Utilising a Terrestrial Observation Predictive System for Emergency Plant Pest Incursion management

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EXTENDED ABSTRACT

Australia's management of bushfires illustrates how we should respond to major incidents. With up to date weather information, GIS, models predicting hotspots, outbreaks and potential control lines on the time scale of hours to days, agencies have an enhanced ability to manage fires.

However for other major incursions, such as emergency plant pest outbreaks, our technological ability and support is far less advanced. This project aims at investigating the use of the NASA Terrestrial Observation and Prediction System (TOPS) for management of Emergency Plant Pest (EPP) incursions in Australia.

In theory, by combining the daily environmental and climatic parameters (soil moisture, soil type, temperature, light exposure, aspect, etc.) with the host's biology, one can predict what the photosynthetic rate (in terms of $gC/m^2/day$) or fitness of a crop is. By combining the crop fitness with pest biology and host parameters, predictive climate-based simulations can then lead to estimates of the stages of pest outbreaks and guide the selection of feasible and effective containment or management options.

A large computational resource will be required to do these three way interactions for any large scale mapping in a reasonable time. NASA's supercomputers will initially be used to assist the process of modelling photosynthetic rates or GPP for Victoria and southwest West Australian. Initially one or two defined EPPs, such as the Glassy-winged sharpshooter, will be piloted with the project aiming to produce a more generic template model for other pest species.

1. INTRODUCTION

The greater emphasis on bio-protection and biosecurity in Australia has led to adoption of similar management strategies or plans for disasters, major incidents or incursions, such as fire, flood, diseases or pest outbreaks (DISPLAN, PLANTPLAN and AUSVETPLAN). All of these plans require decisions on management to be based upon best available information. In the case of bushfires, the amount of up to date or real time information on fire activity is impressive. This timely information enables sound and effective decisions on the location of control lines and back burning. This information relies heavily on spatial and temporal data such as exact location of the fire front, local weather patterns, vegetation type, slope and aspect which all feed into fire behaviour models. This data is obtained by airborne remote sensing, on site weather stations and from detailed maps of the area. However for plant pest incursions, this level of detailed up to date information and models to support effective management strategies is often lacking.

Decision making is then based upon local knowledge or expertise that may not be specific to the situation or to the pest. Expertise in the pest maybe brought in from outside the area or from overseas but this obviously takes time and hence reduces the effectiveness of any quarantine, control or eradication process. For example the outbreak of a serious parasitic plant, branched broomrape, *Orobanche ramosa*, in southern Australia required an expert from Israel to visit and advise on control options (Jupp *et al*. 2002). A faster more efficient process would allow experts, from anywhere in the world, to input into a model which could be used to determine best management control options.

Development of such a process requires modelling the interaction between the static environmental layers, (soils, topography, landuse, vegetation type), dynamic environmental layers (climate, leaf area index (LAI) and fraction photosynthetically active radiation (fPAR), and a pest ecological model. This concept is illustrated in Figure 1. Obviously the more complex the interactions, the more difficult or more variable the predictions will be. For example if a disease requires a vector then there maybe the need for another layer of interactions between the vector, disease, their relationship to the host and the environment.

Land surface phenology, defined as the seasonal pattern of variation in vegetated land surfaces observed from remote sensing, has been well-studied with historical remote sensing data (Jolly *et al*. 2005, Justice *et al*. 1985, Lloyd, 1990 and Schwartz *et al*. 2002). White and Nemani (2004) combined static and dynamic layers to produce an ecosystem forecasting model for the United States of America. This process of ecological forecasting (nowcasts of ecosystem conditions) was developed under the NASA's Terrestrial Observation and Prediction System (TOPS) program. TOPS is a data and modelling software system designed to seamlessly integrate data from satellite, aircraft and ground sensors with weather/climate and application models. TOPS operates at a variety of spatial scales, ranging from individual vineyard blocks to global monthly assessments of vegetation net primary production. More detailed information on the TOPS process is described in the methodology.

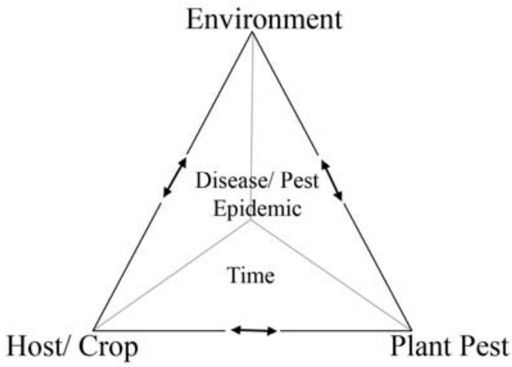

Figure 1. Plant disease triangle illustrating the interrelationships between the static and dynamic environmental layers, the host and the pest.

This paper describes the process by which new plant pest incursions into southern Australia could be modelled in near real time and the use of forecasting to enable the most effective control practises to be implemented. The incursion management model of an emergency plant pest (EPP), the bacterium *Xylella fastidiosa,* which causes Pierce's disease, a serious threat to viticulture, will be piloted. The vector, *Homalodisca coagulata,* Glassy-winged sharpshooter (GWSS) and the bacterium that causes Pierce's disease are not present in Australia. The bacteria blocks the xylem vessels of plants and causes symptoms similar to water stress. The grapevine may die within 2 years of infection depending on the variety.

As this is work in progress and in the 1st year of a 3-year project, this paper focuses on the methodology and discussion on potential barriers.

2. METHOD

The development of a management model for emergency plant pests incursions into Australia will rely on the integration of an Ecocast-TOPS model and a life history, dispersal model of the pest.

The production of an EPP – habitat suitability model will rely upon the existing ecosystem models developed under the TOPS process. These models use the soil-plant-atmosphere continuum concept to estimate various water and carbon flux processes. The models are initialised with ground based soil physical properties and satellite based vegetation information (type or class, leaf area index). Following the initialisation process, daily weather conditions (maximum & minimum temperatures, solar radiation, vapour pressure deficit and precipitation) are used to drive various ecosystem states and fluxes (e.g. soil moisture, transpiration, evaporation, photosynthesis and snowmelt) that can be translated into drought, crop yield, net and gross primary production (NPP & GPP) and water yield estimates. Figure 2 illustrates the data flow in determining GPP in the TOPS ecosystem model. The full description of the TOPS process and models can be found at http://ecocast.arc.nasa.gov and in Nemani *et al.* (2001) Nemani *et al.* (2003) White and Nemani (2004) and Kathuroju *et al.* (2006).

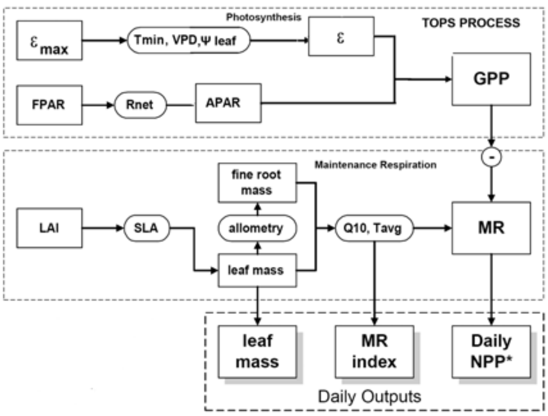

Figure 2. Flowchart illustrating data flow in determining daily outputs of NPP of the MOD17 algorithm. The TOPS process for estimating daily GPP is illustrated in the top panel (adapted from Running *et al*, 2000).

The second component is the development of a dispersal model for Pierce's disease which will focus on modelling the dispersal of the bacterium's vector, the GWSS. There are a few main approaches to ecological dispersal modelling. One could use dynamic systems or life history model and couple this to a GIS distribution or dispersal process, or to develop cellular automaton model, or to utilise individual or agent based modelling. The more widely used ecological modelling processes; dynamic, cellular automata and individual/ agent based are discussed below.

3. MODELING DISCUSSION

An incursion management model relies on the two underlying processes; the Ecocast-TOPS model and the pest dispersal model. TOPS already produces daily GPP information at a 0.5 degree global and continental US scale, a 1 km resolution for California and Yosemite National park and a finer 4m resolution (aerial imagery) for parts of the Napa valley (http://ecocast.arc.nasa.gov). This system will then be trialled using Australian vegetation, soil, topography and climate data for south eastern Australia. Although the process has been validated for the continental US, it will also have to be verified against Australian field data by performing a three way comparison among model, observation and satellite derived fields.

The development of a pest dispersion model and integrating it with the daily Ecocast-TOPS model will be more complex. It is important that these two models are integrated as often the pest is reliant on the quality of or the host's growth rate. For example it has been demonstrated that the pine pest woodwasp, *Sirex noctilioi,* is able to determine the osmotic quality of the phloem sap and preferentially oviposits on stressed trees (Madden, 1974). In contrast, with the blackberry rust fungus, *Phragmidium violaceum,* infection rates are higher in actively growing and healthy plants (Piggot *et al.* 2003).

The potential range of GWSS and Pierce's disease has been modelled (Hoddle 2004). However this only illustrates the gross maximum potential range solely based on a climate matching process and does not consider the temporal daily dispersal component. To build a daily dispersal model requires a more complex simulation model. The more widely used ecological modelling process are; dynamic, cellular automata and individual/ agent based.

The product Structural Thinking, Experiential Learning Laboratory with Animation (Stella) was developed for general modelling education. It is a tool for building and simulating models of dynamic systems and processes, geared primarily at compartment models. The graphical interface allows the user to build mathematical relationships without any knowledge of programming. Using a simple set of building block icons, the user can construct a map of a process or system. Although Stella has no explicit spatial-modelling capability, Maxwelll and Costanza (1997) have linked Stella modelling to GIS by creating a modelling interface with a code generator that is then coupled to a GIS to produce the graphic component.

The code in many of these dynamic, life history models is limited, and consists mainly of establishing mathematical relationships between the various components. In addition to mathematical relationships in the form of equations, one can also input graphical relationships between variables. Simulation time, time interval and computation method can all be set (Edelfeldt 2005). Another difficulty is coupling these pest dispersal models to a spatial – temporal GIS mapping process and although this has been done in a few instances, for example by Wu (1994) and Aurambout *et al.* (2005) who linked Stella through a spatial modelling environment interface into a cellular automaton model. However there is no defined procedure or user friendly program to do this easily.

Cellular automata models (CAM) consist of a regular grid of cells, each in one of a finite number of states. Every cell has the same rule for updating, based on the values of it and its neighbouring cells. The rules are applied iteratively for as many steps as desired, creating a new generation. The theory of cellular automata is immensely rich, with simple rules and structures being capable of producing a great variety of behaviours (Hassell 1991, Balzter 1998). Similarly to the dynamic models, cellular automata models often have a static base layer (i.e. non changing) which will need to be interlinked to the dynamic Ecocast-TOPS layer. The dynamic outputs of Ecocast-TOPS will produce a daily GWSS habitat quality or preference layer. This would allow a CAM to determine daily probabilities of dispersion of GWSS within the gridded region

The third type of pest dispersion model considered are the individual or agent based models. There are various types of these. In a commonly used approach, the behaviour and fate of each individual is modelled in a simulation. The behaviour and fate (e.g. survival, reproduction and dispersal) of individuals depends on their location, age sex, physiological and other characteristics.

Individual or agent based models in contrast to the other two types are a simulation environment which facilitates development and experimentation with simulations involving a large number of agents behaving and interacting within a dynamic environment. One of the problems facing new users of agent based models is the steep learning curve required to utilise these programs some of which are open source.

4. CONCLUSION

There is a need for spatial temporal modelling of plant pest incursions to assist natural resource managers in determining the most cost efficient and feasible control strategy. The use of Ecocast-TOPS or ecoforecasting to determine the health or growth rate of the host is vital to understanding how the pest interrelates with both the environment and the host. It is planned that in the future additional socio-economic tool add-ons to the model will assist in the determination of the cost:benefit and most effective control options. The use of TOPS with relevant pest dispersal models will support decision making in containment of emergency plant pests incursions in Australia.

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