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Invasive exotic plant indicators for ecosystem restoration: An example from the Everglades restoration program

Robert F. Doren [a,*], *John C. Volin* [b], *Jennifer H. Richards* [c]

[a] Southeast Environmental Research Center, Florida International University, 11200 SW 8th Street, Miami, FL 33199, USA
[b] University of Connecticut, Department of Natural Resources Management and Engineering, 1376 Storrs Road, Storrs, CT 06269, USA
[c] Department of Biological Sciences, Florida International University, 11200 SW 8th Street, Miami, FL 33199, USA

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ABSTRACT

We have developed a comprehensive ecological indicator for invasive exotic plants, a human-influenced component of the Everglades that could threaten the success of the restoration initiative. Following development of a conceptual ecological model for invasive exotic species, presented as a companion paper in this special issue, we developed criteria to evaluate existing invasive exotic monitoring programs for use in developing invasive exotic performance measures. We then used data from the selected monitoring programs to define specific performance measures, using species presence and abundance as the basis of the indicator for invasive exotic plants. We then developed a series of questions used to evaluate region and/or individual species status with respect to invasion. Finally, we used an expert panel who had answered the questions for invasive exotic plants in the Everglades Lake Okeechobee model to develop a stoplight restoration report card to communicate invasive exotic plant status. The report card system provides a way to effectively evaluate and present indicator data to managers, policy makers, and the public using a uniform format among indicators. Collectively, the model, monitoring assessment, performance measures, and report card enable us to evaluate how invasive plants are impacting the restoration program and how effectively that impact is being managed. Applied through time, our approach also allows us to follow the progress of management actions to control the spread and reduce the impacts of invasive species and can be easily applied and adapted to other large-scale ecosystem projects.

1. Introduction and background

Invasion by exotic species is an ecosystem level problem in restoration (Pimentel, 2002; Cox, 1999; Cronk and Fuller, 1995). Exotic species present a threat to the restoration of many natural areas and often drive ecological changes that may be irreversible and thus preclude successful restoration. Invasion prevention, early detection and removal of exotics are key to their control and management (Hulme, 2006). Understanding trends in the spread and density of invasive exotic species, including the impact of control and management activities, is necessary to manage invasive species and needs to be a vital part of large-scale ecosystem restoration programs (Hulme, 2006; Fridley et al., 2004; D'Antonio and Meyerson, 2002). To date, developing effective strategies that include invasive species management in large landscape-scale ecosystem restoration programs has posed a particular challenge (Sheley et al., 2006; Doren et al., 2002). Here, we present a conceptual model (see Doren, Richards and Volin, 2009), performance measures, and communication tools that

* Corresponding author.
E-mail address: dorenr@fiu.edu (R.F. Doren).
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can be used as fundamental components of strategies for assessing restoration success.

1.1. *Applicability of indicator to the Everglades*

An indicator for invasive exotic plants is not similar in nature or context to the other indicators presented in this journal issue because exotic species are not good indicators of ecological function, process or structure, especially for restoration. In addition, measurements of their biological performance do not provide any insight into how they may or may not impact other biological functions or restoration. While invasive exotic plants may result in changes in ecological function and structure, they do not necessarily ‘‘indicate’’ anything regarding ecological condition, or restoration success except as pertains to their level of invasion and adverse impacts on the ecosystem (Doren, Richards and Volin, 2009). However, without control and management of exotic species, there is the potential that restoration could fail, since exotics have the capacity to drastically alter the natural environment (Mack et al., 2000). Therefore, this exotic plant indicator was developed to report regularly on the status of and progress controlling invasive species in a restoration context. The invasive exotic species that are monitored as part of this indicator may change over time as new invasive species arrive and others come under control.

To address this challenge, we present an approach that incorporates invasive exotic species monitoring and management into ecosystem restoration programs, focusing on invasive exotic plants and using the 50-year, multi-billion dollar Everglades ecosystem restoration program in southern Florida, USA, as our example. The foundation of our approach is a conceptual model that establishes the framework for evaluating both the impact of invasive exotic plants and our knowledge about that impact on an ecosystem; this model is presented as a companion paper in this special issue (see Doren, Richards and Volin, 2009). The invasive exotic plant indicator we present here is one of an integrated set of eleven ecological indicators developed for Everglades restoration and also presented as companion papers in this special issue. Evaluations of the ecological indicators are based on individual performance measures that are assessed through individualized monitoring programs. Typically, performance measures are specific metrics (e.g. chicks per nest) that have measurable targets (e.g. 2.5 chicks per nest per year) that, when reached, indicate that restoration goals are being met. However, performance measures available for exotic species account only for the numbers of species present and area infested. Targets for invasive exotic species are generally meaningless since there is insufficient science, except for a few species (e.g., melaleuca in South Florida), to be able to set meaningful non-zero targets. As control and monitoring programs continue to collect data on additional species, we may be able to set target levels that account for reductions in exotic species presence – without total eradication – that are documented to result in significant ecological and biological restoration of habitats and communities. Such targets should be able to be documented as meeting biologically meaningful restoration goals (Tipping et al., 2008).

The methods used to collect and analyze the data in each of the indicator programs affect the possible formats that we could use to communicate the results. In recognition of this interrelationship, we developed a methodology for evaluating the invasive exotic plant indicator that is functionally integrated with all the other Everglades ecosystem restoration indicators. We use a communication tool (the stoplight restoration report card) to report the results of this evaluation; this tool reports the status of exotic plant invasions and the results of control and monitoring programs to policy-makers, managers and the public in a meaningful and easily understood format.

2. Indicator development and regions this indicator covers

2.1. *Performance measure development*

Development of performance measures for the Everglades exotic plant indicator was constrained to the use of information on invasive exotic plants collected by existing monitoring and research. Given the costs of collecting such information, this constraint may be common to other ecosystem restoration programs. Most large managed ecosystems have existing monitoring and management activities, however, and these can provide valuable data to assist in restoration assessments. The challenge in using these data, which are collected for a variety of purposes, is integrating information of different types collected by different groups for different purposes. To aid in this process, we developed and applied the criteria in Table 1 to evaluate data from monitoring programs; we used this evaluation to select programs that could supply appropriate input for an invasive exotics indicator. Using the selection criteria (Table 1) to review the existing monitoring programs for invasive exotic plants in south Florida, it was clear that even using a set of the most comprehensive programs, much less using only a single program, would still not provide an exhaustive, rigorous and geographically inclusive database that met all the criteria (Table 1). While combining several monitoring programs has limitations, other

Table 1 – Criteria that were used to assess the elements of different exotic plant monitoring programs to determine if they would be useful in developing an invasive exotic plant indicator for Everglades restoration

(1) How many different invasive exotic plant species does the program monitor?
(2) How large is the geographic coverage of the monitoring program?
(3) Are new species detectable by this monitoring program?
(4) Are existing species detectable when they invade previously uninvaded areas or habitats?
(5) How accurately are the locations and densities of invasive exotic plants able to be determined?
(6) Can the rate of invasive exotic plant spread be determined?
(7) Can the effectiveness of control actions/programs for invasive exotic plants be measured using the monitoring program?
(8) Can the overall spatial extent of the exotics be measured?

options either were not available or were considered less informative.

Through questioning Everglades scientists and restoration program managers and discussing invasive exotic programs and research in expert panels and restoration meetings, we assembled a list and descriptions of eleven programs that survey Everglades invasive exotic plants. We evaluated each of these programs using the criteria in Table 1. Although no program satisfied all of the criteria, four of the programs met almost all the criteria, and these four taken together provided data on all key aspects. The other seven programs that were evaluated failed to meet even a small number of the criteria in Table 1 and were therefore rejected as possible programs for use in developing the invasive exotic plant indicator.

Using data from these four programs, each south Florida physiographic region (module) (defined in Doren, Trexler, Gottlieb, and Harwell, 2008) was assessed and each surveyed invasive plant species within a region was evaluated for species presence and species abundance to determine their status (Table 2). Because data collected by each program varied spatially, temporally and in overall accuracy and precision, statistical comparisons among projects were not possible. Therefore, each data source was evaluated individually using the questions presented in Table 2, then the responses were integrated by drawing on the expertise of invasive plant species researchers and managers utilizing an expert panel approach (*sensu* Oliver, 2002) to assess the overall status of exotic plants.

The ratings applied for each criterion in Table 2 represent a relative valuation for helping panel members interpret actual data from the four monitoring programs. Because the data from the individual monitoring programs could not be statistically integrated or correlated, criteria applied had to be applicable to all data, either collectively or individually by project, without exceeding the ability of the data to provide accurate and objective information.

2.2. *Stoplight restoration report card*

To communicate the results of our performance measure assessments, we used an easily interpretable stoplight restoration report card that utilizes the collective set of performance measures to assess the status of invasive exotic plants as a group for different physiographic regions (modules), and as individual species. For the process to be reproducible and objective individual responses (red–yellow–green) are directly related to data from the monitoring programs. This synthesis (Fig. 3) was conducted by the expert panel.

Table 2 – Questions used to assess invasive exotic plant status among regions and by species in the Everglades ecosystem restoration invasive exotic plant monitoring

Module level questions[a]	
1. How many species identified as high priority for control have been found in this module?	
None	Green
Cannot determine	Yellow
Less than 10	Yellow
10 or more	Red
2. How many previously undetected species (new species never found in this module before) have been found within this module?	
None	Green
Cannot determine	Yellow
5 or less	Yellow
More than 5	Red
3. Do the four monitoring programs cover the entire spatial area or region within the module?	
Yes	Green
Cannot determine	Yellow
No	Red
Species level questions[b]	
1. How many acres within the module does this species occur in?	
Undetected	Green
Cannot determine	Yellow
less than 1000 acres	Yellow
more than 1000 acres	Red
2. Are the acres of the species in the module documented to be increasing, decreasing or static?	
Increasing	Red
Static	Yellow
Cannot determine	Yellow
Decreasing	Green
3. If the species is decreasing in coverage, is it a direct result of an active biocontrol or chemical/mechanical control program?	
Yes	Green
Cannot determine	Yellow
No (program is in place but too early to tell)	Yellow
No (no program in place)	Red

There are spatial (Module level) and taxon-specific (Species level) questions. The answers to these questions were used to create the traffic lights presented in Fig. 3.

[a] These apply to species that have been identified as high priorities for control based on the information in the South Florida Environmental Report (SFWMD, 2006) by module. Results from these three questions are reflected in the module level results in Fig. 3 and are examples from the Lake Okeechobee Module.

[b] These questions apply to each species known to be present within the module. Results from these questions reflect species level results in Fig. 3.

3. Results and discussion

3.1. *Program evaluation*

Data from four programs met the most evaluation criteria, and these projects were selected as sources of performance measure data. The approach presented here uses the cumulative information from these four programs, each of which had different attributes and functional aspects to develop an assessment that produces a more meaningful measure of trends in exotic plant invasion and control than from any individual program (Figs. 1 and 2). The four programs are:

- R-EMAP—Region 4 Environmental Protection Agency R-EMAP vegetation survey.
- SRF—South Florida Water Management District (SFWMD), National Park Service (NPS), and US Fish and Wildlife Service's (USFWS) Systematic Reconnaissance Flight (SRF) for invasive exotic plants.
- RECOVER MAP—Everglades RECOVER Vegetation Classification and Mapping program.

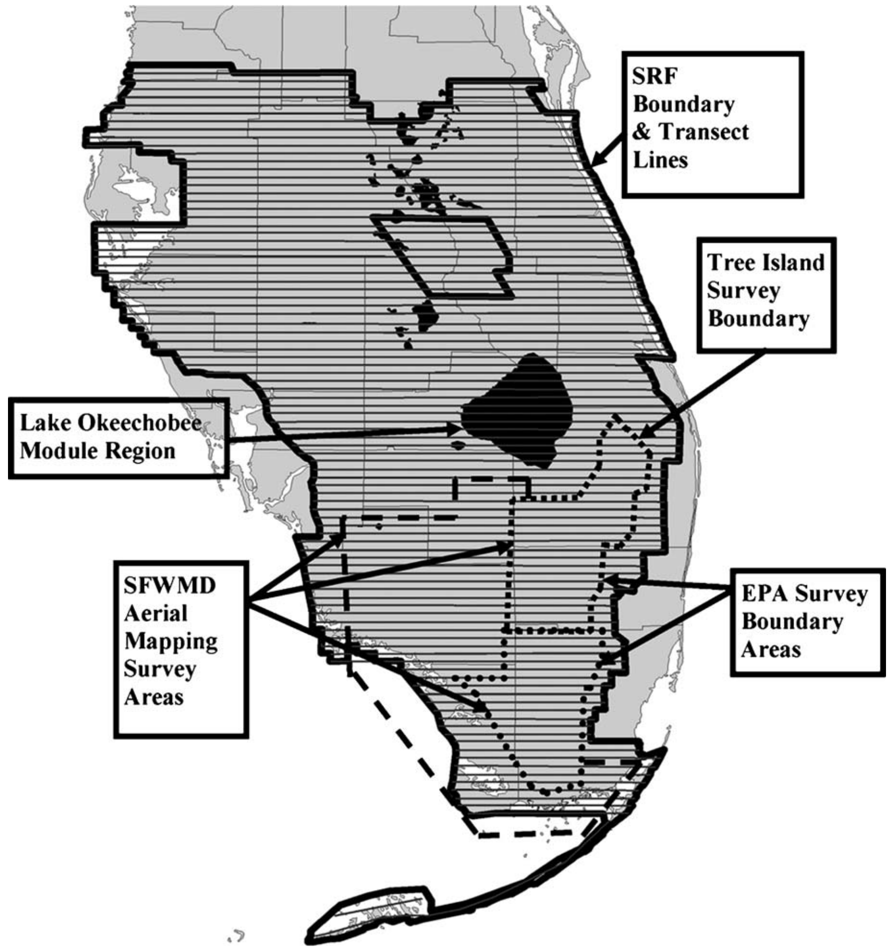

Fig. 1 – Map showing spatial coverage of the four south Florida invasive exotic plants monitoring programs described in Section 2. Data from these programs was used in developing the performance measure and the communication tools presented in Fig. 3. The Lake Okeechobee module region used in these examples is shown in black.

- Tree islands—South Florida Water Management District (SFWMD) Tree Island Exotics Survey.

3.1.1. *R-EMAP*

The Environmental Protection Agency R-EMAP project covers the central Everglades within the Greater Everglades Module (Fig. 1) (RECOVER, 2005). This project provides four key elements toward the development of an exotic plant indicator. First, the sample protocols incorporate a rigorous statistical design using GRTS (Generalized Random-Tessellation Stratified) sampling, stratified across four regions with sampling intensity proportional to area; the design includes several visual samples for exotic species presence, as well as quantitative subplot plant species censuses. This design provides the ability to detect (using a rigorous statistical approach) ''new'' species presence (especially individual and seedling plants) and species locations. It provides predictive capability relating to frequency of species finds, temporal and spatial aspects to species numbers (how many new species, how often and rates of spread), and species locations in relation to natural habitats being invaded. Finally, the sampling census design provides complete accuracy in ground-truthing plant species presence and location. Because of the spatial dominance of open marsh habitats, however, the sampling design of this project does not provide sufficient information on hammocks and tree-islands for general exotics monitoring, and it covers only a portion of the central Everglades habitats (Fig. 1).

3.1.2. *Systematic Reconnaissance Flights (SRF)*

The joint South Florida Water Management District-Department of Interior, Systematic Reconnaissance Flight (SRF) Survey for invasive exotic plants covers virtually the entire southern Florida area (SFWMD, 2006) (Fig. 1). This program provides the largest spatial coverage of any monitoring program in south Florida. The seven most widespread and serious exotic plant species are targeted in the survey, which is conducted biennially, providing good spatial, temporal and species density information across the entire region. Results from this survey have been used to document large-scale invasive exotic species spread rates and effects of region-wide control programs. This program offers a landscape-scale assessment for species that are considered the most serious invasive exotics in south Florida and for those with active control programs in place. These data provide ecosystem-scale evaluations of species increases or decreases both spatially and temporally. The drawbacks of this program

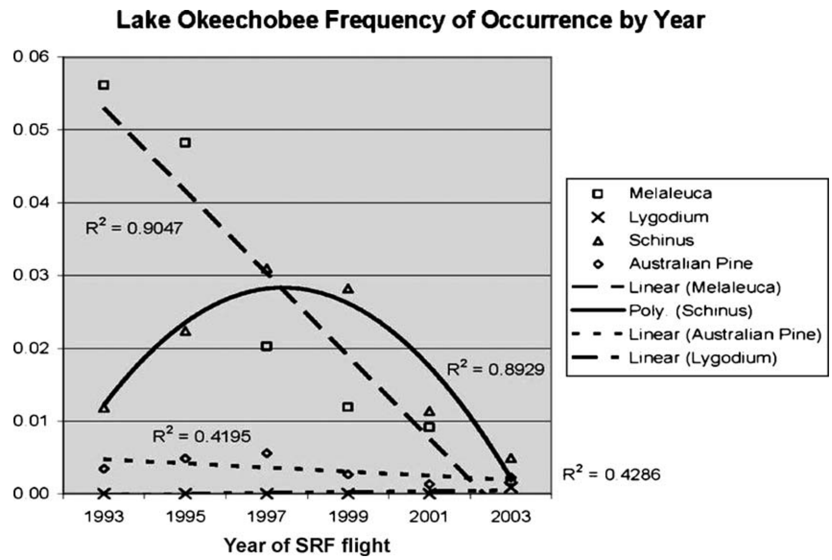

Fig. 2 – Plot of data for frequency of occurrence using the Lake Okeechobee module region for the sample analysis. The y-axis is the Frequency of Occurrence (I) (see text for formula). Data were derived from the SRF surveys. This figure clearly illustrates that *Melaleuca* abundance decreased through out the survey period and that *Schinus* abundance first increased and then decreased during the survey period. Both periods of decrease coincided with major invasive control programs for these species. A *Melaleuca* control program was well underway before the survey period began indicating the continued decline of the species throughout the survey period. A program to control *Schinus* was began later (1995) as *Schinus* started to replace *Melaleuca* in many areas where it was being controlled.

are that it monitors only seven species, and GPS locations are not precise enough to permit spatial analysis of individual observations. Moreover, the SRF cannot detect invasions of exotic species that cannot be seen from low-flying observation aircraft.

3.1.3. *RECOVER Vegetation Classification and Mapping*

The RECOVER Vegetation Classification and Mapping program is a complete vegetation mapping effort that will cover a large region of the natural Everglades (Fig. 1). This project will classify vegetation community coverage, including exotic species. The project uses the classification system "Vegetation Classification System for South Florida Natural Areas" developed by Rutchey et al. (2006), based on an earlier south Florida vegetation classification system (Jones et al., 1999). This program utilizes false color infrared photography and stereoscopic photo-interpretation with a 0.25 ha minimum mapping unit. The project will provide a large scale data set that identifies exotics and surrounding native vegetation communities and is planned to be repeated at 5-year intervals. This data set serves as a GIS vegetation layer upon which data from the EPA R-EMAP and Tree Island survey (see below) may be superimposed, allowing for additional evaluation of which native plant communities may be more vulnerable to invasion by exotics. If differences in invasion rates are documented, this tool may also serve to provide information for managers as to which habitats are most susceptible to invasion by exotic species, thus saving control program resources. This program is spatially limited to the southern Everglades regions (Fig. 1). The classification, however, takes 5 or more years to complete; maps are finished for WCA 2A and WCA 1A, but are not yet done for other regions.

3.1.4. *Tree island exotic plant survey*

The survey of tree islands is a project funded by the SFWMD to evaluate *Lygodium microphyllum* spread and impact, as well as to monitor the presence of other exotic plant species on tree islands in Water Conservation Areas 3A and 3B (Fig. 1). Hammocks and tree-islands are often the least surveyed sites in the Everglades ecosystem because they are difficult to access, densely vegetated, difficult to move through, and occupy an overall small spatial extent in the landscape. Often, however, these sites are the most impacted by invasive exotic plants and may serve as the first invasion sites for species spread and establishment. The Tree-island Exotic Plant Project is surveying more than 100 randomly selected tree islands, recording UTM locations and size of each island, dominant species, and exotic species presence. This project provides information on the presence and movement of invasive exotic plant species in understory tree island habitats that are not monitored adequately in any of the other survey methods. Because exotic species are difficult if not impossible to detect under canopies from aerial surveys, this project provides key information on a habitat that is difficult to monitor and is not represented in the other monitoring approaches. This program is limited, however, to two central Everglades regions (Fig. 1).

3.2. *Performance measures*

Because the SRF program had the longest temporal data set covering the largest geographic area, these data were used to develop and evaluate a measure using frequency of occurrence (I), where $I = O_a/O_p$. O_a is the number of actual observations of a given exotic species, and O_p is the number of possible observations of that species. This mirrored the general approaches and methods for the development of other types of indices for measuring biological responses (e.g. Gerritsen, 1995; Andreasen et al., 2001; Parrish et al., 2003). We plotted *I* for species of concern against time to observe trends in species occurrence using the Lake Okeechobee region as an example (Figs. 1 and 2). The number of possible observations was determined by the sampling protocol. In the case of the SRF flights, the total number of possible observations (O_p) was determined as the number of seven second intervals along the length of a given flight line times the number of flight lines. The other three monitoring programs had sampling protocols that were broken down into presence–absence data, allowing us to integrate among data sources. Invasion trajectories for individual species, represented by plotting the performance measure against time, showed *M. quinquenervia* and *S. terebinthifolius* decreasing from previous high levels of occurrence (Fig. 2), indicating success with control measures in this south Florida landscape module, while *C. equisetifolia* and *L. microphyllum* maintained or decreased slightly in presence (Fig. 2). The graphic also allows for comparisons among species, showing the severity of *Melaleuca* and *Schinus* invasions as compared to *Casuarina* and *Lygodium* in the early 1990s, and the more equivalent threat posed by all four species in 2003 (Fig. 2).

	2006 STATUS	2007 STATUS		2 YEAR PROSPECTS	
LAKE OKEECHOBEE MODULE (Results in row reflect module-level questions, not species-level questions)	Y	Restoration efforts under way for while, much progress made; however, several serious species occur in module and continued disturbance of littoral zone may increase chances of new invasions	Y	Module has had large control program under way for many years; progress on many species evident, but continued monitoring and control efforts needed to prevent serious reinvasions of the many species threatening region	Y
Alligator Weed (*Alternanthera philoxeroides*)	G	Effective biocontrol program under way for many years; control programs achieved complete control in most areas	G	Biocontrol and monitoring programs in place and achieving good results	G
Australian Pine (*Casuarina* spp.)	G	Effective removal program in place, not currently a serious problem in this module	G	Chemical control effective; natural areas clear with modest effort; biocontrol research under way	G
Indian rosewood (*Dalbergia sissoo*)		Not new to module but recent addition to priority plant table. Large efforts recently brought population under control	G	Recent control efforts brought population to maintenance levels; only modest effort needed in future to control new seedlings	G
Water Hyacinth (*Eichhornia crassipes*)	G	Control programs under way for years; maintenance control goals currently met due to record lows of Lake.	G	Ongoing control and monitoring programs in place; increases in water levels could trigger massive regrowth from seedbank	Y
Hydrilla (*Hydrilla verticillata*)	G	Control programs in place, not necessary in recent years; hurricanes, hydrologic conditions, flocculent substrate prohibit widespread expansion	G	Effective control and monitoring programs in place and have been achieving good results; increases in water levels could trigger massive regrowth from seedbank	Y
West Indian Marsh Grass (*Hymenachne amplexicaulis*)	Y	Little known about spread or distribution throughout system; not included in Indicator systematic monitoring program	Y	Increases in spread/distribution may be occurring; may become serious pest in areas where other exotics have been controlled	R
Melaleuca (*Melaleuca quinquenervia*)	G	Effective chemical control program under way for several years with excellent efficacy	G	Chemical and biocontrol effective; spread of agents, new agents expected in 2007/2008	G
Torpedograss (*Panicum repens*)	Y	Impacts at least 20,000 acres of wetlands; static; not included in Indicator systematic monitoring program	Y	Control efforts under way but frequently under-funded; lake management,drawdowns may increase spread despite program	R
Water Lettuce (*Pistia stratiotes*)	Y	Control programs under way for years; maintenance control goals currently met due to record lows of Lake.	G	Ongoing control and monitoring programs in place; increases in water levels could trigger massive regrowth from seedbank	G
Brazilian Pepper (*Schinus terebinthifolius*)	G	Not new to module but recent addition to priority plant table. Effective removal program in place, not currently a serious problem in this module	G	Chemical control effective; natural areas clear with modest effort; biocontrol research under way, new releases 2007/2008	G

Fig. 3 – Traffic Light report card for the Lake Okeechobee module region. The key to the color symbols is given below. The Current Status reflects the immediate answers to the questions, whereas the 1–2 year prognosis reflects trends in the data based on repeated sampling. In the report card, the summary for the module is given at the top, whereas summaries for individual species are given below. Red—substantial deviations from restoration targets creating severe negative condition that merits action. Yellow—Current situation does not meet restoration targets and merits attention. Green—Situation is good and restoration goals or trends have been reached. Continuation of management and monitoring effort is essential to maintain and be able to assess "green" status.

3.3. Stoplight restoration report card

Our report card approach takes the data from the four invasive exotic plant monitoring programs and integrates them qualitatively to answer questions about invasion status (Fig. 3). The answers to the questions in Table 2 were used to rank the status of the species from Red (severe negative condition) through Yellow (situation is improving, or species is still localized) to Green (situation under control for several years). This integrated summary is presented as a colored traffic light that has a universal understanding and a message that is easy to grasp.

The example presented evaluates the Lake Okeechobee module and provides assessments for eight species (Fig. 3). The stoplights provide immediate visual summaries of status of the region, and status of each species, making comparison among species easy (Fig. 3). The ''Current Status'' and ''2 Year Prognosis'' text provide brief summaries of the basis for the stoplight evaluations. This method, which relies on scientists and managers going through the evaluation process outlined in Table 2, then meeting in an expert panel to discuss the results and develop the report card, allows recognition of progress (e.g., alligator weed, Australian pine, melaleuca, Fig. 3), incorporation of new information where data may be lacking (e.g. West Indian marsh grass, torpedo grass, Fig. 3), as well as evaluation and monitoring of on-going control programs (e.g. hydrilla and water lettuce, Fig. 3).

This stoplight approach allowed us to incorporate geographical information that is of interest to managers and policy makers for different parts of the south Florida ecosystem, or to focus on species of concern to address how restoration efforts are affecting spread or control of particular species. The approach is useful for illustrating the current status and predicting short-term status, based on trends observed in the data. In presenting a restoration report card for synthesizing and communicating complex and diverse data about exotic species, we believe this approach could easily be tailored to other ecosystem restoration programs.

4. Longer-term science needs

Monitoring invasive exotic plants is essential to be able to understand the status of these species and their possible impacts on restoration. A particular problem with monitoring exotics and using presence/absence data is the asymmetry in presence/absence data. A species can be absent because it was actually not there or because it was not detected (i.e., the sampling program may not be capable of detecting it or the methodology may not be designed to detect species in certain situations). The four independent monitoring programs being used for the South Florida exotic plant indicator need to be reviewed for accuracy and precision in detecting exotic plants on a system-wide basis. When gaps in these programs (e.g. gaps in spatial coverage, differences in accuracy and repeatability) are evaluated, we will be able to determine our ability to assess the overall status of invasive exotic plants in relation to restoration. The advantage of our approach, however, is that we have a systematic way to make this evaluation. This indicator, as a tool for presenting an assessment of invasive exotic plants, will only be able to insure an accurate system-wide analysis if the methods used to collect the data are understood, evaluated and integrated.

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