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PERSPECTIVES AND PARADIGMS

Developing cost-effective early detection networks for regional invasions

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Abstract Early detection and rapid response (EDRR) seek to control or eradicate new invasions to prevent their spread, but effective EDRR remains elusive due to financial and managerial constraints. As part of the Great Lakes Early Detection Network, we asked stakeholders to indicate their needs for an effective EDRR communication tool. Our results led to the development of a website with five primary features: (1) the ability for casual observers to report a sighting; (2) a network of professionals to verify new sightings; (3) email alerts of new sightings, including data from all data providers across the region; (4) maps of species distributions across data providers; and (5) easy communication channels among stakeholders. Using results from our stakeholder discussions, we provide a cost-effective framework for online EDRR networks that integrate data and develop social capital through a virtual community. This framework seeks to provide real-time data on current species distributions and improve across jurisdictional collaboration with limited oversight.

Keywords Early detection · Rapid response · Data synergy · Virtual community · Social capital

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Introduction

Early detection and rapid response (EDRR) has commonly been cited as a best management practice for controlling and/or eradicating new biological invasions (Westbrooks 2004; Wittenberg and Cock 2001). A national model for effective EDRR has been described for invasive plants (FICMNEW 2003), but its implementation has been hampered by inadequate financial resources and the difficulty in managing such efforts across jurisdictional boundaries (US General Accounting Office 2001). Examples of successful eradication or control of plant species using EDRR methods are rare (Simberloff 2003) as are efforts that seek to protect entire ecosystems (Hulme 2006).

Failures in implementing EDRR may be an artifact of ignoring a basic tenet of success: knowledge of the current distribution and abundance of known invaders. All of the elements described for effective EDRR (i.e., detection and reporting, identification and vouchering, rapid assessment, planning, rapid response;

FICMNEW 2003) require this knowledge to be successful (Crosier and Stohlgren 2004; Lodge et al. 2006; Myers et al. 2000). However, research has shown that most local and regional invasive species datasets within the United States remain unconsolidated for professional and volunteer data contributors (Crall et al. 2006, 2010), leaving gaps in our knowledge of species distributions. The lack of data sharing of species occurrence records strongly limits our ability to detect the arrival of new invaders and respond effectively (Graham et al. 2008; Ricciardi et al. 2000).

These issues were brought to light at a regional workshop in January 24–25, 2008 held at the University of Wisconsin-Madison. Multiple stakeholders (N = 91) from the Midwest (Illinois, Indiana, Iowa, Ohio, Minnesota, Michigan, Missouri, and Wisconsin) discussed how to implement a more collaborative EDRR network in the region. A primary goal of the workshop was to provide a forum for stakeholders to share information and approaches on data collection and management and to alert local natural resource managers of existing resources and software tools available to them for data sharing.

At that time, many of the states did not have a statewide data management system available and, of the groups across the region that collected invasive species data, many had no knowledge of data collection efforts occurring elsewhere. State (e.g., the Invasive Plant Association of Wisconsin; IPAW) and regional groups (e.g., the Midwest Invasive Plant Network; MIPN) identified mapping and monitoring as critical areas and expressed interest in improving regional collaboration, but progress has been slow due to personnel and funding constraints.

The great lakes early detection network

Since the 2008 workshop, efforts have continued to improve collaborative approaches to invasive plant species data collection and management. Recently, the University of Wisconsin-Madison, in partnership with the National Park Service and MIPN, received funding to initiate a Great Lakes Early Detection Network (GLEDN). The Network fosters invasive species data sharing and increases awareness of invasive species issues, facilitating rapid response and management efforts for newly reported populations of invasive plants. As part of this partnership, we gathered feedback from stakeholders in the region on their needs for an effective, web-based EDRR network. We use this feedback to propose a cost-effective framework for EDRR that could be adopted nationally and globally.

Methods

In 2010, we held three open discussion sessions with regional stakeholders (e.g., natural resource managers, researchers, and volunteers) to gain input on their needs for a web-based EDRR network. Discussions lasted approximately 1 h and targeted five areas: (1) type of alerts (e.g., email, RSS); (2) data type (e.g., presence, treatment); (3) online data management; (4) data quality; and (5) web-based communication. Our methods allowed us to use qualitative methods similar to focus group research to conduct analyses on the feedback we received (Krueger and Casey 2000). We recorded each discussion to identify themes and categorize results, taking into account frequency, specificity, emotion, and extensiveness during this process (Krueger and Casey 2000). Frequency refers to how often something was said while extensiveness refers to the diversity of people that said it. Specificity refers to the detail provided in a comment, and emotion accounts for comments in which stakeholders showed strong emotions (positive or negative; Krueger and Casey 2000).

Results

One hundred and seventy individuals participated in these open discussions. Participants represented diverse organizations (Table 1) scattered across 17 states (Colorado, Connecticut, Georgia, Illinois, Indiana, Massachusetts, Michigan, Minnesota, Missouri, Montana, New Hampshire, New York, Ohio, Pennsylvania, Vermont, Virginia, Wisconsin) and one Canadian province (Ontario). We identified four primary themes representing the needs of these individuals for an effective web-based EDRR: (1) online data management services; (2) email alerts; (3) online mapping; and (4) a communication network.

Online data management services

A range of web-based features were identified by the stakeholders as necessary for successful EDRR. These

Table 1 Number of participants within diverse stakeholder groups

Stakeholder group	Number of participants
Non-Profit Organization	39
State/Provincial Government	31
Local Government	16
University	14
National Park Service (NPS)	10
Local Park	10
Master Gardener/Master Naturalist/Volunteer	10
Arboretum/Herbarium/Zoo	10
Private Sector	9
Cooperative Weed Management Area (CWMA)	7
Private Landowner	6
US Fish and Wildlife Service (FWS)	3
Environmental Learning Center/Nature Center	3
Other Federal Agency	6
Tribal Organization	2

The total number of participants in this table is greater than 170 because some participants represented multiple groups

included photo sharing for species identification; smartphone applications for real-time data entry; inclusion of areas surveyed where no invasive species were found; and treatment data associated with location information. Treatment data would include the type of treatment, time of application, who applied the treatment, chemical used (if any), location, and effectiveness. Some stakeholders mentioned the adoption of a wiki-type model for viewing real-time monitoring at a specific location to see what actions have been taken and contact information for individuals that have taken those actions. Finally, many existing online data management systems require a user to be registered prior to entering a sighting. Many individuals felt this hindered sightings from casual observers. Therefore, a system that allowed online data entry with no prior registration was preferred.

Numerous stakeholders emphasized data quality as a concern. Primarily, there was a need to develop automated new sighting verification procedures. The verification process would require a network of taxonomic experts that could verify new sightings as they come in. Photo or specimen vouchers could be sent to the appropriate contact based on the reporter's location. Additional data quality features might include flagging incoming data for species locations not previously known to occur in an area or allowing observers to self-rate their expertise with the species they are reporting.

Email alerts

A majority of the discussion centered on the development of an effective email alert system that included a defined process for reporting new sightings. Attendees felt alerts should be automated and sent to a manager on the ground when a new sighting is reported while an alert to the reporter should be sent once the new sighting has been managed. Many users wanted the ability to customize these alerts for a select area and for a select species at an established frequency (i.e., immediate, daily, weekly, monthly).

The selection of the type of alerts individuals wanted to receive was also commonly cited. Tiers of alerts were discussed, including: the quality of the observation (e.g., volunteer vs professional; trained observer vs casual observer); verification status (e.g., verified, non-verified); or statewide management classification (e.g., restricted, prohibited).

Online mapping

Stakeholders were interested in having a Google maps interface that displayed point, line, and polygon data that could link to metadata for each location record. The ability to add a new sighting to a map by clicking on a location was believed to benefit participation for users that do not have global positioning system units to geolocate species (e.g., casual observers).

A communication network

Many stakeholders expressed the need for easily accessible contact information to aid EDRR. Specific examples included: contact information associated with new sighting reports; contact information for who to report a new sighting to; links to best management practices for treating species; and information on local organizations that can be called on to help eradicate and/or manage new sightings. An effective communication network would also provide links to important websites and species fact sheets that could be easily accessed by anyone in need of that information. Use of social networking features would provide users the ability to share knowledge in a widely adopted forum.

Discussion

While the needs for EDRR have been previously identified and described (FICMNEW 2003; Moncrieff 2006; NISC 2003; Westbrooks 2004), limited success of EDRR has been observed. Advancements in technology may improve EDRR efforts currently limited by budgets and personnel. Such tools can increase participation of groups by developing an effective virtual community (Chiu et al. 2006) that can improve knowledge of current species distribution and abundance from professional and volunteer sources (Crall et al. 2010; Fornwall and Loope 2004; Ricciardi et al. 2000; Simpson et al. 2009).

Data integration

We know that merging disparate datasets can increase knowledge of species richness, distribution, and abundance in an area (Crosier and Stohlgren 2004). To improve EDRR efforts, data integration should be made a priority because databases that operate independently are limited (Ricciardi et al. 2000). A large-scale integration of invasive plant species data has the potential to aid management by providing the ability to track and map current plant invaders; focus management activities where there is the most need; make high-quality, real-time data available to scientists and natural resource managers; and maximize limited financial and personnel constraints.

Occurrence data for native and non-native species integrated with environmental data layers from diverse data providers can also be used to prioritize monitoring and management activities by developing habitat suitability models (Lee et al. 2008; Stohlgren and Schnase 2006). Habitat suitability models attempt to predict species distributions by relating species presence or abundance information to various environmental variables such as temperature and precipitation (Elith et al. 2006). This approach requires large amounts of data to increase model performance for invasive species at multiple spatial scales (Ficetola et al. 2007).

To facilitate the integration of invasive species data at a global scale, the Global Invasive Species Information Network (GISIN; www.gisin.org) developed an invasive species data exchange protocol (Graham et al. 2008). The protocol allows registered data providers to exchange invasive species information by linking commonly shared database fields. For example, the exchange of occurrence records requires the species' scientific name and location fields of a database to be mapped to those fields within the protocol. By requiring a minimum set of fields, the GISIN protocol facilitates data exchange while maintaining the utility of the original data provider. Therefore, this tool serves as the building block for the GLEDN.

Great lakes early detection network framework

Many stakeholders emphasized that a new online data management system was not needed as part of GLEDN's efforts. Since the workshop in 2008, some states and/or local agencies had begun use of existing online data management systems, so methods for data exchange across existing systems needed to be developed. By connecting existing systems, participation from disparate stakeholders can be improved, thus increasing the local number of data contributors. If an entirely new and disconnected system was created to replace existing systems, (1) data contributors could be lost during the transition between systems and/or (2) key stakeholders in the community, who had expended time and effort to create and develop existing systems, could be alienated.

Currently, eight known online databases store invasive plant species data in the Great Lakes region (Table 2). Each of these databases has a set of unique features that meet the needs of the region's stakeholders, and each has compiled data from multiple sources. For example, the Great Lakes Indian Fish and Wildlife Commission database has 48 different data contributors (Miles Falk, *personal communication*). The GLEDN plans to integrate data from these local, regional, and national data systems using the GISIN protocol.

With these participating systems linked, new data can be fed into a common data portal in real-time. Occurrence records will feed into the GLEDN website to facilitate data sharing among multiple data providers. The website will then host four primary features as dictated by our stakeholder discussions: report a sighting, verify a sighting, register for alerts, and communication (Figs. 1, 2).

Table 2 Online databases within the Great Lakes region, including their species and area scope

Online database	Species scope	Area scope
Cattail volunteer monitoring project	Single species	Global
EDDMapS	All taxa	National
Great Lakes Indian fish and wildlife commission (GLIFWC)	Plants	Regional
iMapInvasives	All taxa	National
Midwest invasive species information network (MISIN)	All taxa	Regional
International biological information system (IBIS)	All taxa	National
New invaders	21 Target plants; 2 invertebrates	Local
Surface water integrated monitoring system (SWIMS)	Aquatic plants and animals	Wisconsin

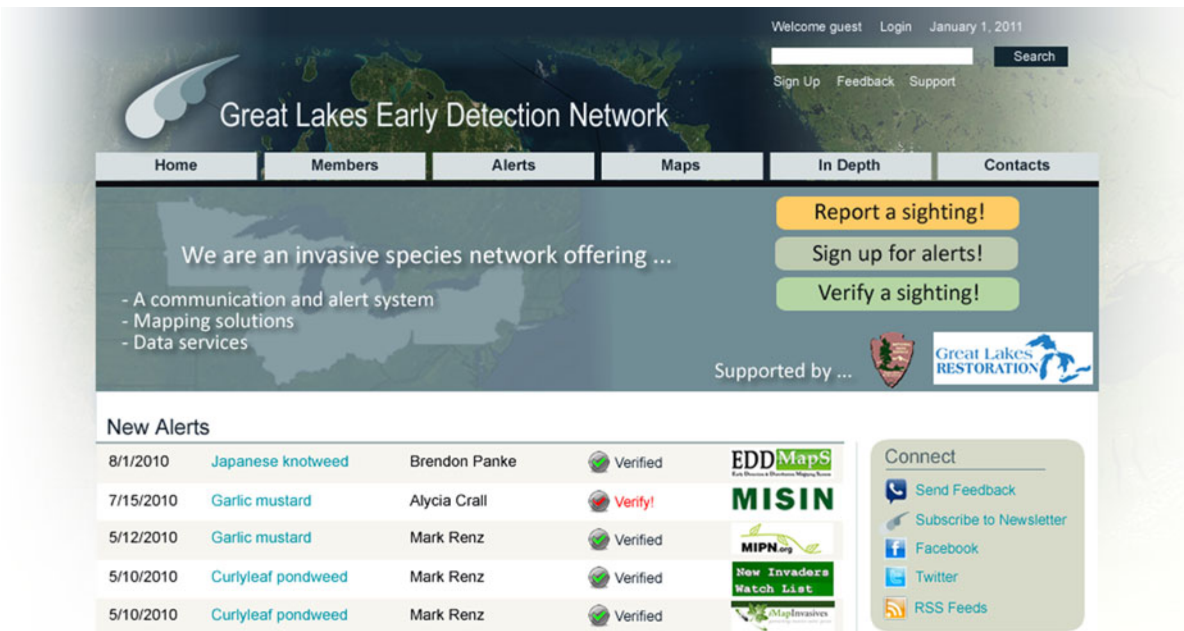

Fig. 1 The GLEDN website homepage with its three primary features *highlighted* (report a sighting, sign up for alerts, and verify a sighting). New alerts will be continuously displayed along with the data provider from which the alert originated

Report a sighting

Many existing data management systems require a user to register with the website, potentially limiting observations from casual observers. These potential data contributors need the ability to quickly report a new sighting without completing a registration form. Therefore, GLEDN's website will have a button on its homepage, "Report a Sighting," which does not require registration (Fig. 1). A user will be able to an online data entry form for which they can select a species, enter a location, and upload pictures for verification. Once submitted, these observers will be acknowledged for their contribution and provided with a link to find additional information on invasive species (Fig. 2). The intent is to facilitate education and continued involvement in monitoring by these individuals. These new sighting entries will be tagged as coming from a "guest" user and will require verification prior to an alert being sent to our registered members (Fig. 2).

Verify a sighting

As part of this collaborative effort, MIPN will generate a network of professionals spatially distributed throughout the region to verify new species sightings as they are generated from the "Report a Sighting" feature (Fig. 1). Each verifier will be assigned to a county or counties based on where they currently reside or work. Email alerts will be sent to the appropriate contact when a new sighting is reported in each verifier's target area (Fig. 2). This email will contain a link to the new record with an option for the verifier to verify the record as entered or to ask for additional information (i.e., photo or specimen voucher) from the original reporter. Acknowledgement to the original reporter will be continued through this step to further facilitate education and continued involvement.

Register for alerts

The GLEDN will differ from existing data management systems by providing email alerts of new sightings across existing systems using the capabilities of the GISIN. Data contributors for the GLEDN will include those listed in Table 2 with the potential addition of others as the network grows. By clicking the button "Register for Alerts" on the GLEDN home page (Fig. 1), website users will be able to sign up for customized alerts based on an area or species of interest. Because the GISIN will only connect the GLEDN to species occurrence records, users will be directed to the original data provider for additional metadata. This guarantees that the original data provider's services are not masked or made obsolete by contributing data to the larger network.

Mapping

Mapping services that use a Google maps interface will also be available on the GLEDN website. Similar to the alert system, these maps will display point locations derived from GISIN occurrence records. Users will be able to view metadata for each point, which will send them to the appropriate data provider for additional information on each sighting. Users will also be able to customize maps by selecting species or data providers of interest. Once created, users will be able to convert these maps to the Portable Document Format (PDF) to distribute to interested stakeholders.

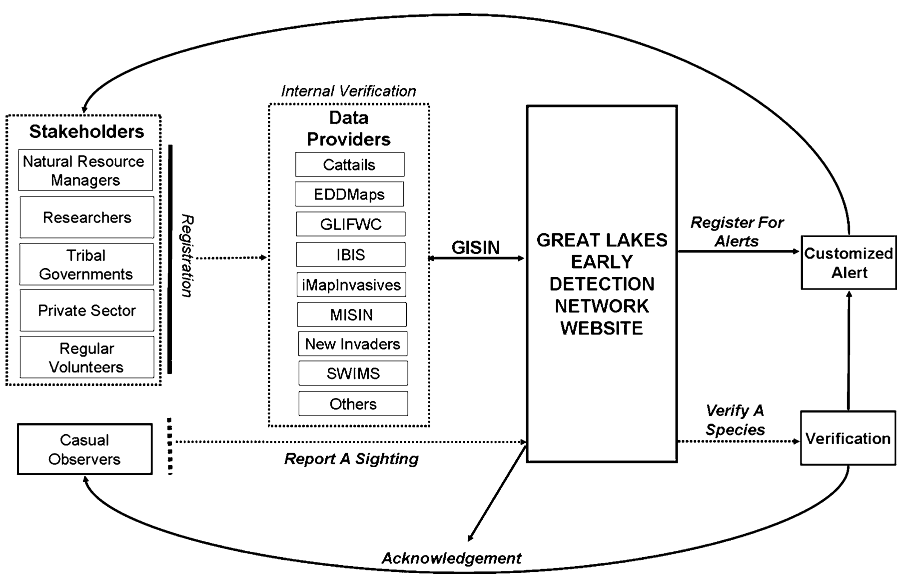

Fig. 2 The EDRR framework as developed for the Great Lakes Early Detection Network. Stakeholders contribute data using existing online data management systems. These disparate systems link occurrence records using the Global Invasive Species Information Network (GISIN) protocol and make them available on the GLEDN website. Users of the website register for customized alerts through the GLEDN website. To accommodate casual observers, new sightings can be reported directly to GLEDN without registration. These new sightings are distributed to taxonomic experts for verification

Communication

To facilitate communication among participants of the GLEDN, the website will host social networking features. These will include Facebook, Twitter, and RSS feeds. These features will provide users the ability to coordinate efforts at the regional scale and to share photos, events, and experiences relevant to the larger community.

New approaches for cost-effective EDRR

A regional EDRR network, as described here, is still limited by its spatial extent. Ideally, global efforts of this type are needed to truly address the invasive species problem, and more needs to be done to build upon existing, successful programs (Ricciardi et al. 2000). New Zealand has one of the most aggressive national programs for prevention, early detection, and containment of invasive species. New Zealand leads the Pacific Invasives Initiative, a multi disciplinary network that leverages the expertise of its participating collaborators. The initiative provides regional technical support and advice, specialist assistance, peer review, planning assistance, training and skill sharing, and information to the region's stakeholders (Cooperative Islands Initiative 2011). The success of these collaborative approaches could be easily integrated into developing programs along with new, emerging technologies as described in the GLEDN framework (Fig. 1).

The integration of occurrence data from a species' native and non-native range will improve the ability to predict the risk of invasion into new areas under future climate and land use scenarios and help prioritize monitoring and management efforts (Ficetola et al. 2007; Thuiller et al. 2005). Alert customization could grow to include the ability to select an ecosystem type (e.g., terrestrial, aquatic, marine) or new sightings of native species outside their current range. The framework could also be integrated with other emerging databases such as the Global Biological Information Facility (Flemons et al. 2007) and the Ocean Biogeographic Information System (Halpin et al. 2006). These databases could exchange information on both invasive and native species because a species that is native in one country may be invasive in another. The combination of frameworks could contribute to the Global Earth Observing System of Systems, providing an overall better picture of species distributions at local to global scales (Muchoney and Williams 2010).

Considering the lack of financial resources available to hire national and regional coordinators, the development of an online virtual community of invasive species stakeholders may provide the resources necessary to facilitate EDRR with limited managerial oversight (Chiu et al. 2006). Virtual communities are "online social networks in which people with common interests, goals, or practices interact to share information and knowledge, and engage in social interactions" (Chiu et al. 2006). Participation in virtual communities can increase social capital while having a significant and positive effect on knowledge sharing (Chang and Chuang 2011).

Participation in virtual communities is voluntary, so considering the motivations of the community's stakeholders will be essential to the success of such an approach. Several social science studies have found motivations for contributing knowledge within these communities to include identification with a common subject (Chiu et al. 2006), shared language and mutual knowledge (Cramton 2001), enhancement of professional reputations (Wasko and Faraj 2005), and seeking knowledge to resolve problems (Chiu et al. 2006). As a consequence, the likelihood of this approach being successful within the invasive species community should be high.

Efforts for effective knowledge sharing could go beyond basic social networking websites to include an invasive species wiki. The use of wikis for sharing scientific information has been growing in recent years (Waldrop 2008) due to their ability to transform historical methods of publishing biological data into more dynamic approaches (Hoffmann 2008). The BugwoodWiki, developed by the University of Georgia's Center for Invasive Species and Ecosystem Health, currently provides a source of information on invasive species, integrated pest management, and forest health. "Wiki" technology provides great promise in its ability to centrally consolidate information, promote collaborative writing, and provide a channel of authoritative information for diverse audiences. However, its success will be dependent on its use by the professional community.

The model developed for WikiGenes could be adopted for an invasive species wiki to facilitate professional contributions. In this model, every word in an article is contributed to its author and metadata on authors are provided. Users can also rate contributions by each author to generate a self-regulating reputation system in a peer review manner consistent with traditional scientific publishing (Hoffmann 2008). Hyperlinks could also be added to provide readers with information on terminology used and associated references. A specialized "wiki" site provides a mechanism of appropriate peer review for all articles and restricts contributors to qualified individuals. This will allow articles to achieve academic status for referencing purposes and ground the content solidly in the knowledge base of the discipline.

Smartphones also provide tools for rapid and efficient dissemination of new data to facilitate EDRR. Most smartphones feature high-resolution cameras, GPS, and Internet connectivity, making them ideal devices for reporting sightings of invasive plants and animals. Several smartphone applications have been developed for invasive species. The application, What's Invasive, has been drawing attention among the scientific community (Meadows 2011). The University of Georgia's Center for Invasive Species and Ecosystem Health has also developed a scaled-down version of the Early Detection and Distribution Mapping System (EDDMapS) for iPhone and Android-based smartphones. These applications allow users to submit reports with images directly from their mobile devices. The first application, funded by the National Park Service's Everglades National Park, allows reporting of invasive animals and plants in Florida and features an interactive field guide. The second application, funded by the US. Forest Service's Southern Research Station, converted a regional field guide (see Miller et al. 2010) into an interactive iPhone application. These frameworks have been expanded to other regions of the country to develop applications for the Missouri River Watershed Coalition, Mid-Atlantic Early Detection Network, Southeast Early Detection Network and an application for reporting invasive insects in Massachusetts entitled Outsmart Invasive Species. Applications are currently under development for the Invasive Plant Atlas of New England and the GLEDN.

As these and new technologies become available, it will continue to be important to update methods of EDRR that can be applied across scales. By collecting input from a diverse group of stakeholders in this study, we have developed a framework and related website that incorporates their needs while laying out a vision for how the framework will continue to develop in the face of new technologies and new challenges. We hope this approach can serve as a baseline for future regional, national, and global initiatives aimed at preventing, eradicating, or containing new and existing invasions.

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