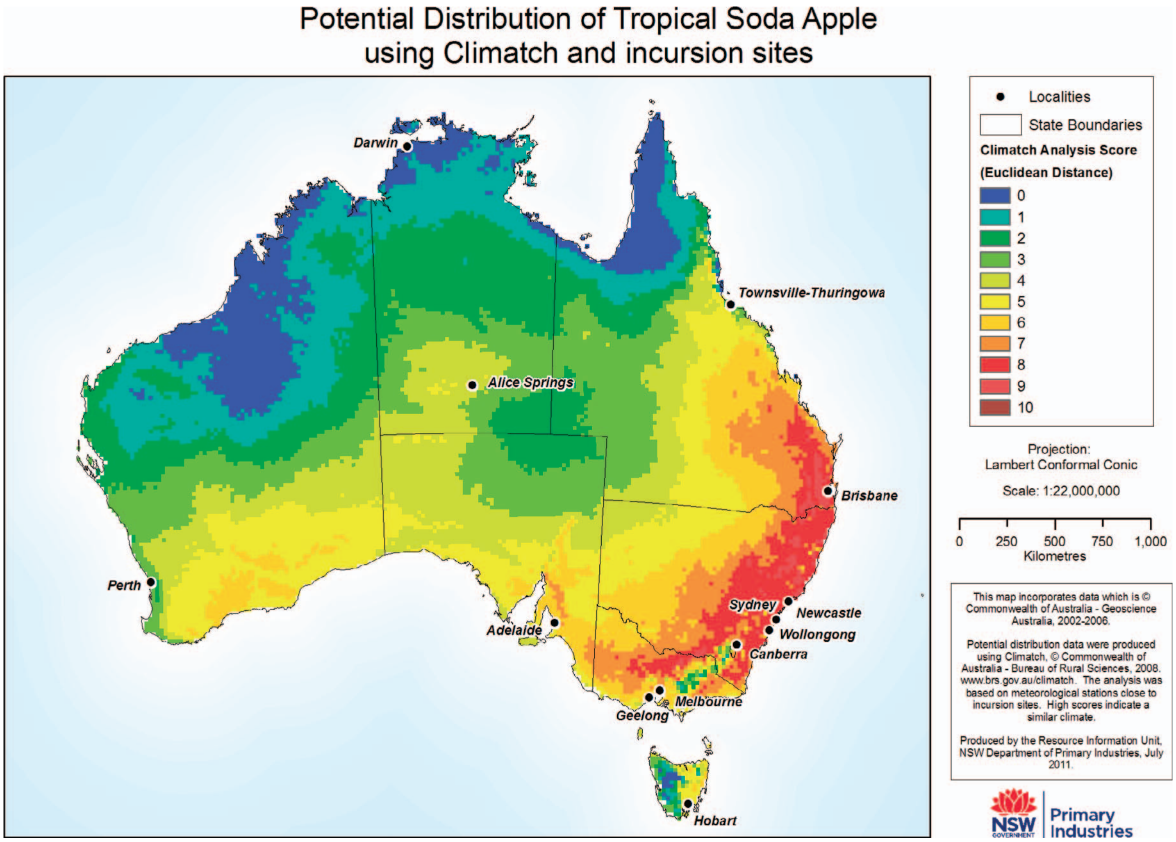

Figure 2. Potential distribution of tropical soda apple in Australia using Climatch and incursion sites. (Color for this figure is available in the online version of this article.)

Industries (Figure 1). A template and extension material was also supplied to assist with this process. It was also requested that the identified properties receive follow-up surveillance as part of routine weed inspections. In a second assessment of properties of interest in spring 2012, the data identified 2,111 in New South Wales, 282 in Queensland, and 33 in Victoria. The New South Wales properties were distributed across 37 weed Local Control Authorities with small coastal infestations at Wingham, Nana Glen, Karangi, Copmanhurst, Glenreagh, and Grafton. The weed was also detected inland at Attunga, Bonalbo, Casino, Inverell, and Holbrook (northeast of Albury). In November 2010 and January 2011, incursions were reported at Warwick and Coominya in Queensland. Surveillance is ongoing.

Outcomes

The early identification of three separate incursions across New South Wales demonstrates that this is a valuable pathway analysis tool for predicting the movement of livestock-borne weeds. This novel technique resulted in the discovery of tropical soda apple at Holbrook (near Albury in southern New South Wales) 1,200 km (746 mi) from its original infestation (Figure 1). Despite this significant outlier, most dispersal was found closer to the original infested properties. This finding may reflect the time taken for holding and transport, which allowed stock to be purged of seeds before the stock were delivered to properties clean of infestation. Subsequent surveys also found infestations at isolated locations near Tamworth and Inverell. These incursions could be eradicated quickly and cheaply because of their relatively small size. Furthermore, this analysis gives managers valuable information to model delimitation of the weed's range based on its most common vector.

This program has been very successful in engaging various stakeholders across New South Wales. Participation in this tracing activity has provided weed officers with an opportunity to positively engage with landowners in weed management because there is a direct benefit for the landowner. This proactive interaction with landowners has been invaluable in building a rapport with landowners that can be used for broader weed management outcomes and establishing a culture of "ownership" of weed infestations by local landholders.

The identification of specific properties of interest has also enabled local control authority weed officers to legitimately engage specific stakeholder groups, such as the beef cattle industry, for the distribution of extension and educational material. Although a convincing case could be made to restrict cattle movements in response to this weed, it was critical that industry was not unnecessarily impeded and that trade continued. A positive outcome from this project has been the development of several best-practice hygiene protocols to mitigate the risk of future weed incursions due to cattle movement.

Feedback from local control authority weed officers has been invaluable in identifying ways that the use of the NLIS can be improved. It was reported that some property data were incorrect. In many cases, owners reported that they had never had cattle on their property or that their land was used exclusively for another purpose such as cotton production. It was also established that many cattle buyers purchase bulk lots that are distributed to several other properties without changing transfer details. Other issues identified included the retagging of cattle with incorrect tags when tags are lost in transit, and the ability to trace manure from feedlots. Since this analysis has been conducted, New South Wales Department of Primary Industries has commenced streamlining the NLIS tracing process through the introduction of a cloud-based biosecurity information system. This system has enhanced the linkages between various data sets, thus allowing the rapid interrogation of spatial data relevant to weeds and livestock, These changes will allow officers quicker access to data required for tracing activities.

Conclusion

By manipulating NLIS data normally reserved for managing animal pests and diseases, high-risk tropical soda apple properties and potential infestation pathways were identified across New South Wales, Queensland, and Victoria. This strategy is a significant advantage for weed managers and cattle producers, allowing them to eradicate outlying weed populations before they become expensive and impractical to control.

It is important that weed managers think laterally when conducting pathway analysis and exploit these novel types of resources where they are available. Although not applicable to all situations, this approach should be considered in the repertoire of techniques for weed pathway analysis. This particular technique allows weed managers the ability to electronically trace the movements of weeds where the vector is directly related to stock movements recorded in the NLIS database.

This again reinforces the value of tools such as geographic information systems, databases, data warehousing, and the importance of accurate recording of information. One caveat should be stated: that the time used to analyze the pathway should be proportional to the importance of the vector of interest. There is little point spending inordinate amounts of time analyzing animal movement if the majority of seed is transported by a different vector.

Acknowledgments

Many people contributed to the success of this program. In particular, the authors wish to acknowledge the efforts of Marion Bennett, Rod Ensbey, John Tracey, Olga Ozols, Udai Pradhan, and Chris Ryan. Many weed local control authority staff from several regions provided data and conducted inspection work.

Literature Cited

Akanda RU, Mullahey JJ, Dowler, CC, Shilling DG (1997) Influence of pest emergence herbicides on tropical soda apple (*Solanum viarum*) and Bahia grass (*Paspalum notatum)*. Weed Technol 11:656–661

Cacho OJ, Hester SM (2011) Deriving efficient frontiers for effort allocation in the management of invasive species. Aust J Agr Resour Ecol 55:72–89

Diaz R, Overholt WA, Samayoa A, Sosa F, Cord-eau D, Medal J (2008) Temperature-dependent development, cold tolerance, and potential distribution of *Gratiana boliviana* (Coleoptera: Chrysomelidae), a biological control agent of tropical soda apple, *Solanum viarum* (Solanaceae). Biocontrol Sci Technol 18:193–207

Downey PO, Scanlon TJ, Hosking JR (2010) Prioritizing weed species based on their threat and ability to impact biodiversity: a case study from New South Wales. Plant Prot Q 25:111–126

Hosking JR, Conn BJ, Lepschi BJ, Barker CH (2011) Plant species first recognised as naturalised or naturalising for New South Wales in 2004 and 2005. Cunninghamia 12:87–114

Jones RE, Vere DT, Alemseged Y, Medd RW (2005) Estimating the economic cost of weeds in Australian annual winter crops. Agric Econ 32:253–265

McGovern RJ, Polston JE, Mullahey JJ (1994) *Solanum viarum*: weed reservoir of plant viruses in Florida. Int J Pest Manag 40:270–273

Medal JC, Charudattan R, Mullahey JJ, Pitelli RA (1996) An exploratory insect survey of tropical soda apple in Brazil and Paraguay. Fla Entomol 79:70–73

Mullahey JJ, Shilling DG, Mislevy P, Akanda RA (1998) Invasion of tropical soda apple (*Solanum viarum*) into the US: lessons learned. Weed Technol 12:733–736

Pearse BHG, Traub RJ, Davis A, Cobbold R, Vanderlinde PB (2010) Prevalence of *Cysticercus bovis* in Australia. Aust Vet J 88:260–262

Pimentel D, McNair S, Janecka A, Wightman J, Simmonds C, O'Connell C, Wong E, Russel L, Zern J, Aquino T, Tsomondo T (2001) Economic and environmental threats of alien plant, animal and microbe invasions. Agric Ecosyst Environ 84:1–20

Sinden J, Jones R, Hester CS, Odom D, Kalisch C, James R, Cacho O, Griffith G (2005) The economic impact of weeds in Australia. Plant Prot Q 20:25–32

Tonsor GT, Schroeder TC (2006) Livestock identification: lessons for the US beef industry from the Australian system. J Int Food Agribusiness Marketing 18:103–118

Trevarthen A (2007) The National Livestock Identification System: the importance of traceability in E-business. J Theor Appl Electron Commerce Res 2:49–62

Received December 5, 2014, and approved December 17, 2015.

Associate Editor for this paper: Stephen F. Enloe, University of Florida.

https://doi.org/10.1614/IPSM-D-14-00079.1 Published online by Cambridge University Press