SECTION 1. ADMINISTRATIVE INFORMATION:

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Project title: Making decisions in complex landscapes: headwater stream management across multiple agencies

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SECTION 2. PUBLIC SUMMARY: There is growing evidence that headwater stream ecosystems are especially vulnerable to changing climate and land use, but their conservation is challenged by the need to address the threats at a landscape scale, often through coordination with multiple management agencies and landowners. This project seeks to fill a gap, providing an example of cooperative landscape decision-making to address the conservation of headwater stream ecosystems in the face of climate change.

SECTION 3. PROJECT SUMMARY: Cooperative landscape conservation approaches can improve outcomes for species, habitats and ecosystems by addressing multiple threats and utilizing diverse sets of actions available to multiple decision-makers at various spatial scales. However, natural resource managers and conservation practitioners face unique and complex challenges that can preclude the creation and implementation of optimal landscape conservation strategies. Based on our collective experience working with diverse natural resource organizations on management problems in headwater stream ecosystems, we describe nine unique challenges facing the development and implementation of landscape collaborative conservation from a decision analytic perspective. Challenges generally occurred within two major phases: 1) identifying and engaging decision-makers, and 2) creating and evaluating outcomes of alternative landscape collaborative conservation strategies. We propose that many impediments can be reduced by challenging perceived constraints, promoting creativity, and recognizing spatial and temporal trade-offs. Utilizing frameworks and tools from decision analytics can help natural resource managers and conservation practitioners more rapidly develop robust and cost-effective and solutions to complex landscape conservation problems.

SECTION 4. <u>PURPOSE AND OBJECTIVES:</u>

Because current collaborative decision-making processes are often implicit and lack clear measures of success, there is considerable variability in the perceived costs and benefits of collaborative landscape conservation (Conley and Moote 2003, Sayer et al. 2013, Cordingley et al. 2015), a lack of coherence as to why developing successful collaborative strategies can be difficult, and little guidance for agencies to quantify any benefits of collaborative conservation via measurable criteria. Thus, it remains challenging for decision-makers to assess when collaborative conservation provides benefits in addressing a resource management problem, especially when decision-makers: 1) believe they are already engaged in optimal landscape management, 2) perceive no additional benefits from implementing new collaborative actions, or 3) are faced with socio-political challenges in developing realistic collaborative strategies (Armsworth et al. 2015).

<u>Organization and Approach:</u> We describe the unique challenges facing natural resource agencies through each of 9 steps for developing collaborative landscape-scale conservation decisions (Fig. 1). We offer insights and tools from decision theory that can help identify, reduce or overcome key impediments facing decision-makers within two major phases where collaborative conservation has struggled: 1) identifying and engaging a network of decision makers in collaborative conservation and 2) creating and assessing alternative collaborative strategies. Here we relay our experience working in headwater stream socio-ecological systems, and provide guidance to improve capacity of natural resource organizations and scientists developing decision support tools to improve collaborative landscape-scale decision-making.

Our motivation was to improve the development of collaborative management of headwater streams in the northeastern United States. Although landscape conservation has been long expected to benefit headwater streams, collaborative efforts have been typically restricted to small spatial scales (e.g., site or tributary) or focused on a narrow set of actions (e.g., habitat restoration and barrier removal), resulting in project-by-project collaboration. Between February 2014 and December 2015, we held five, 2 to 4-day workshops with federal, state, and local natural resource management agencies and nonprofit organizations in three headwater stream networks (Potomac River Basin located in VA, MD, PA, and WV; Merrimack River Basin located in NH and MA; Deerfield Watershed located VT and MA). Although previous watershed initiatives (e.g., Massachusetts Watershed Initiative, Vermont Clean Water Initiative and EPA's Healthy Watershed Initiative) have increased awareness and resources available for landscape conservation, organizations involved in these efforts are challenged to assess the benefit of collaborative approaches. "Successful" efforts typically focused on information-sharing, and opportunistic collaborations based on the funding availability. Potential reasons for "failed" efforts include inconsistent funding, and limited administrative support to maintain collaborative relationships across jurisdictions and over time necessary for project completion (Lauber et al. 2011).

During workshops, we explored opportunities and impediments for collaborative landscape strategies using tools and principles of decision analysis, which generally included: 1) framing collaborative landscape conservation problems as decisions, 2) identifying unique and shared management objectives for each management authority, 3) creating collaborative management alternatives (i.e., combinations of actions or new strategies), 4) modeling the consequences of each alternative, 5) evaluating trade-offs among conflicting or competing objectives within and among management authorities (Keeney 2002, Gregory et al. 2012). Collectively, we identified challenges related to identifying and engaging decision makers (Fig. 1; phase 1) and creating and assessing collaborative landscape strategies (Fig. 1; phase 2). Based on these challenges, we outlined steps for developing effective landscape conservation efforts. Although challenges and steps were identified within the context of headwater stream ecosystems, they are broadly applicable to other ecosystems and landscape decision contexts characterized by multiple decision-makers and objectives, numerous management options, high levels of uncertainty, and potential trade-offs across spatial scales.

Project Results, Analysis and Findings:

Phase 1: Identifying and engaging a network of decision makers

The first phase of any collaborative landscape conservation effort is to identify and engage a network of decision-makers motivated to solve landscape problems. Three challenges in this phase include: 1) framing landscape conservation problems as decisions and identifying those that may benefit from collaboration, 2) engaging relevant management organizations, and 3) establishing collaborative governance. Because these components set the stage for landscape conservation, they should be given systematic thought to avoid technical solutions and decision support tools for ill-defined (and sometime the wrong) conservation problems (Keeney 2007). A lack of adequate framing of problems early in the process can unintentionally direct which decision-makers are identified and engaged in the process and ultimately limit the ability to identify optimal solutions because the scale of the problem is either too narrow or too broad in scope (e.g., there exists a social-ecological mismatch; Cumming et al. 2006, Guerrero et al. 2013, Game et al. 2013, Wilson et al. 2016). By structuring problems in terms of alternative allocation strategies, potential outcomes, and valuation of outcomes, they become more tractable and solvable even at large spatial scales (Gregory et al. 2012, Johnson et al. 2015). Using this decision-framing approach to organize and identify opportunities for collaborative management can identify critical interacting or linked decisions across organizations and across broad spatial scale. Deciding the location, type and timing of variation management activities lays at the heart of collaborative landscape conservation and commonly includes habitat-focused actions such as land purchases, restoration activities, or active habitat management and population-level actions such as translocation, propagation, and harvest regulation (Jenni and Nieman 2012, Johnson et al. 2015).

Define landscape problems as decisions

A management decision is the irrevocable allocation of resources - doing something, somewhere, at a specified time (Wilson et al. 2007). Landscape collaborative decisions typically involve dispersed resources and require coordination among multiple decision-makers. These decisions may include explicit consideration of timing, location, extent, frequency, duration of multiple types of actions (e.g., Table 1). Understanding the complexity of options for collaborative management can ensure that spatial and temporal scales of planning have measurable impacts on valued resources. Adequate framing of landscape problems will include explicit understanding of the decision context for each decision-maker. Before engaging with partners, decision-makers can improve their own understanding of decision problems by articulating why a given landscape-scale decision is needed, and by identifying the agencies and stakeholders essential for implementing this decision, what resources may be affected, and what other dependent or antecedent decisions may be needed.

For headwater streams, management authorities collectively framed the overarching landscape problem in terms of utilizing multiple types of actions available to a diverse set of agencies (federal and state natural resource agencies and nonprofit organizations) across the watershed over a relatively short-time period (5-years) to improve headwater stream habitat, biota, and ecosystem services under the threat of climate and land use change. This collective frame allowed a common understanding for collaborative management which may be stepped down to more specific decision problems related to a particular set of decision-makers, regions, threats, or activities. Each landscape decision ultimately should be complex enough to surround the problem, but simple enough to tailor and implement a solution. For example, one decision problem may focus on creating new water-focused policies and permits that influence cold-water headwater stream protection, land management activities and best management practices (BMP's), and water use, while another may focus on improving fish and salamander population resilience to climate change on private lands by creating and maintaining riparian and instream habitats within local forest management plans.

Engage decision makers and stakeholders

Central to any collaborative conservation effort is identifying key agencies, organizations or individuals that have the legal authority and jurisdiction to take action and affect change.

Facilitators of landscape conservation are increasingly turning to tools, such as stakeholder analysis and social network analysis (Prell et al. 2009, Reed et al. 2009, Vance-Borland and Holley 2011), to better understand the roles and relationships of organizations and individuals in a collaborative conservation process. Such approaches ensure that landscape networks include organizations that ultimately have the ability to develop and implement actions, and clarify role(s) of each participant (i.e., organizer/facilitator, decision-maker, stakeholder, expert, researcher and/or analyst) in the decision-making process. During initial headwater stream workshops, we identified relevant decision-makers for collaborative headwater stream conservation using an informal stakeholder analysis approach, initially focused on federal agencies with the authority to take action across large contiguous networks of headwater streams and that had a primary objective of protecting and restoring various aspects of headwater streams (Fig. 2). Using an iterative process for identifying decision-makers can help re-evaluate the perceived essential, peripheral, and marginalized authorities and stakeholder groups in current and future decision-making (Bixler et al. 2016).

Establish network governance

A continued challenge for managing distributed public resources, such as common widespread species in headwater streams, is deciding who is ultimately responsible and whose values (e.g., persons within an organization or members of the public) should be considered when making spatial public-resource decisions (Brown et al. 2014). Exploring options for collaborative governance can help decision-makers and stakeholders clarify roles and responsibilities and how decisions will be made, and ensure the interests, values, and goals of those involved are represented in the collaborative process (Armitage et al. 2012, Alexander et al. 2016). A major challenge is that critical decision-makers may be unable or unwilling to engage in collaborative decision-making for several reasons, including a lack of funds, staff or support to engage in the process, lack of ownership and responsibility over the decision problem and resources, difficulty envisioning the perceived benefits of landscape conservation, and a lack of trust among organizations (Beever et al. 2014). Cooperative landscape collaborations are often novel organizations without an existing governance agreement or structure; a transparent and explicit decision process establishes the terms of cooperation.

We explored with decision-makers both informal and more formal governance approaches for joint-decision making for headwater management and three approaches emerged: a watershed forum approach, a shared learning approach, and a collaborative decision-making approach (Fig. 3). The watershed forum approach (least formal) represented a more passive information exchange of past, current, and future actions affecting headwaters, and an ability to both maintain existing relationships and engage with new decision-making authorities, and provide a space for collaborations to develop through opportunistic interactions (e.g., a bi-annual watershed conference). The second approach, of shared learning, represented coordinated information gathering (monitoring, assessments, and data management), as well as jointly designing and funding projects to gather this information. However, decisions related to actions across the landscape and management strategies remain largely independent and rely on individual or small ad-hoc groups of engaged decision-makers. The last, and most formal approach included jointly defining a particular decision-problem(s) (and at what scale it would be best explored; watershed, subwatershed, or tributary), identifying relevant decision-makers to involve, and creating and selecting management strategies as a group. Although consensus would not be required in this joint decision-making approach, methods for including opposing views, hypotheses, and interests would be formally addressed with governance rules and the process for decision-making would be explicit and transparent to all parties involved. This ensures the ability to find mutually beneficial solutions by creating a space for negotiations within the collaborative network (Gregory et al. 2001, Regan et al. 2006). We argue this last, more formalized collaborative governance approach provides a more transparent and explicit structure for assessing alternative collaborative strategies compared to informal collaborative methods. Although most headwater stream organizations were familiar with less-formal governance approaches, they saw value in pursuing a joint decision-making process for a subset of decision-problems and the Deerfield watershed created a cooperative to formally explore this approach. Organizations valued transferability of the process to other landscape problems and utilized a subset of organizations (actions considered) to pilot a joint decision-making approach for watershed management.

Flexible, dynamic, and decentralized governance structures can build capacity for addressing multiple decision problems over time (Game et al. 2014, Bixler et al. 2016, Imperial et al. 2016a and 2016b, Scarlett et al. 2016). Thus, creating governance structure for particular decision problems that matches the landscape scale, outlines roles and responsibilities of each stakeholder, identifies potential for mutual gains, and sets end-points for the collaborative effort is an effective strategy. Although most headwater organizations were familiar with less-formal governance approaches, they saw value in a joint and dynamic decision-making for a subset of decision-problems and created a formal collaborative decision-making process for a pilot subwatershed that could be transferred and adapted to other landscape problems throughout the watershed. This approach can ensure that "healthy and useful" network governance is developed for each set of landscape decision problems of interest to the collaborative network (Imperial 2016b).

Phase 2: Creating and assessing collaborative landscape strategies

The second phase of cooperative landscape conservation uses the tools of decision analysis to frame and solve landscape-scale problems. Cooperative landscape conservation decisions can face unique complexities even after they are framed and a network of decision-makers is engaged. Decisions can become challenging to solve because 1)there are often many diverse and often competing management objectives (both in a single location and among decision makers), 2) new collaborative management actions are often outside explicit agency missions, 3) outcomes of these strategies are difficult to precisely predict with high levels of certainty, and 4) variations in acceptable spatial and temporal trade-offs across decision-makers can be a source of conflict. Using principles of decision theory and associated analytical tools, we explore how facilitators, organizers, and participants in collaborative landscape conservation can recognize and address these challenges.

Identify relevant landscape-scale objectives

The first step in this phase of cooperative landscape conservation is articulating a shared vision, which is then used to identify specific and relevant objectives for each decision maker. Carefully identifying overall goals and stepping down these goals into meaningful and specific objectives continues to challenge collaborative conservation (Beever et al. 2014). For headwater streams, decision makers identified diverse objectives (for example, Table 2 represents the objectives identified in the Merrimack watershed) at several scales: local, tributary, subwatershed, and watershed-scale. Some objectives were place-based, with particular locations being important for maintaining high quality recreational opportunities and flood control, while other objectives occurred at larger scales, such as maintaining high water quality and salamander occurrence across all headwater streams within the watershed. Especially in landscape problems, objectives occurring at different scales may often directly compete for shared management resources. For example, maximizing occupancy of a species across all stream reaches may require management actions to be conducted near source populations while maintaining persistence within a single tributary may require management upstream. Guidance for the ranking of objectives and explicit guidance on trade-offs among scales may not be specified within agency mission statements or mandates (Jenni and Nieman 2012, Johnson et al. 2015). Organizations involved in cooperative landscape conservation have an obligation to consider both local and regional objectives (Brown et al. 2014, Johnson et al. 2015).

Articulating a shared vision, and articulating agency-specific objectives, was an important step for engaging decision-makers to explore collaborative management. Shared objectives are not required (e.g., not all agencies need to place value on recreational opportunities), but accepting all objectives as valid for the cooperative is essential. In fact, landscape collaborative management may offer unique solutions when objectives are most divergent and when actions are beneficial to other agencies. Agencies did share objectives (Fig. 4), but while some agencies viewed an objective as a means to achieving something fundamental to their agency, other organizations considered a similar objective as fundamental importance (Table 3).

However, even when objectives were shared, decision makers described measurement of success for similar objectives using different metrics. Since these metrics are not necessarily positively correlated, and the selection of metrics can have a strong influence on the assessment of landscape strategies, developing and selecting metrics for landscape decision-problems should be given thoughtful consideration (Keeney 2007).

Create diverse alternative solutions

Collaborative conservation promises to identify novel solutions to shared or common resource management problems that could not be realized by a single decision maker or agency alone. However, a typical starting point for landscape conservation is to promote mutual learning and trust through joint information gathering (via monitoring or research), with little emphasis on implementing new collaborative actions (Munoz-Erickson et al. 2010). Although information gathering efforts are important for building trust (Lauber et al. 2011), they have no *direct* impact on conservation. Improvements in conservation will only be realized when partners develop and implement on the ground management.

Although a motivator for investing in collaborative landscape conservation efforts is to decide what to do, when, and where, creating collaborative "on-the-ground" actions remains a major challenge. To assess the potential benefits of collaborative landscape strategies, new or joint actions (i.e., the irrevocable allocation of resources) must be explored. However, decision-makers typically rely on actions that have worked in the past, have been used in similar problems, or are readily available for implementation (Fig. 5; Keeney 1996). Challenging perceived constraints, such as legal authority and implementing "best practice" approaches, as well as transferring funds or defining acceptable losses among organizations, can increase creativity in developing collaborative management actions. Tension between promoting creativity and utilizing best practice approaches can be compounded at the landscape scale because of the perceived complexity of decision problems, requiring leadership that encourages discussion of diverse and out-of-the-box ideas (Game et al. 2014).

For any particular decision problem, the scale of collaborative actions must be able to influence landscape objectives (Keeney 1992). If there is substantial mis-match, then collaborative actions could be scaled down to a finer spatial or temporal scale or the scope of the landscape decision problem could scaled up to include additional decision-making authorities. If decision-makers cannot develop new or joint actions across the landscape, then the benefits of collaborative action cannot be explicitly assessed. Instead, individuals within the collaborative network may seek win-win solutions by using formal negotiation (Regan et al. 2006) to aid in deciding under what conditions is collaboration beneficial (Greene et al. 2009).

In headwater streams, opportunities for mutually beneficial collaborative strategies appeared obvious in watersheds where interests and knowledge of diverse organizations were highly spatially correlated (Bode et al. 2011). Less obvious were actions that were immediately beneficial for one organization's interests that benefited other organizations when there was no spatial overlap in jurisdiction. This led to new collaborative actions (Fig. 6) between a terrestrial conservation organization (a land trust), an aquatic-focused organization (a national fish conservation organization), and local council of governments. Decision-makers jointly developed new forestry practices to benefit fish populations that, when combined with culvert replacement and stream geomorphology restoration, had greater expected benefits to aquatic and forest health as well as improved local economic opportunities. By recognizing the potential tools of each organization, they can be uniquely combined to maximize benefits to the collaborative network, and may result in more effective collaborative conservation than in landscapes with high degrees of spatial overlap in resources, when individual decision maker objectives are not complementary (Bode et al. 2011).

Collaborative strategies typically include aggregations of individual actions. The recent application of portfolio decision analysis, which aids in the selection of groups of actions when the best choice of one action (e.g. habitat restoration) directly depends on the status of another action (e.g. habitat connectivity), offers insights into how collaborative actions can be combined to reduce risk, cost, and provide greater benefits in terms of conservation outcomes in complex conservation problems (Convertino and Valverde 2013, Salo et al. 2011). However, the sheer number of possible actions available from all organizations in each combination of location and levels of effort may result in challenges in how best to combine diverse actions to find optimal strategies. Although we could not explore the full range of feasible collaborative actions (e.g., portfolio combinations of diverse, collaborative actions) for headwater streams in each watershed, encouraging decision-makers and researchers to focus on landscape-level objectives and important components affecting these objectives (i.e., the system model) led to unique insights about collaborative actions.

Predict potential outcomes of each strategy

Prediction is a fundamental role of science. Two aspects of collaborative landscape conservation warrant careful attention in predicting the outcomes of collaborative actions. First, the fragmentation and heterogeneous distribution of resources in real landscapes mean predicting consequences for spatial subunits of the landscape is challenging. Second is that predicting consequences of actions that have never (or rarely) been conducted previously (i.e., collaborative actions) may result in large uncertainty.

One outcome of information-sharing may be a map of resources across a landscape, and is a common initial step in developing collaborative (e.g., the Merrimack watershed reference a watershed-scale report on resource conditions and priority forest resources; SPNHF 2014). Recent advances in the development of spatial predictive models for species and habitats at fine scales allows the development of spatially-explicit landscape predictions for local and regional decisions, though these models are often data- and computationally-intensive. Predicting the outcomes of collaborative strategies in high dimensional decision-problems (e.g., those involving multiple management units, types of actions, levels of effort, and multiple objective) requires technical expertise and increased processing time and may only be useful for clearly defined landscape decision problems (Sayer et al. 2013).

A common challenge to making accurate predictions at landscape scales is that fine-resolution landscape data are often unavailable, resulting in a reduction of precision and potential for bias in predictions. Modeling relationships between spatially-explicit environmental drivers and population responses is additionally challenging in large, diverse landscapes due to the potential for multi-scale interactions that compound uncertainty. Uncertainties such as environmental variability, system or model uncertainty, and parameter uncertainty are commonly perceived as important to landscape decisions, but in the context of decision analysis, not all uncertainties are equally important to selecting among potential actions (Conroy et al. 2011, Nichols et al. 2011, Wenger et al. 2013).

For headwater stream conservation, selecting meaningful aquatic health metrics (e.g. cold water habitat quality, quantity, and distribution) and identifying key system uncertainties (e.g., effect of near-stream and upland land protection on habitat quality and metapopulation persistence) are critical elements for predicting outcomes of collaborative landscape strategies. Although environmental data available in the watershed can be used to predict physical, chemical and biotic conditions, expert judgement is also needed for many aspects of the ecological system where data were lacking or not easily transferable (i.e., stream salamander occurrence, effect of riparian and upland forest on aquatic biota, effect of increasing stream temperatures and hydrology on population occupancy) using well-established expert elicitation methods (O'Hagan et al. 2006, Kuhnert et al. 2010, Speirs-Bridge et al. 2010).

Selecting metrics and ecological modeling frames without considering the decision problem can lead to sophisticated predictive models that have little or no value to decision-making (Keeney and Gregory 2005, Tear et al. 2005, Burgman et al. 2007). For decision problems with substantial knowledge gaps, predictive models may be unreliable, inappropriate, or unavailable. Information gap theory (Ben-Haim 2001) and value of information theory (Raiffa and Schlaifer 1961, Canessa et al. 2015) are both underutilized frameworks that help understand how much uncertainty can be tolerated before the "best" landscape decision would change and which uncertainties could be reduced (and by how much) to benefit landscape outcomes. Creating predictive models of collaborative landscape alternatives should quantify completeness, precision, and accuracy to avoid bias and inaccurate predictions, as well as incorporate relevant uncertainties that to the decision context.

Evaluate trade-offs for each decision maker

Collaborative landscape conservation efforts are largely motivated by the desire for win-win solutions that balance multiple objectives. Additionally, there is an expectation that a single objective (ie. maximizing conservation at a landscape scale) can be maximized via collaboration. Although landscape approaches have been proposed to reduce, reconcile, or eliminate difficult social-ecological trade-offs (Polasky et al. 2008, Nelson et al. 2009, Sayer et al. 2013, Cordingley et al. 2015), recognizing irreconcilable trade-offs and the need to make difficult choices is essential for successful collaborative decision-making (McShane et al. 2011). Ultimately, a fully maximal solution may not be possible, and organizations must recognize there may be only a small improvement in conservation outcomes under collaboration. Trade-offs are inevitable within and among organizations, among objectives, and across spatial scales.

To improve the potential to identify overlapping objectives, each organization must have a clear understanding of their objectives and the relative importance of each objective to their agency. Not only do organizations have to balance competing objectives, but also potentially conflicting conservation goals within and across scales. For a given a budget, maximizing both biodiversity and persistence of targeted species may be not be possible (Di Fonzo et al. 2015) and in predator-prey systems, actions that benefit one species likely result in decline of another (Probert et al. 2011). Additionally, the relative importance of these conflicting conservation targets often varies across organizations (and even is likely to vary among individuals within organizations), thus recognizing that reconciling potential trade-offs early can help promote creative “out-of-the-box” development of mutually beneficial strategies (through negotiations).

Given that landscape objectives are spatially distributed, with some areas having greater importance than others, a major challenge is explicitly assessing collaborative strategies in terms of local vs. regional benefits. Justifying these spatial trade-offs are often not specified in policy or mandates and interpretation of their relative importance varies with the defined landscape decision context (Johnson et al. 2015). As a consequence, the capacity for individual agencies to manage a resource may be locally optimal (e.g., headwater stream reaches or tributaries), but inefficient or suboptimal for the conservation of the resource at a larger spatial scale (i.e., the watershed or river basin). This issue was especially salient in considering watershed management, where issues of connectivity, correlated disturbances, and fragmentation (e.g., Fagan 2002) induce spatial mismatches in management actions and ecosystem outcomes (Johnson et al. 2015).

Portfolio approaches can be used to guide the development of collaborative alternatives that aim to balance resource allocation over time, space and among-organizations, while minimizing risk and reducing short-term losses within a collaborative to achieve long-term gains. Modern portfolio theory (MPT, Markowitz 1952) is seeing increased use in decisions with multiple objectives and alternatives (e.g., to select sites for conservation actions; Ando and Mallory 2012), and offers promise for considering high-dimensional problems in collaborative landscape conservation (Hoekstra 2012). When combinations of actions or locations are considered jointly in a portfolio, spatial or temporal correlations may make outcomes across all objectives different from the outcomes of each individual action if they were considered separately and then combined (Salo et al 2011).

Evaluating portfolios within a collaborative network, under rules for negotiation established in a formal governance structure, can help integrate the desire to achieve diverse objectives and force decision-makers to articulate trade-offs they are willing to make in the landscape decision. These portfolios of actions can then be managed over time (i.e., annual, 5-year, 10-year re-evaluation) as the future becomes more certain and new actions become available. Developing dynamic solutions that include multiple types of alternatives implemented at different times may offer more robust solutions to uncertainty in temporal trade-offs (Johnson et al. 2015). Additionally, forcing decision-makers to articulate the spatial trade-offs can offer insights into how trade-offs may be perceived, separating those which are only perceived to be barriers to a decision and those that are real constraints. Identifying spatially-referenced tradeoffs can thus be resolved by coordinating actions across the landscape to meet many multiple objectives – effectively changing the spatial scale of objectives to identify and promote win-win spatial objectives; Cordingley et al. 2015).

Although combinatorial optimization and heuristic algorithms may be useful for well-defined collaborative decisions (e.g., Williams et al. 2005, Westphal et al. 2007, Xue et al. 2014), solutions may be unstable with high degrees of uncertainty and disparate stakeholder interests in large landscapes (Sayer et al. 2013). Thus, evaluating diverse *sets* of collaborative actions in strategic portfolios (i.e. to decrease risk, increase fairness, or target critical ecological components) to identify 'sufficient' (rather than 'optimal') collaborative strategies as a realistic approach if resources and expertise are limited. These collaborative strategies may be compared against the set of individual actions to determine whether collaborative conservation is indeed more efficient or effective (Ando and Mallory 2012).

Conclusions and Recommendations: The final steps in collaborative landscape conservation (Fig. 1) are to select and implement a conservation strategy, which relies on a clearly articulated and acceptable governance structure, recognizing jurisdictional responsibilities, and the sharing of resources when warranted. The last step is shared among all decision problems (assess, learn, revise, adapt), but in collaborative landscape conservation, the maintenance of the collaborative, according to the conditions outlined in the governance structure, is important for learning. Using facilitation techniques from behavioral decision and negotiation theories, establishing governance structure early, and recognizing the role and pitfalls of consensus can help prescribe a fair and transparent decision, with lasting benefits to a collaborative network.

The effective allocation of scarce conservation resources remains an important and pressing applied problem in natural resource management. We outlined challenges within two major phases of decision-making: 1) identifying and engaging decision makers and 2) creating and evaluating benefits of collaborative landscape conservation with highlighted unique challenges for headwater stream conservation. Using a systematic approach consistent with principles of decision analysis can efficiently diagnose and respond to these challenges (Fig. 1), allowing facilitators of landscape conservation to be more effective. Additionally, using principles of decision theory to guide collaborative conservation can build trust among stakeholders, facilitate information sharing, and promote efficient use of management resources (Lauber et al. 2011, Williams and Johnson 2013).

Sometimes collaborative landscape conservation might not be warranted, if the opportunity for effective collaboration is minimal, if the independent optimal actions of the partners are nearly as good as a collaborative solution, and if the constraints on collaboration are just too high. Collaboration is only warranted and possible under certain conditions (Table 4). In challenging landscapes where objectives are not acknowledged among decision makers, science is disputed, or there is little ability or desire to share resources other support – including conflict resolution, joint-fact finding and negotiation - may be needed prior to engaging in collaborative landscape decision making.

In the U.S., Landscape Conservation Cooperatives (LCCs) were designed, in part, to help identify and reduce challenges facing collaborative landscape conservation, with a focus on developing information tools and scientific products at regional scales (Jacobson & Robertson 2012). However, recognition that improved landscape conservation may not exclusively depend on predictive or spatial optimization modeling has focused efforts on better understanding of unique challenges associated with collaborative decision-making (Keeney 1992, Gregory et al. 2006, Game et al. 2013). In fact, increasing predictive modeling power, resolving scientific hypotheses through research, or assessing ecological states through monitoring may, in fact, have relatively little (or no) impact on conservation decisions and outcomes (Hauser et al. 2006, Maxwell et al. 2015, Canessa et al. 2015). Although LCCs have contributed significantly to our understanding of ecological problems and can facilitate landscape conservation by providing structure and incentives (Jacobson & Robertson 2012), new emerging challenges now face organizations in collaborative decision-making that, if not addressed, can prevent the development and implementation of landscape conservation strategies. Leadership (e.g., facilitators of landscape conservation efforts) that are well versed in the principles of decision analysis can help conservation practitioners, biologists, and researchers clearly articulate landscape problems into decisions and recognize impediments to the development and implementation of cost-effective solutions (Johnson et al. 2015). Finally, while there has been much written about the process and social factors that lead to effective collaborations, there is little empirical evidence that these processes lead to better ecological and societal outcomes. Documenting how future collaborative decisions are made (using the explicit, structured approach outlined here) may allow for more explicit assessment of the factors affecting successful collaborative conservation efforts.

Outreach and Products:

The results from this project will be submitted as a peer-reviewed scientific journal article. The *SDM process* itself will help identify management strategies for the local management agencies involved, and the relationship built between the collaborators and participants will help ensure continued transfer of results throughout the northeast region.

References

Alexander SM, Andrachuk M, and Armitage D. 2016. Navigating governance networks for community-based conservation. *Frontiers in Ecology and the Environment* **14**: 155–164.

Armitage D, de Loë R, and Plummer R. 2012. Environmental governance and its implications for conservation practice. *Conservation Letters* **5**: 245–255.

Armsworth P.R., Larson E.R., Jackson S.T., Sax D.F., Simonin P., Blossey B., Green N., Klein M.L., Lester L., Ricketts T.H., Runge M.C., & Shaw M.R. 2015. Are conservation organizations configured for effective adaptation to global change? Frontiers in Ecology and the Environment 15: 163–169.

Ball IR, Possingham HP, and Watts M. 2009. *Marxan and relatives: software for spatial conservation prioritization*. In Spatial conservation prioritization: quantitative methods and computational tools. Eds Moilanen A, Wilson KA, and Possingham HP. Oxford University Press, Oxford, UK, pgs 185–195.

Beever EA, Mattsson BJ, Germino MJ, *et al.* 2014. Successes and challenges from formation to implementation of eleven broad-extent conservation programs. *Conservation Biology* **28**: 302–314.

Burgman MA, Lindenmayer DB and Elith J. 2007. Managing landscapes for conservation under uncertainty. *Ecology* **86**: 2007–2017.
Bode M, Probert W, Turner WR, *et al*. 2011. Conservation planning with multiple organizations and objectives. *Conservation Biology* **25:** 295–304.
Brown, G., Kelly, M. & Whitall, D. 2014. Which 'public'? Sampling effects in public participation GIS (PPGIS) and volunteered geographic information (VGI) systems for public lands management. *J. Environ. Plan. Manag.* **57:** 190–214.
Canessa S, Guillera-Arroita G, Lahoz-Monfort JJ, *et al.* 2015. When do we need more data? A primer on calculating the value of information for applied ecologists. *Methods in Ecology and Evolution* **6***:* 1219–1228.
Conley A, and Moote MA. 2003. Evaluating collaborative natural resource management. *Society and Natural Resources* **16**: 37–41.
Conroy MJ, Runge MC, Nichols JD, *et al*. 2011. Conservation in the face of climate change: The roles of alternative models, monitoring, and adaptation in confronting and reducing uncertainty. *Biological Conservation* **144**: 1204–1213.
Convertino M and Valverde LJ. 2013. Portfolio decision analysis framework for value-focused ecosystem management. *PLoS One* **8**: e65056.
Cordingley JE, Newton AC, Rose RJ, *et al*. 2015. Can landscape-scale approaches to conservation management resolve biodiversity-ecosystem service trade-offs? *Journal of Applied Ecology* **53**: 96–105.
Cumming GS, Cumming DHM, and Redman CL. 2006. Scale mismatches in social-ecological systems: causes, consequences, and solutions. *Ecology and Society* **11**: 14–33.
Di Fonzo MMI, Possingham HP, Probert WJM. 2015. Evaluating trade-offs between target persistence levels and numbers of species conserved. *Conservation Letters* **9:** 51–57.
Fuentes MMPB, Blackwood J, Jones B *et al.* 2014. A decision framework for prioritizing multiple management actions for threatened marine megafauna. *Ecological Applications* **25**: 200-214.
Game ET, Kareiva P, and Possingham HP. 2013. Six common mistakes in conservation priority setting. *Conservation Biology* **27**: 480–485.
Game ET, Meijaard E, Sheil D, and McDonald-Madden E. 2014. Conservation in a wicked complex world; challenges and solutions. *Conservation Letters* **7**: 271–277.
Gregory R, Daniels T, Fields D, 2001. Decision aiding, not dispute resolution: creating insights through structured environmental decisions. *Journal of Policy Analysis and Management* **20**: 415–432.
Gregory R, Failing L, Ohlson D, McDaniels TL. 2006. Some pitfalls of an overemphasis on science in environmental risk management decisions. *Journal of Risk Research* **9**: 717–735.
Gregory R, Failing L, Harstone M, *et al*. 2012. *Structured decision making: A practical guide to environmental management choices*. Wiley-Blackwell, West Sussex, UK.
Guerrero AM, McAllister RRJ, Corcoran J, and Wilson KA. 2013. Scale mismatches, conservation planning, and the value of social-network analyses. *Conservation Biology* **27**: 35–44.
Hoekstra J. 2012. Improving biodiversity conservation through modern portfolio theory. *PNAS* **109**: 6360–6361.

Imperial MT, Johnston E, Pruett-Jones M, *et al.* 2016a. Sustaining the useful life of network governance: life cycles and developmental challenges. *Frontiers in Ecology and the Environment* **14**: 135–144.

Imperial MT, Ospina S, Johnston E, *et al.* 2016b. New ways of leading in a world of shared problems: Advancing networked governance in large landscape conservation. *Frontiers in Ecology and the Environment* **14**: 126–134.

Jacobson C and Robertson AL. 2012. Landscape Conservation Cooperatives: bridging entities to facilitate adaptive co-governance of social–ecological systems. *Human Dimensions of Wildlife* **17**: 333–343.

Jenni KE and Nieman TL. 2012. *Decision analysis framing and structuring for the Western Alaska Landscape Conservation Cooperative: summary of a workshop held February 16-17, 2011*. Western Alaska Landscape conservation Cooperative Report 12-1, 39 pp.

Johnson F, Eaton M, Williams J, Jensen G, and Madsen J. 2015. Training conservation practitioners to be better decision makers. *Sustainability* **7**: 8354–8373.

Keeney, R. L. 1992. Value-focused thinking: a path to creative decision making. Harvard University Press, Cambridge, Massachusetts, USA.

Keeney, R.L., 1996. Value-focused thinking: Identifying decision opportunities and creating alternatives. European Journal of Operational Research, 92: 537-549.

Keeney, R.L., 2002. Common mistakes in making value trade-offs. Operations research, 50: 935-945.

Keeney RL. 2007. Developing objectives and attributes. In: Edwards, W., Miles Jr., R.F., von Winterdfeldt, D. (Eds.), *Advances in Decision Analysis.* From Foundations to Applications. Cambridge University Press, Cambridge.

Keeney RL and Gregory RS. 2005. Selecting attributes to measure the achievement of objectives. *Operations Research* **53**: 1–11.

Lauber, T.B., Stedman, R.C., Decker, D.J. and Knuth, B.A. 2011. Linking knowledge to action in collaborative conservation. Conservation Biology, 25: 1186-1194.

Leong KM, Emmerson DP, and Byron R. 2011. The new governance era: implications for collaborative conservation and adaptive management in Department of the Interior agencies. *Human Dimensions of Wildlife* **16**: 236–243.

Markowitz H. 1952. Portfolio selection. Journal of Finance 7: 77–91

Maxwell SL, Rhodes JR, Runge MC, *et al*. 2015. How much is new information worth? Evaluating the financial benefit of resolving management uncertainty. *Journal of Applied Ecology.* **52**: 12–20.

McKinney M, Scarlett L, and Kemmis D. 2010. Large landscape conservation: a strategic framework for policy and action. Cambridge, MA: Lincoln Institute for Land Policy.

McShane T, Hirsch PD, Trung TC, *et al*. 2011. Hard choices: Making trade-offs between biodiversity conservation and human well-being. *Biological Conservation* **144**: 966–972.

Nelson E, Mendoza G, Regetz J, *et al*. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. *Frontiers in Ecology and the Environment* **7:** 4–11.

Nichols JD, Koneff MD, Heglund PJ, *et al*. 2011 Climate change, uncertainty, and natural resource management. *Journal of Wildlife Management* **75**: 6–18.

Obama B. 2010. Presidential memorandum – America's great outdoors. Washington, DC: The White House.

Petersen B, Montambault J, and Koopman M. 2014. The potential for double-loop learning to enable landscape conservation efforts. Environ Manage 54: 782–94.

Prell C, Hubacek K, and Reed M. 2009 Stakeholder Analysis and Social Network Analysis in Natural Resource Management. *Society and Natural Resources* **22**: 501–518.

Polasky S, Nelson E, Camm J, *et al*. 2008.Where to put things? Spatial land management to sustain biodiversity and economic returns. *Biological Conservation* **141**: 1505–1524.

Probert WJM, Drechsler M, Baxter PWJ and Possingham HP. 2011. Resource allocation in two species systems: Is it worth acknowledging species interactions? *Ecological Modelling* **222**: 1781–1789.

Raiffa H and Schlaifer RO. 1961. *Applied Statistical Decision Theory*. Graduate School of Business Administration. Harvard University, Cambridge, MA, USA.

Reed MS, Graves A, Dandy N, *et al*. 2009. Who's in and why? A typology of stakeholder analysis methods for natural resource management. *Journal of Environmental Management* **90**: 1933–1949.

Regan HM, Colyvan M, and Markovchick-Nicholls L. 2006. A formal model for consensus and negotiation in environmental management. *Journal of Environmental Management* **80**: 167–176.

Sayer J, Sunderland T, Ghazoul, J, *et al*. 2013. Ten principles for a landscape approach to reconciling agriculture, conservation, and other competing land uses. *PNAS* **110**: 8349–8356.

Salo A, Keisler J, Morton A. 2011. *Portfolio Decision Analysis: Improved Methods for Resource Allocation*, 1st Edition, XV, 409 pg.

Scarlett L, and McKinney M. 2016. Connecting people and places: the emerging role of network governance in large landscape conservation. *Frontiers in Ecology and the Environment* **14,** 116–125.

SPNHF (Society for the Protection of N.H. Forests). 2014. A Land Conservation Plan for the Merrimack River Watershed of New Hampshire and Massachusetts. http://forestsociety.org/landconservation/merrimack-watershed.asp (accessed August 15, 2014)

Wenger SJ, Som NA, Dauwalter DC, and Isaak DJ. 2013. Probabilistic accounting of uncertainty in forecasts of species distributions under climate change. *Global Change Biology* **19**: 3343–3354.

Westphal MI, Field SA, and Possingham HP. 2007. Optimizing landscape configuration: A case study of woodland birds in the Mount Lofty Ranges, South Australia. *Landscape and Urban Planning* **81**: 56–66.

Wiens J.A. & Bachelet D. 2010. Matching the multiple scales of conservation with the multiple scales of climate change. Conservation Biology 24: 51–62.

Wilson KA, Underwood EC, Morrison SA, *et al*. 2007. Conserving biodiversity efficiently: What to do, where, and when. *PLoS Biology* **5**: e223.

Wilson RS, Hardisty DJ, Epanchin-Niell RS, *et al*. 2016. A typology of time-scale mismatches and behavioral interventions to diagnose and solve conservation problems. *Conservation Biology* **30*:*** 42–49.

Williams J, ReVelle C, and Levin S. 2005. Spatial attributes and reserve design models: a review. *Environmental Modeling and Assessment* **10**: 163–181.
Williams BK and Johnson FA. 2013. Confronting dynamics and uncertainty in optimal decision making for conservation. *Environmental Research Letters* **8**: 025004.
Vance-Borland K and Holley J. 2011. Conservation stakeholder network mapping, analysis, and weaving. *Conservation Letters* **4**: 278–288.
Xue S, Fern A, and Sheldon D. 2012. Scheduling conservation designs via network cascade optimization. *Journal of Artificial Intelligence Research* **52**: 331–360.

Figure 1. Steps for developing landscape collaborative conservation efforts occur within two major phases 1) identify and engage decision-makers and 2) create and assess alternatives strategies. Within each phase, steps are iterative and the process should be revised as new decision problems are framed (e.g., via double-loop or triple-loop learning; Petersen et al 2014). Once a decision problem is solved, the remaining steps are to implement a selected strategy and monitor to assess and learn to improve future collaborative decisions.

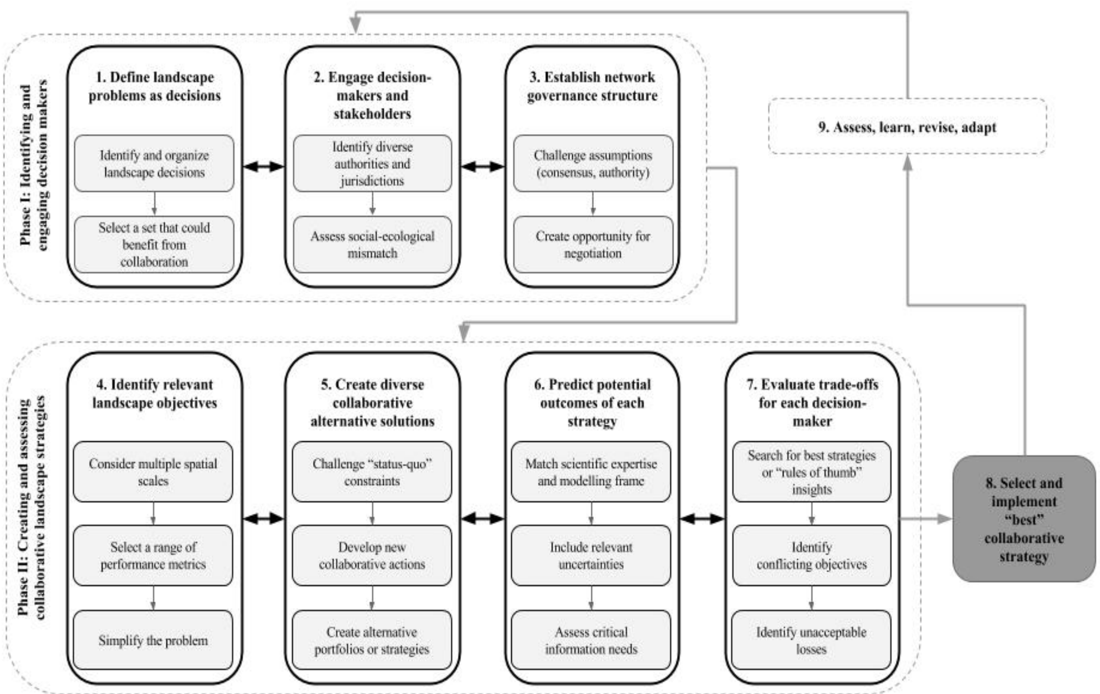

Figure 2. Initial headwater stream workshops within the Potomac watershed focused on federal landowners (FWS, NPS, FS). Decision makers from Shenandoah NP (SNP), Canaan Valley NWR (CVNWR) and George Washington NF (GWNF) considered collaborative opportunities across agencies. Although aquatic and terrestrial resources in these high elevation mountain ridges are particularly vulnerable due to climate change, agencies perceived few additional benefits of collaborative landscape management, whereas collaborations with adjacent landowners (state and private properties adjacent to protected lands) had smaller areas to affect change, but offered potential large gains through developing new collaborative strategies. Thus, we adapted and broadened the scope of potential decision-makers for future workshops in the Merrimack (Fig 5) and Deerfield (Fig 6) watersheds to include federal and state agencies as well as nonprofit conservation organizations (own or manage land or have strong relationships with private landowners) to increase the jurisdiction and options for effective landscape management throughout the watershed.

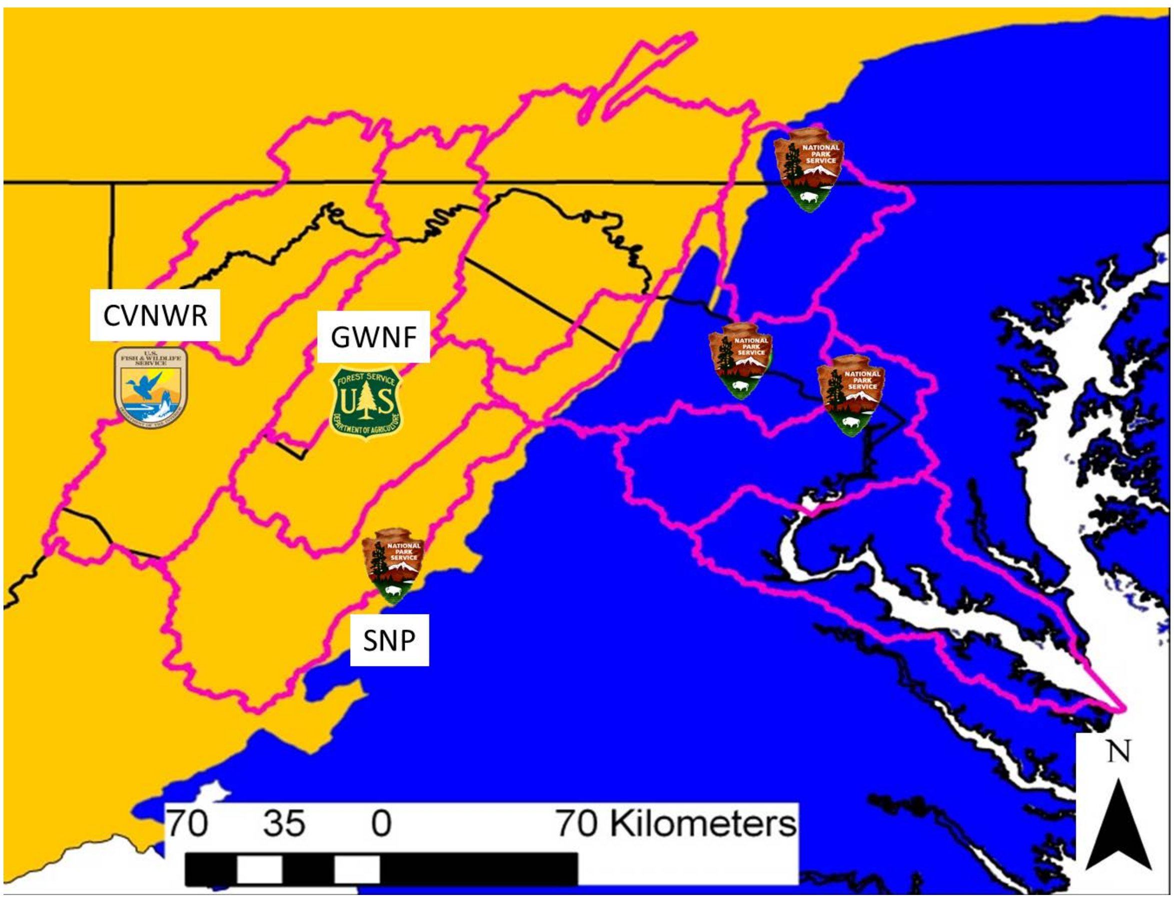

Figure 3. Three broad collaborative governance options explored in headwater stream conservation. Formal collaborative governance also include essential elements of less formal approaches (i.e., evolving social networks, sharing technical expertise).

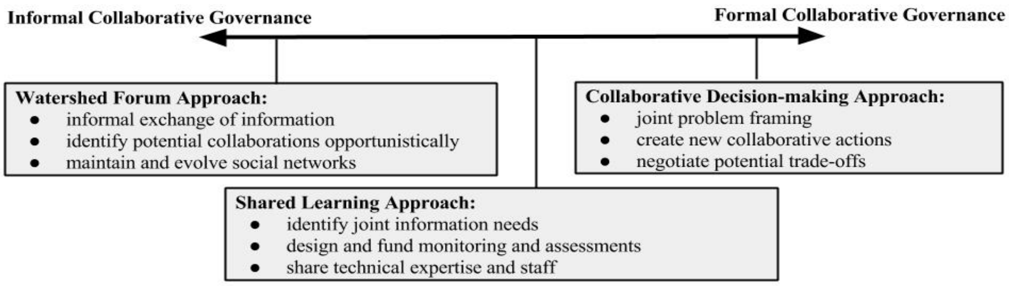

Figure 4. A) Hierarchical cluster diagram [fit using package hclust in R; each fundamental objective (Table 3) was assigned to every stakeholder with binary categories of yes/no] and B) PCA indicating similarity of landscape fundamental objectives for collaborative headwater stream conservation (cost, public support, stream health, forest ecosystem health, public safety, recreational opportunities, water supply, economic opportunities) among organizations in the Deerfield Watershed Cooperative. (A: left branch = stream health/recreational focus, right branch = ecosystem, economic, public safety focus; B: lower right - forest health, upper right = aquatic/recreational, upper left = ecological, center = safety, economic, water supply). MADNR = Massachusetts Dept. of Natural Resources; TNCAM = The Nature Conservancy; FWS = Region 5 US Fish and Wildlife Service; TU = Trout Unlimited; FS = Northeast US Forest Service; FLT = Franklin Land Trust; WRC = Windham County (VT) Regional Council of Governments; VTDEC = Vermont Department of Environmental Conservation.

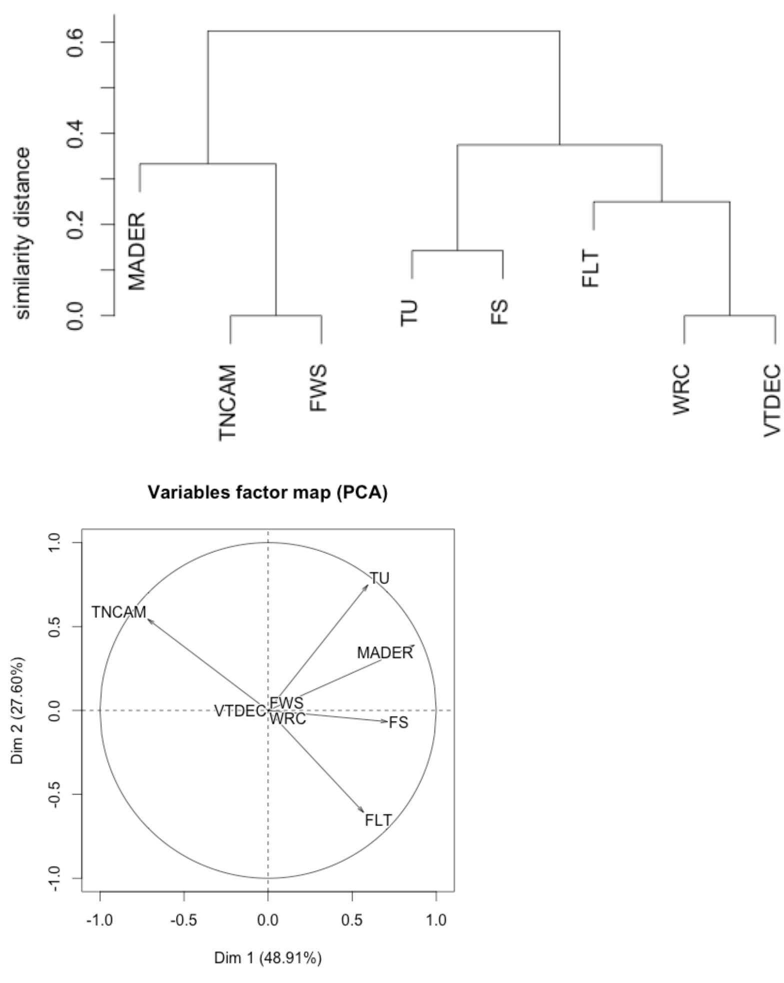

Figure 5. Merrimack Watershed actions mapping. We asked participating organizations to brainstorm objectives or goals that they wanted to achieve within the Merrimack watershed in relation to headwater stream ecosystems. These objectives reflected what they wanted the watershed to look like (i.e., an "ideal watershed") over the long-term. Participants identified several themes of management actions available to each organization that help them work towards achieving their management objectives (here, Water Quality and Ecological objectives are shown). We asked each individual to place up to five sticky notes on a map of the Merrimack watershed indicating 1) places and projects that were highly successful (i.e., they had the right partners and tools to complete a management action; green notes) and less successful (i.e., projects required additional partners and tools; orange notes). After the mapping exercise, participants listed a range of specific management actions that they had access to and could access if required. After this list was generated, participants acknowledged that, as a group, they shared a wide range of management tools that could help achieve their diverse objectives (i.e., one organization alone did not have access to all management actions due to differences in authority, staff, and tools).

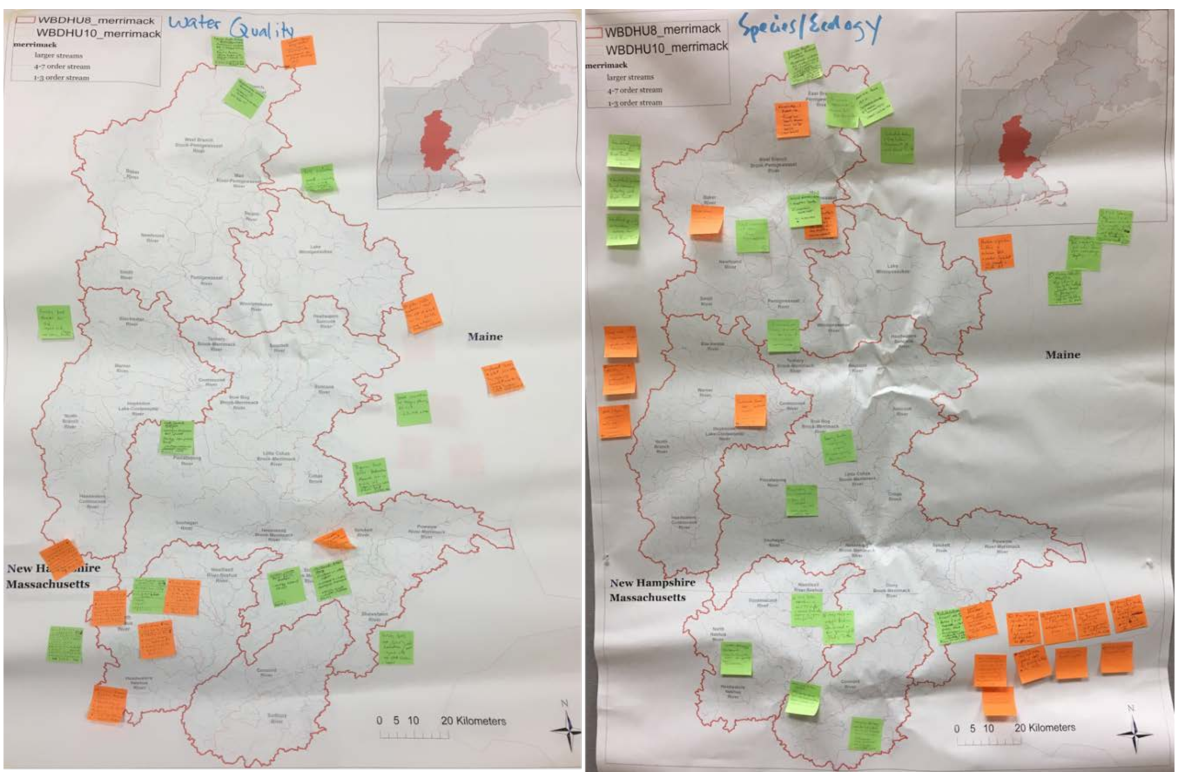

Figure 6. Headwater streams contain a high diversity of endemic aquatic species (Lowe and Likens 2005, Meyer et al. 2007) and many species continue to decline due to local and global scale stressors such as habitat fragmentation and degradation, land use development, and climate change (Strayer and Dudgeon 2010). Agencies and organizations are interested in the headwater conservation for multiple reasons (*objectives*), including aquatic biodiversity (fishes and amphibians), ecosystem services (drinking water and flood control), recreational opportunities (angling and aesthetics), and economic growth (land development and water supply), which may be conflicting or competing for a pool of shared resources. Multiple authorities (e.g. private landowners, federal and state natural resource agencies and nonprofit organizations) manage headwaters and lands affecting headwaters, resulting in greater difficulty identifying the "best" combination of management actions. Fragmented jurisdiction of headwaters increases the collective range of possible actions to mitigate threats than are possible with a single authority. *Alternative* collaborative strategies may include, but are not limited to, instream actions (dam removal, culvert replacement, and habitat and riparian restoration), upland habitat actions (land acquisition, forest management, urban planning) and water resource regulations (water withdrawal and pollutants) .Predicting *consequences* of management actions is challenging because biota are distributed across a network of connected habitats affected by longitudinal, lateral, vertical, temporal connectivity (Ward and Wiens 2001). Choosing a landscape strategy will depend on the relative cost-benefit to each organization and will most likely not optimal for all parties. The combination of diverse management objectives, potential actions, and trade-offs within and among organizations in a complex array of headwater stream decision problems that can be framed and solved to influence the future state of headwater stream ecosystems.

Figure 1. The Deerfield Watershed Cooperative partners jointly assess collaborative actions (i.e., instream restoration, upland and riparian land and riparian management, invasive species removal) to take upstream and downstream of headwater streams managed by a local and national conservation organization Franklin Land Trust and Trout Unlimited.

Table 1. Themes of actions that collaborative headwater stream strategies could consider when creating collaborative strategies (combinations of actions or creating new actions) to influence a diversity of objectives.

Major project themes	**Possible actions**	**Authority and jurisdiction**
stream habitat restoration	riparian restoration, instream habitat manipulation, channel geomorphology alteration	federal, state and private lands
road crossing infrastructure	culvert replacement and bridge construction	county, state, and federal government
land management	forest management, timber harvest, agricultural fields	federal, state, and private foresters and nonprofit land trusts, private farmers
water policy	water use permits, cold water resource regulations	state regulatory agency and US Environmental Protection Agency (EPA)
developmental planning	stormwater, wastewater, and road crossing infrastructure improvements	county governments and and conservation commissions
BMP enforcement	enforce and improve of development and agricultural regulations	county and state law enforcement, EPA
pesticide and contaminant use	public incentives and outreach	state regulatory agency and EPA
dam infrastructure	dam removal or fish passage structures	private landowners (typically)

Table 2. List of example management objectives (classified into 5 themes: Ecological, Ecosystem Services, Economic and Social, Recreation, and Cost) and their proposed desired direction across organizations in the Merrimack watershed.

Management Objective	Desired Direction
Ecological Objectives	
Brook trout occupancy	maximize
Stream salamander occupancy	maximize
Native fish species diversity (migratory and non-migratory)	maximize
Native bird diversity (riparian and floodplain species)	maximize
Native species communities (multi-taxa; biodiversity)	maximize
Free-flowing stream ecosystems	maximize
Ecosystem Service Objectives	
Estuary and marine nutrient export	minimize
Water quality (municipal water use)	maximize
Water quantity (municipal water use)	maximize
Water quantity (industry; breweries, ski resorts)	maximize
Waste assimilation (municipal waste disposal/dilution)	maximize
Flood control (water quantity)	maximize
Channel stabilization	maximize
Economic and Social Objectives	
Hydropower and legacy dam use (historic mill dams)	maximize
Impoundment property value (via dams)	maximize
Residential growth (development and infrastructure)	maximize
Commercial growth (development and infrastructure)	maximize
Property values (riparian and floodplain)	maximize
Transportation (emergency and daily)	maximize
Local economies (tourism = “New England town” and ecosystems)	maximize
Recreation Objectives	
Upland recreation (camping, hiking, skiing, open-space use, hunting)	maximize
Near-water recreation (trail crossings, ATV and snow mobile use)	maximize
On-water recreation (angling, swimming, boating downstream)	maximize
Cost Objectives	
Cost (funds, resources, staff time)	minimize

Table 3. Range of objectives (and desired direction; min = minimize, max = maximize) considered in watershed management by agencies and organizations in the Deerfield Watershed. Objectives were grouped into 'themes' of Fundamental objectives, and each organization was scored whether they stated that objective (=1) or did not consider that objective to be important in making decisions within their jurisdiction (=0).

Objective	Desired direction	Objective type	Fundamental Objective#	Trout Unlimited (TU)	Franklin Land Trust (FLT)	Windham Regional Commision (WRC)	Mass. Department of Natural Resources (MADNR)	Vermont Depart. of Environmental Conservation (VTDEC)	The Nature Conservancy (TNCAM)	Region 5 US Fish and Wildlife Service (FWS)	Northeast US Forest Service (FS)
Cost	min	fundamental	1	1	1	1	1	1	0	1	1
Public Support	max	fundamental	2	1	1	1	1	1	1	1	0
Stream Ecosystem	max	fundamental	3	1	0	1	1	1	1	1	1
Forest Ecosystem	max	fundamental	4	0	1	1	0	1	1	1	1
Public Safety	max	fundamental	5	1	0	1	1	1	1	1	1
Recreation	max	fundamental	6	0	0	1	0	1	1	1	0
Water Quality, Quantity	max	fundamental	7	0	0	1	0	1	1	1	0
Local Economy	max	fundamental	8	0	1	1	1	1	0	1	1
towncost	min	means	1	1	1	1	1	0	0	1	0
cooperatorcost	min	means	1	1	1	1	1	1	0	1	1
regulatoryburden	min	means	1	1	1	1	0	0	0	1	0
outreach_town	max	means	2	1	1	1	1	0	0	0	0
taxpayercosts	min	means	2	0	1	1	1	0	0	0	1
public engagement	max	means	2	0	0	1	1	1	0	0	0
outreach_private	max	means	2	1	1	0	0	0	0	0	0
brooktrout	max	means	3	1	0	0	0	0	0	0	0
connectivity	max	means	3	1	0	1	1	1	1	1	1
waterquality	max	means	3	1	0	1	1	1	0	1	0
invertebrates	max	means	3	0	0	0	0	1	1	1	0
hydrogeomorphology	max	means	3	1	0	0	1	1	0	1	1
flows	max	means	3	0	0	1	1	1	0	1	1
assemblage	max	means	3	0	0	1	0	1	0	1	0
function	max	means	3	1	0	1	1	1	0	1	1
floodplain	max	means	3	0	0	1	1	1	0	1	0
salamander	max	means	3	0	0	0	0	0	0	0	0
riparian	max	means	3	0	0	1	1	1	1	1	1
instream	max	means	3	1	0	1	1	1	1	1	0
coldwater	max	means	3	1	0	0	1	0	0	0	1
composition	max	means	4	0	0	1	0	0	0	0	1
groundwater	max	means	4	0	0	1	0	1	0	0	0
forestconversion	min	means	4	0	0	1	0	1	0	0	0
largeintactacres	max	means	4	0	1	1	0	0	0	0	0
temporarywaterstorage	max	means	4	0	0	1	0	1	0	0	0
infrustructure	min	means	5	1	0	1	1	1	1	0	1
harm	min	means	5	0	0	1	1	1	0	0	0
consumptiverec	max	means	6	0	0	1	0	0	0	0	0
angling	max	means	6	0	0	0	0	1	0	0	0
swimming	max	means	6	0	0	0	0	1	0	0	0
water_industry	min	means	7	0	0	1	0	1	0	0	0
water_domestic	min	means	7	0	0	1	0	1	0	0	0
ageconomies	min	means	8	0	1	0	0	1	0	0	0
workinglandscapes	max	means	8	0	1	1	0	1	0	0	1
jobs	max	means	8	0	0	1	1	0	0	0	0

Table 4. Impediments to and conditions for collaborative landscape management.

Impediments to Collaborative Management	Conditions for Collaborative Management
1. The agencies cannot see or imagine the synergistic benefits (or the benefits do not exist – independent actions are sufficient or nearly as good)	A. There are desired outcomes that can only be achieved by sharing resources and implementing complementary actions
2. The agencies do not have the authority to act outside their traditional jurisdiction and practices	B. The agencies involved can find an ability to share resources and undertake complementary actions
3. The agencies have hidden objectives or dispute science	C. There needs to be trust among the agencies