On the application of the cyberinfrastructure model for efficiently monitoring invasive exotic species

By Kurt Lewis Helf

INVASIVE EXOTIC INSECT FOREST pests and pathogens (IFPs) pose a serious, permanent threat to natural and cultural resources in parks administered by the National Park Service (NPS). Though the attrition of these immigrant species is undoubtedly great, the few populations that survive are, de facto, part of the affected community, and can have a profound influence at the population, community, and ecosystem levels (Mack et al. 2000). Oak (*Quercus* sp.), the most abundant tree genus in many forested southeastern units of the National Park System (NatureServe, R. White, ecologist, personal communication, August 2009), is under constant threat from multiple IFPs (fig. 1). A serious outbreak of an exotic species with a wide host range (e.g., European gypsy moth, *Lymantria dispar*) could affect energy and nutrient flux in the short term (Fajvan and Wood 1996; Lovett et al. 2006). A potent exotic invasive (e.g., hemlock woolly adelgid, *Adelges tsugae*) could, by killing dominant tree species, alter the hydrologic processes and successional dynamics of an entire ecosystem over the long term (Ellison et al. 2005; Stadler et al. 2006; Ford and Vose 2007; Nuckolls et al. 2008). Further, IFPs' effect on forested areas is approximately 45 times greater than wildfire because the damage is incurred over a greater area, relatively synchronous, and continuous over a period of years (Dale et al. 2001). Interactions between stressors such as IFPs and global climate change could lead to compounded effects that further increase the likelihood of long-term, unpredictable alterations to forest ecosystems (Paine et al. 1998; Hansen et al. 2001; Walther et al. 2002). Finally, their estimated annual aggregate economic damage is estimated in the billions of dollars (Pimentel et al. 2000; Dale et al. 2001). The environmental and economic damage caused by IFPs justifies their monitoring by numerous federal and state agencies, universities, and nongovernmental organizations.

Cyberinfrastructure stimulus

Numerous entities acquire and publish valuable IFP information on the Internet and so collectively constitute a robust cyberinfrastructure to be harnessed as an adjunct to monitoring in the field. To be effective as an NPS monitoring tool, the IFP cyberinfrastructure should at least (1) provide data on their characteristics and location, (2) provide watch lists for new and established IFPs at several scales, (3) send early detection alerts, (4) model the current and predicted extent of an IFP's range, and (5) provide information on best management practices for rapid responses to new invasions (Graham et al. 2008; Galaz et al. 2010). The prompt dissemination of such information enables NPS park managers to plan a response in advance of when an IFP is detected within a park. Rapid response to the early stages of an outbreak is critical to stopping its spread and minimizing its impact on native ecosystems (Liebhold and Tobin 2008). However, conventional Web searches would be tedious and inefficient in that the user would have to filter out verified information, such as USDA–Forest Service data, from among hundreds of thousands of hits (e.g., the search term "gypsy moths" yields more than 700,000 hits). A number of group efforts (e.g., the Global Invasive Species Information Network, http://www.gisinetwork.org/) are aimed at realizing a relatively self-contained invasive species cyberinfrastructure wherein data could be efficiently acquired (fig. 2, next page); limited funding decreases the likelihood that these goals will be met with alacrity. However, the recent introduction of tools that exploit Web 2.0 enables concerned individuals to efficiently acquire data on IFPs from extant cyberinfrastructure.

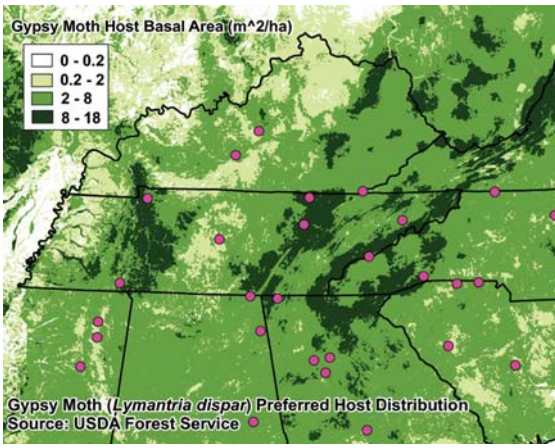

Figure 1. Distribution of white oak (*Quercus alba*), the gypsy moth's preferred host species, by basal area (m^2/ha). Basal area is closely correlated with foliage cover. Dots indicate locations of national parks in the Southeast Region.

Web 2.0 refers to those Web sites that allow users to contribute, share, and ma-

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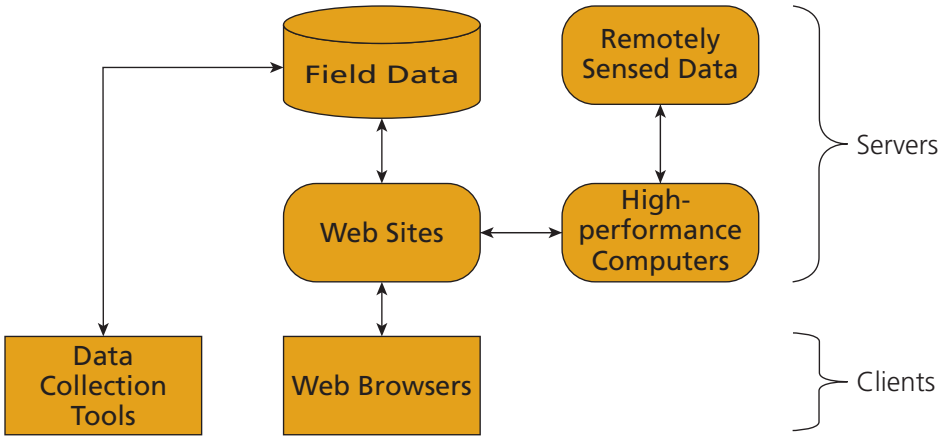

Figure 2 (above). Model for invasive species cyberinfrastructure (from Graham et al. 2008 with permission).

nipulate (or "mash up") data rather than passively viewing or retrieving it. Since the software applications that provide this functionality are run entirely through Web browsers, users avoid expending their own scant resources. Web feed formats such as Really Simple Syndication (RSS) are the key to efficiently using cyberinfrastructure to access IFP data on federal, state, and nongovernmental Web sites. The nearly ubiquitous RSS icon (fig. 3) indicates that a Web site contains a feed, to which viewers can subscribe, that displays frequently updated content in a standard format. The feed displays Web content (e.g., news stories, videos) that typically includes a title, a summary, and a link to the source. Content is usually displayed in chronological order but can be sorted by title. Some feeds enable users to search for specific content and filter it by category (fig. 4). Thus users can manipulate a feed's content to reflect their interests. However, a feed's most convenient function allows users to receive syndicated content automatically by subscription. Subscribers can view the feed page on any electronic device that supports a Web browser (e.g., a smart phone), or even receive it as an e-mail.

Occasionally, a useful IFP Web page is not syndicated via an RSS feed. In these cases, Feedity.com provides a service that lets users generate RSS feeds from almost any Web page. For example, the North American Plant Protection Organization, a group of North American countries that promotes protection of plant resources while facilitating trade, posts pest reports on its Web site and disseminates them via e-mail, but does not syndicate their reports via RSS. Using Feedity.com, I created an RSS feed of their Official Pest Reports, information compliant with the Food and Agriculture Organization of the United Nations' International Plant Protection Convention Standard on Pest Reporting, to serve as another convenient, official source of early detection data on exotic invasive species.

Distilled information

A topic as important as insect forest pests and pathogens generates a large amount of Web content, and each source potentially has its own subscribable RSS feed. Thus, the large number of RSS feeds to which one could subscribe would quickly become unwieldy and reduce their utility. However, a number of free, Web-based services (e.g., Yahoo! Pipes, FeedRinse, feed.informer) enable their users to "work smarter not harder" (Farley 2008). For example, Yahoo! Pipes is a free, Web-based application that enables users without programming experience to sign up and collect and manipulate content from multiple RSS feeds and Web pages (fig. 5). With a Yahoo! Pipes account (hereafter, "Pipes") users can aggregate content in which they are interested from multiple RSS feeds and distill it into a single digest. Simple Pipes can be constructed in minutes but the learning curve for constructing more elaborate Pipes is steep; fortunately there are a number of instructional Web sites, including a Yahoo! Pipes developer's forum, as well as several "how to" books (Loton 2008).

Pipes are created in the Pipes Editor by dragging and dropping preprogrammed modules from the Library pane onto the Canvas pane and linking their terminals (fig. 6). These modules are what make Pipes such a powerful, efficient filter, because they allow users to access a wide range of data from the cyberinfrastructure, such as data formatted in comma-separated values, images, and text. The modules can even translate RSS feeds into English from 12 different languages. Furthermore, users may configure search parameters and input/ouput fields in most modules and thereby specify the information extracted by the Pipe. Users can test the functionality of their customized Pipe by clicking the Pipe Output module and examining the results in the Debugger pane (fig. 6).

Dual wield

While constructing elaborate Pipes requires knowledge of Web programming languages, users can search for Pipes made by those adept in Web programming by topic or function, "clone" the pipe, and easily adapt it to suit their purposes (fig. 7). There are two obvious applications to IFP monitoring: (1) the "formal user," the project leader, could employ Pipes as a sort

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Figure 3. RSS icon.

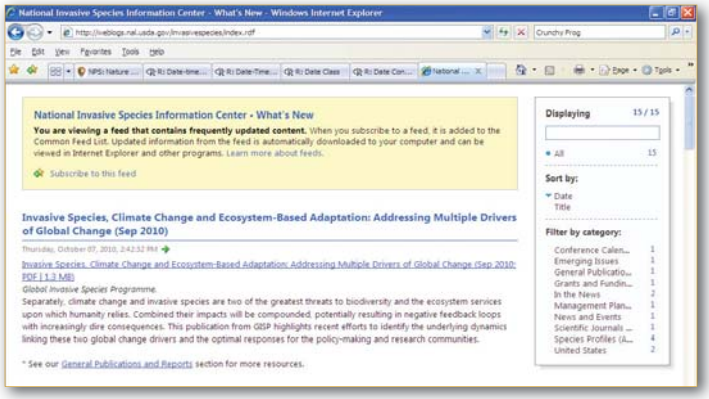


Figure 4. USDA National Invasive Species Information Center feed page. Feed pages enable users to subscribe to the feed and thereby receive automatically updated content. The additional functions to manipulate and customize displayed Web content are at right.

Figure 5. Yahoo! Pipes home page. Yahoo! Pipes can be used with Internet Explorer and Firefox Web browsers. In the Firefox Web browser the RSS feed symbol is located in the URL window.

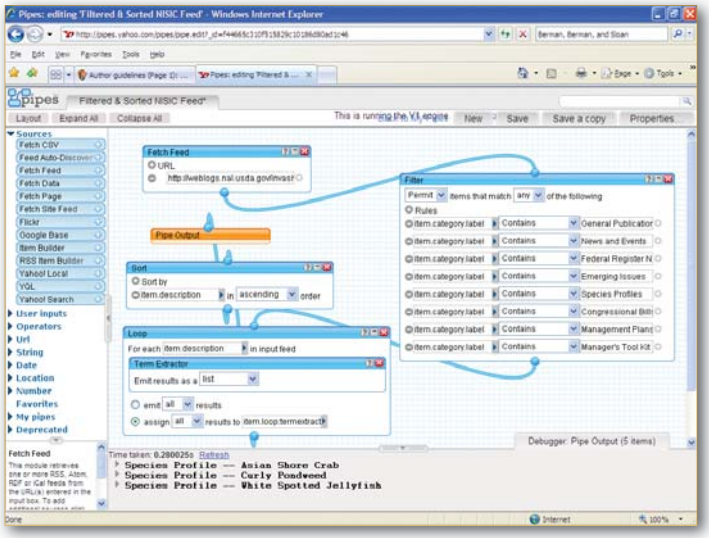


Figure 6. Pipe Editor screen in Yahoo! Pipes. Clockwise from "Fetch Feed" module at the top of the screen: each module, linked at the module's terminals, enables users to download, filter, configure, sort, and emit Web content. Individual modules (in this case, "Fetch Feed") are defined by example in the lower left pane. The "Debugger: Pipe Output" pane at the bottom enables the user to test the Pipe's functionality by clicking on the "Pipe Output" module.

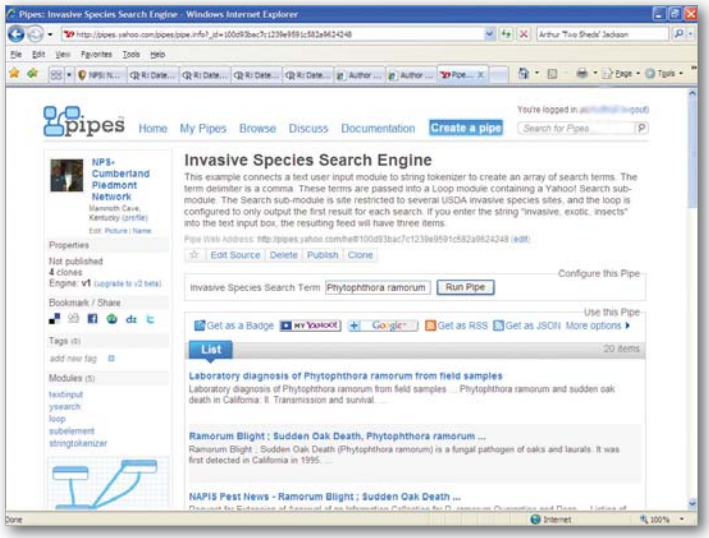
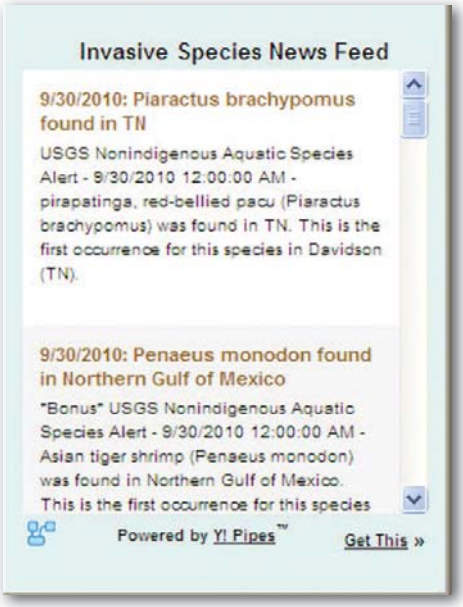


Figure 7. This searchable Pipe was "cloned" from a Pipe constructed by a more adept user and modified to suit my purpose: a Pipe that searches state and federal databases for IFP information. This Pipe emitted 20 items regarding *Phytophthora ramorum*, the fungal organism that causes sudden oak death.



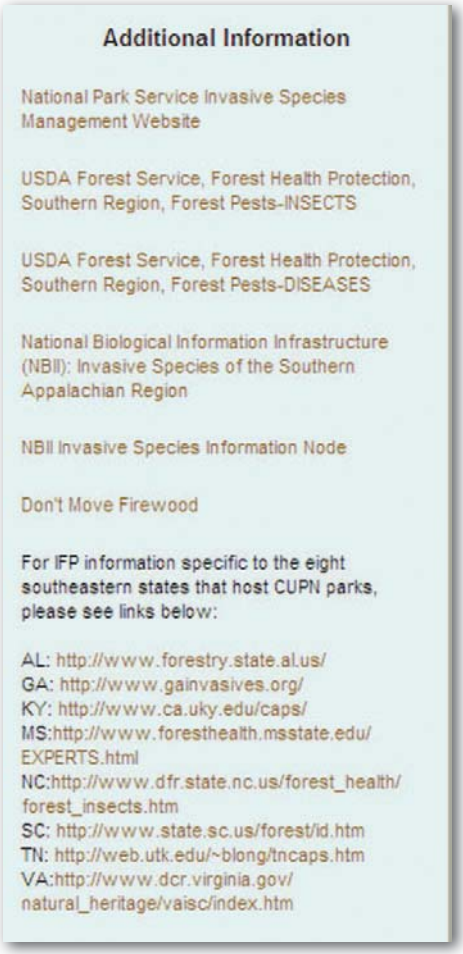


Figure 8. Examples of a badge with customized invasive species news feed (above), a third-party widget (left), and links to state and federal Web sites with information about southeastern invasive species (right) posted on the Cumberland Piedmont Network Forest Pest Web page. The "Get This" link at the bottom right of the news feed badge allows viewers to add the badge to their own Web pages.

of black box for collecting, synthesizing, and reporting information to NPS resource managers; and (2) Pipes' output could be widely disseminated or "opened up" to the "informal user," or the public (Farley 2008). This latter application is yet another avenue for providing the interested public, in addition to resource managers, with up-to-date information about this important topic.

One of the most intriguing ways to distribute customized information emitted from Pipes is to post it as a widget or "badge" on a Web site (figs. 8 and 9). Depending on the content of the custom Pipe feeds, badges can be configured in a number of ways, such as a simple list of items, a slide show of available images, or a map with geocoded locations of specific items (e.g., earthquakes). Furthermore, Pipes badges have a "Get This" link that enables viewers to add the badge to their own Web page and so disseminate the information to a different audience (fig. 8).

Practical application

The Cumberland Piedmont Network's (CUPN) forest pest Web page (http://bit.ly/9rhUZQ) uses various Web 2.0 applications that serve both NPS resource managers and the public as a clearinghouse from which verified information from reliable sources can be conveniently accessed (figs. 8 and 9). One badge posted there, a cloned and customized Pipe titled "Invasive Species News Feed," searches multiple RSS feeds from the U.S. Department of Agriculture (USDA) and the Department of the Interior, for national and international news media stories, in addition to official alerts about invasive species (fig. 8). The "Invasive Species of the Week" widget, which links to a digital (PDF) fact sheet, was provided by the Invasive Species Specialist Group, a global network of scientific and policy experts on invasive species. The widget was designed to raise awareness of the impacts of invasive species on native biodiversity and threatened ecosystems. More conventionally, the CUPN Forest Pest Web page also hosts multiple links to state and federal government Web sites with information about IFPs affecting the Southeast (fig. 8). Finally, another cloned, customized Pipe, the "Invasive Species Search Engine" badge, enables interested parties to simultaneously search multiple USDA RSS feeds for news media stories, official species profiles, survey data, distribution maps, management plans, and grants (fig. 9). This badge also searches feeds from both the North American Plant Protection Organization's Phytosanitary Alert System and the United States Geological Survey's Nonindigenous Aquatic Species Alert System for official reports on exotic insect and aquatic species, respectively. After users conduct a search, they can click on "Subscribe to this feed" to begin receiving a custom RSS feed based on the results of their search (fig. 9).

Conclusion

Efficiencies realized by using the cyberinfrastructure to mine, synthesize, and disseminate IFP data should have positive repercussions for inventory and monitor-

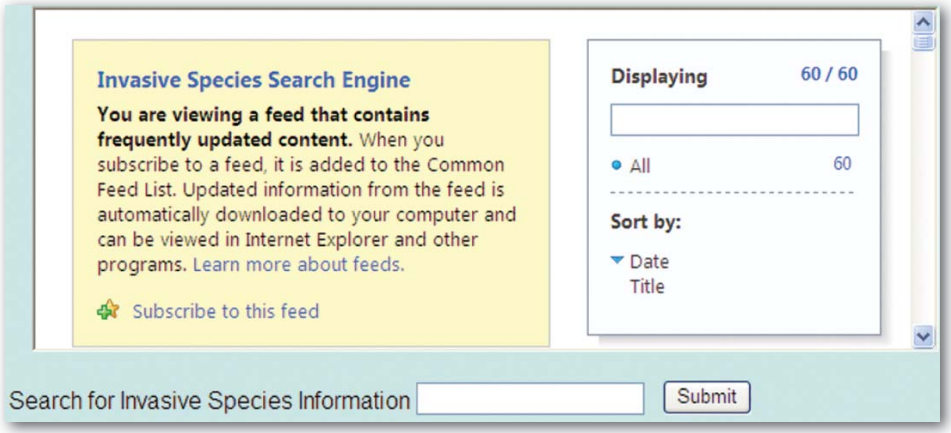


Figure 9. Searchable custom badge posted on the Cumberland Piedmont Network's Forest Pest Web page.

ing programs. These efficiencies should allow resource managers to reduce preparation time for management assistance requests in response to IFP outbreaks. Rapid response is critical to stopping IFP spread and minimizing their impact on native communities. The National Park Service will also realize cost savings by mining data collected by other governmental and nongovernmental agencies. Using these tools presents an opportunity to better inform the public of NPS efforts to monitor IFPs. Keeping the interested public informed about this vital sign, or indicator of an ecosystem's health, will buttress early detection efforts by increasing awareness and volunteer recruitment. However, the uses and research topics to which the Web 2.0 tools detailed in this article could be applied are manifold.

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