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The authors describe two invasive insect forest pests; the hemlock wooly adelgid (HWA) has already arrived in Maine, and the emerald ash borer (EAB) has not yet reached Maine, but will have a devastating effect on the state's Indian basketmakers when it does arrive. With funding through Maine's Sustainability Solutions Initiative, teams based at the University of Maine and Unity College are bringing together faculty, students, and stakeholders to better understand the threats that infestations pose to the ecology and economy of the Maine's forests and to longstanding cultural practices.

INTRODUCTION

One of the increasingly complex problems for environmental and resource-oriented science has to do with the management response to and study of the impacts of invasive species on natural resources. Developing scientific research programs that are both accurate and responsive to the needs of resource managers and users is the topic of this essay. Here, we see how two research teams working through Maine's Sustainability Solutions Initiative (SSI) are addressing two different exotic forest pests, the hemlock woolly adelgid (HWA) and the emerald ash borer (EAB), by working with various partners and stakeholders to produce results that will assist the citizens of Maine to more effectively address the threats to their natural resources.

TWO SPECIES, MULTIPLE PROBLEMS

Most Maine citizens can readily envision a forest dominated by eastern hemlock. Such forests are known for their tall tree boles carrying densely foliated branches that cast dim, dappled light on a sparsely populated understory. The effect is a cool, serene park-like atmosphere. Such forests mark a late-successional end point to the forest communities of this region and as such serve as critical habitat for white-tailed deer and numerous bird species, including ruffed grouse and a variety of warblers. For our neighbors in the southeastern part of the country, however, hemlock forests may invoke very different images: skeletonized canopies, well-lit understory environments, and warming trout streams. In fact, in Shenandoah National Park, as many as 80 percent of the hemlocks have died due to infestation with the hemlock woolly adelgid, a sap-sucking insect native to East Asia. In southern New England, hemlock abundance has declined dramatically. Parts of Connecticut have experienced a 70 percent decline (Small, Small and Dreyer 2005), and researchers in Massachusetts have reported widespread hemlock mortality, with remaining trees averaging a greater than 50 percent needle loss (Orwig, Foster and Mausel 2002).

Following its initial introduction in the eastern United States in Richmond, VA, around 1950, the HWA has spread throughout the hemlock range. It was first discovered in Maine in 1999 on nursery stock transported from Connecticut. The first infestations in Maine forests were discovered in York and Kittery in 2003. Currently HWA has established itself in 29 Maine townships located in Cumberland, Lincoln, Sagadahoc, and York counties. Researchers and officials find new infestations every year.

HWA populations are checked by extreme cold, and in laboratory experiments adelgids rarely survive in temperatures below -30° C (Parker et al. 1998). Currently, the cold temperatures in mid- and northern Maine help to control population spread in that area. However, the fact that hemlock stands tend to produce

Common Names	Latin Names
Plants	
Ash	*Fraxinus* spp.
Brown ash	*Fraxinus nigra* Marshall
Green ash	*Fraxinus pennsylvanica* Marshall
White ash	*Fraxinus americana* L.
Black birch	*Betula lenta* L.
Eastern hemlock	*Tsuga canadensis* (L.) Carr.
Red maple	*Acer rubrum* L.
Birds	
Ruffed grouse	*Bonasa umbellus*
Black-throated green warbler	*Dendroica virens*
Insects	
Hemlock woolly adelgid	*Adelges tsugae* Annand
HWA predators	
Hemlock woolly adelgid lady beetle	*Sasajiscymnus tsugae*
Tooth-necked fungus beetle	*Laricobius nigrinus*
Emerald ash borer	*Agrilus planipennis* Fairmaire
EAB predators	
Smoky-winged beetle bandit	*Cerceris fumipennis*
Mammals	
White-tailed deer	*Odocoileus virginianus*

Hemlock Wooly Adelgid Life Cycle

The HWA life cycle is tied to the production of new hemlock needles and consists of two parthenogenetic generations per year. The overwintering adelgid population (sistens) develops from June to March. Newly emerged sistens settle on young hemlock needles over the summer and begin feeding on ray parenchyma cells at the needle bases in the early fall. The sistens feed throughout the winter and produce a second parthenogentic population the following spring (progrediens). The progrediens continue to feed on the same needles as their parents.

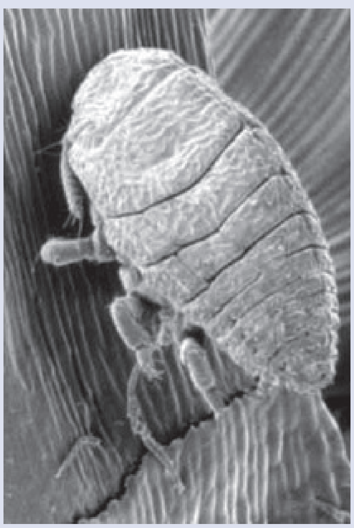

Photo above left: http://www.nps.gov/neri/naturescience/hwa.htm

Photo above right: Chris Evans, River to River CWMA, Bugwood.org, http://www.forestryimages.org/

milder microclimates (Lishawa, Bergdahl and Costa. 2007), combined with the evolution of cold resistance in HWA populations (Butin, Porter and Elkinton 2005) and future climate warming, may lead to increased HWA in the northern stands. In fact, according to a recent study, HWA has the potential to spread throughout the hemlock range within the next 30 years (Albani et al. 2010).

The aftermath forests of states with a longer history of HWA infestation provide clues about what may happen in Maine. Forests south of Maine's borders are becoming increasingly dominated by deciduous hardwoods as mature hemlock trees die. In some parts of southern New England, black birch and the already ubiquitous red maple are regenerating under the dying hemlocks (Orwig and Foster 1998). We also expect to see an overall increase in herbaceous plant diversity that includes a significant increase in opportunistic, invasive species as the once thick canopy begins thinning, allowing light to penetrate to the forest floor. Effects on wildlife are also expected. There are at least eight bird and ten mammal species strongly associated with hemlock forests of the northeastern United States (Yamasaki, DeGraaf and Lanier 2002) and future conservation of these species could prove problematic when hemlock is absent. The limited data available on wildlife populations in diseased stands indicate changes in the wildlife communities. For example, Connecticut has witnessed significant declines in populations of the black-throated green warbler in HWA-infested stands (Tingley et al. 2002). Consequently, as hemlock becomes rarer, we expect shifts in the distribution of wildlife in Maine forests. Given that Maine is more forested than any other state and almost 10 percent of that forest is comprised of the hemlock/red spruce cover type, we have to ask: "How will Maine's forested landscape be altered by the hemlock woolly adelgid and how can Maine citizens prepare for this change?"

While hemlock forests are found throughout the region, Mainers may have less familiarity with the often wet, low-lying environments that support the growth of brown ash (also referred to as black ash) trees—although many Mainers have white and green ash lining the main street of their towns or for shade in their yards. As in the hemlock forest described above, an invasive insect threatens to destroy the ecology of this place and erode the deep cultural heritage associated with this tree species. Unlike the hemlock woolly adelgid, the emerald ash borer, or EAB, is not yet found in Maine. The EAB is an invasive beetle from Asia that has caused widespread loss of ash across the central and northeastern United States, killing at least 50 to 100 million trees. EAB was first discovered in the U.S. in Michigan in 2002 and despite aggressive eradication efforts has since spread to 15 states and two Canadian provinces. Since first detected in Detroit, EAB has spread outward, most recently appearing in New York and Quebec (Kovacs et al. 2010; USDA-APHIS 2011). EAB is projected to spread across much of natural range of ash species in the Northeast by

2019 (Kovacs et al. 2010). Kovacs et al. (2010) estimate the economic impact of EAB-related street tree removal and replacement in a 25-state region at $10.7 billion—a cost that excludes community and residential amenity values associated with the loss of street trees, or losses to forest landowners and the forest products sector due to tree mortality, restrictions on wood movement during quarantines, and falling stumpage values as ash markets respond to a glut of dead and dying trees. EAB dispersal occurs when adult beetles fly to a new host tree (usually less than 100 meters), or more significantly, when people unknowingly transport infested trees, logs, or firewood to new locations (Kovacs et al. 2010).

PREVENTING AND RESPONDING TO INFESTATIONS

Both of these infestations require rapid, thorough, and resource-consuming responses. In response to the spreading HWA pest, the Maine Forest Service (MFS) has been conducting annual surveys for HWA, and in 2009 the state began developing a coordinated monitoring program with New Hampshire and Vermont. MFS has also placed the townships of Eliot, Kittery, Ogunquit, South Berwick, Wells, and York under quarantine, which limits the movement of hemlock materials within Maine and across state boundaries. Chemical and biological control methods also are being used to reduce HWA's spread. Chemical control methods include several pesticides such as systemic insecticides with the active ingredient imidacloprid. The long-term economic and ecological costs of the pesticides result in limiting their use to individual specimen trees, usually with outstanding cultural value. In the hopes of protecting forested stands, biological control agents have been released in Maine. Between 2004 and 2010, more than 38,000 individuals of two predatory beetles have been released in Maine to control HWA spread (Maine Forest Service 2011).

As in the case of the HWA, surveys and monitoring are crucial to EAB control efforts, as early detection can lead to a higher probability of success (Katovich and McCullough 2010). Pheromone traps and girdled "trap trees" can be used to detect EAB and to monitor the spread of an infestation once discovered

Emerald Ash Borer Life Cycle

The EAB's life cycle takes one year. Adult beetles take flight in May and June to feed on ash leaves for three to six weeks. EAB mate during this narrow time frame, and females oviposit after several weeks of feeding. Between late July and August, each female lays 30 to 90 eggs on the surface of ash bark or in its cracks and crevices. The eggs hatch in two weeks, and the larvae burrow into the bark to feed on the cambium and phloem from late July through October. This severs the sapwood, damages the phloem and xylem, and disrupts the tree's nutrient and water transport. Pupation occurs in April and May, and adult beetles emerge from their host trees through D-shaped exit holes (Poland and McCullough 2006).

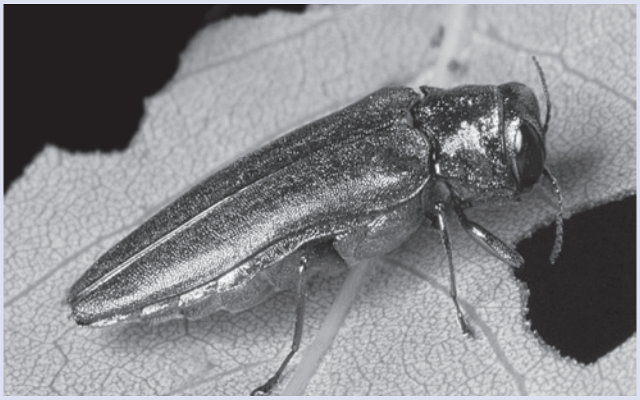

Photo: David Cappaert, Michigan State University, Bugwood.org http://www.forestryimages.org

(Marshall et al. 2009). Purple pheromone traps can be used to detect adults at high population densities. These two-foot-long corrugated plastic purple prisms can be seen in certain areas of the state hanging vertically from a branch of an ash tree in an area that regulators believe is particularly likely to attract EAB. Girdled trap trees are more effective at detecting low EAB densities (Lelito et al. 2008). Girdled trees are more reliable indicators than pheromone traps, but girdling is costly and results in delayed detection since it requires waiting for any eggs laid on each new trap tree during the summer to develop into larvae and then adult beetles (Cappaert et al. 2005).

Once EAB is detected, state and federal governments develop quarantines to prevent further spread at the landscape scale (Poland and McCullough 2006).

Quarantines regulate the movement of ash trees, logs, firewood, and other products to prevent the insect from being transported to new locations. Sometimes vacuum or heat treatment can be used to kill larvae or adult beetles residing in ash lumber before it is transported (see, for example, Chen et al. 2008). Insecticides can be applied to individual trees preemptively although they are more often applied after infestation has occurred.

With the possibility of losing a dominant tree species in parts of Maine, managers and landowners want information about how best to manage their hemlock forests either before or after HWA [hemlock wooly adelgid] infestation.

Biological control agents are increasingly being used in infested stands. Hymenopteran parasitoids of EAB from the insect's native range in Asia have been tested for introduction to North America as potential control agents (Liu et al. 2007; Duan et al. in press). Here in Maine, a native wasp that also preys on EAB is being used for biosurveillance (Careless et al. 2007). Affected trees can also be mechanically removed and destroyed. When a new outbreak of EAB is detected, all ash trees within a half-mile radius can be felled, chipped, and burned, with remaining stumps treated with herbicide to avoid sprouting (Poland and McCullough 2006). Purple pheromone traps and lures, along with girdling, can be used to draw beetles to specific trees before they are salvaged, to increase the number of adults eradicated. The mechanical method is the most common response currently being used, but it is expensive, resource intensive, and unpopular with landowners. Mechanical eradication is also relatively ineffective (Mercader et al. 2011).

STAKEHOLDERS AND SOLUTIONS: LESSONS FROM PARTNERSHIPS FOR ADDRESSING THE THREAT OF INVASIVE PESTS

Multiple stakeholder partnerships provide a key strategy for integrated efforts to prevent and respond to the threat of invasive insects. With funding from SSI, teams at the University of Maine and Unity College are bringing together faculty, graduate, and undergraduate students, and diverse stakeholder groups to better understand the ecology and economy of Maine's forests and threats to longstanding cultural practices that infestations pose.

Hemlock Woolly Adelgid Group

Research on the ecology of hemlock forests by four members of the Unity College faculty, along with a large team of undergraduates, is driven by practical concerns of stakeholders who need to make management decisions about Maine forests in anticipation of HWA. Despite some successes with the use of predatory beetles as biological control agents, decades of effort in other states indicate that there is currently little we can do to prevent widespread hemlock tree death after the pest arrives in an area (Orwig and Kittredge 2005). With the possibility of losing a dominant tree species in parts of Maine, managers and landowners want information about how best to manage their hemlock forests either before or after HWA infestation. While best management practices depend on the goals and values for a particular property, several ecological processes are fundamental to achieving these goals. For example, the manager seeking to maximize growth rates of desirable timber species relies on the ecological processes of seedling recruitment, nitrogen cycling in the soil, and decomposition on the forest floor. The Unity College research team is working to provide information for landowners and other forest stakeholders about how management decisions affect key ecological processes, along with resulting plant growth and biodiversity.

The most common options for HWA management include harvesting hemlock timber prior to HWA infestation, or leaving infested trees to die (Orwig and Kittredge 2005). The Unity College field research experiment compares logged and unlogged forest areas to answer questions about how hemlock harvesting changes the forest ecosystem in terms of tree regeneration, supporting ecological processes, and species diversity. The research results help forest managers to decide whether harvesting hemlock trees would lead to the type of ecosystem desired for ongoing forest management. Additional stakeholder questions about the consequences of leaving HWA-infested trees to die, as may be the practice on a "Forever Wild" land trust property, led the Unity College researchers to add a new dimension to the field experiment. This research includes girdling hemlock trees so that they die slowly in a process that mimics the death of trees infested by HWA.

Frequent interactions between the hemlock researchers and landowners are essential to the success of the project. The study requires working closely with local landowners, foresters, land trusts, and forest-oriented organizations to create the research questions. The researchers have learned about priorities for Mainers and different interest groups based on interactions with stakeholders. At a forest ecology workshop held at Unity College in July 2011 in conjunction with the MFS, the researchers realized that many of the participants wanted to manage their forest so that sugar maple will eventually become one of the dominant canopy tree species. Workshop participants also were interested in birds and the impact of deer. These conversations, followed by similar findings in surveys of broader groups, have led to a redirection of the research to be more focused on wildlife and forest composition following HWA infestation. The team is also continuing to work closely with the MFS to communicate management guidelines and information to broader stakeholders. One of the primary things that the team has learned is that it is important to be flexible and to be able to adapt to stakeholder interests and needs. Engaging with stakeholders changed the hemlock study process, allowed development of new, more applicable ideas, and ultimately will provide better-fitting solutions to the people of Maine.

Work with stakeholders of hemlock forests also revealed socioeconomic concerns about the loss of hemlock that are driven by how an individual or organization values the resource. Stakeholder values can be categorized as ecological, recreational, aesthetic, educational, and/or economic. Taking a walk through a hemlock stand in Maine it is easy to understand the unique aesthetic value, a perception documented throughout New England (Holmes, Murphy and Bell 2006). Hemlock is not of significant value to the lumber industry, but it can be important to local economies (Ward et al. 2004). Other economic loss could be the result of a decrease in property values and lost revenue from recreational opportunities (e.g., hunting, hiking, camping, fishing). Along with ecological data, the Unity College research team is assessing this socioeconomic piece by quantifying how stakeholders value forest resources, particularly hemlock, through a questionnaire using the contingent-valuation method. The results of this survey will inform management recommendations along with a spatial model of potential impacts. The hemlock research team is also using a geographical information system (GIS) to map hemlock throughout the state, which will allow foresters and biologists in the state to understand which areas are at greatest risk of infestation.

Emerald Ash Borer Group

Similarly, the SSI research team working on the emerald ash borer seeks to bring diverse perspectives to the problem. Four members of the University of Maine faculty, the Maine Indian Basketmakers Alliance, and two graduate students have come together to study and facilitate the ways that Wabanaki (translated, *the people of the dawn*) basketmakers, tribes, state and federal foresters, university researchers, landowners, and others come together to prevent, detect, and respond to the EAB. Building on earlier collaborative work between the Maine Indian Basketmakers Alliance, the University of Maine, and the MFS, the current group of invesigators has met with key tribal, state, and federal stakeholders over the last two and a half years (Summer 2009-Fall 2011). Of particular note to the EAB team's research has been the collaboration between the research and the needs of stakeholders, particularly Wabanaki basketmakers. In addition to numerous focus groups, this work has included three stakeholder-engagement meetings at the University of Maine, one in October of 2009 and another in May of 2010, and one focused on emergency-response planning in May of 2011. These facilitated one-day workshops have brought together a diverse set of stakeholders concerned about EAB and the sustainability of Maine's ash resources. Through these workshops and other meetings, the EAB team has identified four areas of collaborative research: (1) mapping ash resources, (2) developing policy guidance, (3) public education and stakeholder engagement, and (4) seed collection.

Maine Indian basketmakers and tribal government resource professionals from all of the Tribal nations in Maine—the Penobscot Nation, the Passamaquoddy Tribe-Pleasant Point, the Passamaquoddy Tribe-Indian Township, the Houlton Band of Maliseet Indians, and the Aroostook Band of Micmacs—have made up close to half of the partners at the three large team meetings so far. This shows the profound commitment that tribal basketmakers and tribal governments have to ash resources, particularly brown ash, in the state. One of the oldest arts traditions in North America, Native woven brown ash baskets are a critical cultural and economic resource to Maine's Indian communities. The critical cultural, social, and economic significance of brown ash to Maine Indians means that it can be thought of as a cultural keystone species (Garibaldi and Turner 2004), wherein its removal will radically change the social, cultural, and physical health of the tribal nations in Maine. It is this fact, among others, that explains the reasons that tribal basketmakers and resource professionals have been at the forefront of planning for the EAB in Maine. Moreover, two of the faculty members on the research team come from Maine Indian basket-making families and have brought their concern for this tradition with them into the research collaboration.

Originally focused on developing a cross-cultural forestry-management tool for tribal foresters to maintain and monitor basket-quality brown ash on tribal lands, the research focus changed because of stakeholder concerns and a group of researchers committed to collaborative research. Thus, a primary objective of the EAB team is to examine the connections between scientific knowledge regarding social ecological system (SES) dynamics and stakeholder actions that potentially affect SES resilience. The research team has chosen to do this by establishing themselves as a boundary organization for the emerald ash borer in Maine by convening diverse interests so that everyone involved, including the researchers, can collectively work on better solutions. Therefore, the team is not only managing the boundary between science and policy as Cash et al. (2003) suggested, but also between science, policy, and the stakeholders. The team is studying and facilitating the process of knowledge development (such as in the areas of policy and emergency response and mapping) that will lead to better solutions, and it is also "provid[ing] a forum in which information can be coproduced by actors from different sides of the boundary" (Cash et al. 2003: 8809).

To maintain this role as an engaged boundary organization, the EAB team is studying how the group of research partners develops and interacts over time with a particular emphasis on how different power positions and knowledge intersect to create barriers and opportunities for sustained collaboration. In this early phase of the research process, the team has gathered baseline data on the different ways that stakeholders see themselves participating in the process for sustainable collective action around an invasive threat. As Van Kerkhoff and Lebel (2006: 466) ask, "What is it that people do differently to shift power balances, challenge the status quo, or resolve specific sustainability problems?" The EAB team's research is also oriented around this basic question and will continue to track the barriers to and opportunities for collaboration, recognition, and integration of different forms of knowledge and enacting policy so that an invasive threat can be prevented, detected, and addressed.

The team is particularly interested in how the group interacts in a context where power and knowledge are unevenly shared and how the group creates power-sharing through a "learning" environment where "researchers and practitioners both share learning experiences with equal power to implement them in their respective contexts" (van Kerkhoff and Lebel 2006: 467). The team is purposefully aiming to create this kind of power sharing in the collaborative context, but is mindful that different forms of power relationships can exist in partnerships between researchers and practitioners (see van Kerkhoff and Lebel 2006). This approach is particularly important as the research team is working with a group of stakeholders with different forms of knowledge that are not always recognized as legitimate in policy-making contexts. By seeing themselves as mutual learners, the "researchers," or those commonly thought of as having the knowledge, are more open to different kinds of questions and different ways of answering these questions that build long-term relationships. This also means that those often thought of as "stakeholders" in such situations are more integral to the overall process that leads to regulatory, scientific, and other potential responses to the EAB threat. In the end, a mutual learning environment contributes significantly to the success on a project in which many types of people with different forms of knowledge must work together to respond to invasive forest pests and build a system of working together that will be in place for the next invasive threat.

POLICIES AND PRACTICES: ASSESSING THE SITUATION AND IMPLEMENTING SOLUTIONS

Because HWA is established in southern Maine, there is obvious concern about containing the spread. The MFS is working to educate the public on how to recognize and monitor the spread (www.maine.gov/doc/mfs/TASvolunteers.htm) and the Unity College hemlock team is collaborating with the MFS to create management guidelines for woodland owners in Maine. The primary concern facing landowners will be whether they should cut their hemlock. If landowners decide not to cut, they can expect a gradual decline of their infested hemlock trees over four to 15 years (Orwig and Kittredge 2005). If they decide to cut, they need to consider multiple variables including the time of year, equipment, severity of cut, state quarantines, and risk of infestation. Harvesting options will differ among landowners depending on whether the management goals are aesthetic, wildlife oriented, focused on water-quality protection, successional dynamics, timber revenue, or a combination of these goals. Current recommendations do not include preemptive cutting of uninfested forests since future interactions between hemlock and HWA are unknown, and the cutting could potentially remove resistant hemlock trees.

The Unity College hemlock ecosystem project is working toward an understanding of both ecological and social changes that will occur with the loss of hemlock along the coast and potentially throughout Maine. The research will provide landowners with information that will allow them to decide how to improve their woodlot for their own personal goals. This project will not provide one foolproof solution, but is working to provide information that will guide landowners toward an array of better management solutions.

STUDENT SPOTLIGHT

Erin Quigley

Ph.D. Student, School of Forest Resources
SSI Graduate Research Assistant

Erin Quigley has covered a lot of ground in her work. She's been a forestry consultant, wetlands assessor, Forest Service field technician, GIS mapper, adjunct faculty member, canoe trail administrator and "climate change superhero," among other things. In SSI, she has found a unique opportunity to combine that experience with her degrees in anthropology and sociology and natural resources to help to solve sustainability challenges. "I was drawn to SSI's focus on working with communities to find solutions to real, local problems," Quigley says. "Not many Ph.D. programs involve that kind of practical work."

What problem are you working to solve?

My research team is working with Wabanaki brown ash basketmakers to prepare for the arrival of the emerald ash borer in Maine. The EAB is an invasive beetle from Asia that destroys all species of ash trees. It was introduced to the U.S. in 2002, and it's not in Maine yet, but it's spreading in this direction. We're trying to bring together basketmakers, tribes, state and federal foresters, university researchers, landowners and others to prevent, detect, and respond to the threat.

Recently, I've been focusing on the policy creation process and state-level response planning. I'm looking at a number of issues including what has been effective so far, what states with response plans wish they had done differently, and how all stakeholders can be involved in response planning. I'm working on a white paper that I hope will be useful for resource managers in Maine and beyond.

What progress are you making toward solutions?

So far we've had several workshops to bring together collaborators, stakeholders, and experts to plan the EAB response process. We've also had seed-collection workshops for youth on Indian Island to start saving ash seeds for future replanting. We've gone out in the field with basketmakers to learn more about how they select basket trees. We're using statistical techniques that incorporate expert knowledge to map the ash resource to prioritize protection areas. And we're assisting the state in the creation of a formal EAB-response plan that works for all stakeholders, including basketmakers, the forest industry, municipalities, and others.

How could your findings contribute to a more sustainable future in Maine and beyond?

A Maine with diverse, healthy socio-ecological systems is a sustainable Maine! We hope to preserve ash species' role in the Maine ecosystem, while at the same time promoting economic and cultural well-being for all Mainers across cultural groups.

— Kim Ridley

Building on the process of collaborative sustainability science outlined above, the EAB team is helping to coordinate policies to respond to the EAB when it gets to Maine. Coordination plans are following the May 2011 stakeholder workshop on EAB-emergency-response plans, which brought together key state, federal, and tribal regulatory agencies and speakers from states already dealing with the impacts of EAB.

...hemlock and brown ash have important cultural significance to different groups of Mainers, and this requires different approaches in linking people to research and policy responses to protect resources.

The approach of the EAB partners is already addressing the potential gaps in invasive pest management. Often, the policies implemented to control an invasive species, from the local to national level, are incoherent and address small pieces of the problem rather than the whole (Simberloff, Parker and Windle 2005). Policy responses also are often applied uniformly across heterogeneous areas due to lack of local knowledge, leading to decreased effectiveness (Albers, Fischer and Sanchirico 2010). Similarly, management plans often address invasive species problems from a technical standpoint, but are less likely to address the social and economic needs of stakeholders at a variety of scales (Larson et al. 2011). The EAB group is developing more comprehensive and well-researched comparative policy analyses and management plans that incorporate both biological knowledge of EAB and an explicit consideration of the environmental, economic, and social factors that concern local stakeholders. To ensure sustainable responses to invasive species, Larson et al. (2011) recommend that management plans and associated policy not only address technical aspects of control, but also involve stakeholders and community members; expand spatial and temporal scales of cost-benefit analysis and economic-impact planning to include those stakeholders; and increase the coordination of agencies and knowledge networks to better inform plans and policies. The EAB team project is uniquely positioned to address these gaps and offer guidance to Maine, Maine tribes, and other states on management planning and policy formulation.

As one could guess by the make-up of the larger group, one of the key tenets of the EAB emergency-response-planning process has been the involvement of Wabanaki basketmakers and tribal governments. Brown ash is valued by the Wabanaki people for its use in basket making, with basket sales estimated at $150,000 annually (Daigle and Putnam 2009). Native American tribes have not been involved in invasive species response at the state level due to uneven power dynamics and long-standing struggles over sovereignty and resource jurisdiction. Few of the response plans that have already been developed in other states mention Native American tribes as a stakeholder, despite their significant forest holdings and status as sovereign nations. Few plans directly address potential impacts on tribes or how tribes might be involved in response as collaborators. Often, tribes are treated simply as an interest group on par with the forest products industry or conservation organizations.

In a broader sense, the EAB team and its partners are exploring how to further incorporate community-based collaboration into the emergency-response-planning process as a way to increase stakeholder investment and sense of ownership, increase social capital and cooperation between various agencies, groups and individuals, and disrupt power dynamics that in the past have led to the exclusion of some groups from the planning process, especially Native American tribes (Reo 2010).

CONCLUSION

Both the HWA and EAB research projects have focused on the long-term effects of invasive insects in Maine forests and on how researchers, stakeholders, and other partners can work together to produce scientific and policy responses to complex problems. These SSI projects have been driven by a need to better understand how resource use can remain sustainable in changing ecosystems and thus address Maine's cultural attributes. In the case of the EAB study, the research questions have been guided by the tribal uses of ash trees. The hemlock study investigates the role of hemlock as an ecological foundational species (Ellison et al. 2005), and the investigators seek to understand forest-regeneration patterns and invertebrate communities in hemlock forests. In working towards achieving sustainable solutions for Maine forests, both studies emphasize the valuation of the tree species based on their cultural and ecological significance in addition to their direct economic worth.

Drawing comparisons between these projects can highlight new directions for each study. For example, with the HWA already in Maine, the regulatory response has begun, and it is clear that the HWA research team has been trying to include the ecological and social perspectives that are often left out of responses to invasive pests. The HWA team has sought to broaden their stakeholder group to represent ecological, recreational, resource management, and economic interests. In response to the threat of an EAB introduction into Maine, the social values and perspectives of Wabanaki basketmakers are obviously influencing the effort to plan responses, which will lead to better processes of inclusion if and/or when the EAB gets to Maine. The EAB team has not yet engaged groups and concerns that may be harmed because of the impact of the EAB on forest ecology (for example, animals that may rely on ash seeds as part of their diet or the institutions that may care about these animals and their habitats). This approach to broadening the involved groups who will fight to protect these resources can and should happen.

The differences in strategy may have a lot to do with the resources themselves, who cares about them, and why. It is clear that both the hemlock and brown ash have important cultural significance to different groups of Mainers, and this requires different approaches in linking people to research and policy responses to protect resources. Working with indigenous resource users will always require an understanding of how different forms of knowledge and the power to access resources and regulatory institutions are situated. Working with woodlot owners to manage hemlock has more subtle, but equally complex dynamics.

In both these studies, the solutions will be determined by multiple entities that draw from the expertise of researchers, woodland owners, forest managers, tribes, basketmakers, politicians, and other stakeholders. For example, both research teams share a common goal to develop management strategies that protect forest resources in the face of pest introductions. Thus our research programs are focused on collecting data that will help guide the best management practices for hemlock-dominated forests and ash resource users. We are using multiple models to predict pest occurrence and social and ecological impacts, and are working to synthesize our findings with those from other parts of the country to help us manage these pests in Maine.

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