HOW-TO-GUIDE

FOR THE CO-PRODUCTION OF ACTIONABLE SCIENCE

How-To-Guide for
DOI Climate Science Centers &
The National Climate Change Wildlife
Science Center

Actionable Science Working Group
Advisory Committee on Climate Change & Natural Resource Science (ACCCNRS)

www.nccwsc.gov/acccnrs

This guide was originally published as Appendix IV of the Report to The Secretary of the Interior from the Advisory Committee on Climate Change and Natural Resource Science (March 30, 2105) with facilitation and logistical support from the Meridian Institute (http://www.merid.org/). The Advisory Committee on Climate Change and Natural Resource Science (ACCCNRS) was chartered by the Department of the Interior (DOI) in September 2012 to advise the Secretary of the Interior on the establishment and operations of its National Climate Change and Wildlife Science Center (NCCWSC) and the Climate Science Centers (CSCs). ACCCNRS is a federal advisory committee comprising representatives of federal agencies; state and local governments, including state membership entities; nongovernmental organizations, including those whose primary mission is professional/scientific and those whose primary mission is conservation and related scientific and advocacy activities; American Indian tribes and other Native American entities; academia; individual landowners; and business interests.

The full report can be accessed from the ACCCNRS page of the National Climate Change and Wildlife Science Center website: https://nccwsc.usgs.gov/acccnrs

From more information on the National Climate Change and Wildlife Science Center and the eight regional Climate Science Centers please visit: https://nccwsc.usgs.gov/

Suggested Citation: Beier P, D. Behar, L. Hansen, L. Helbrecht, J. Arnold, C. Duke, M. Farooque, P. Frumhoff, L. Irwin, J. Sullivan, J. Williams (Actionable Science Workgroup of the Advisory Committee on Climate Change and Natural Resource Science). 2015. Guiding principles and recommended practices for co-producing actionable science: a How-To Guide for DOI Climate Science Centers and the National Climate Change and Wildlife Science Center. Report to the Secretary of the Interior: Advisory Committee on Climate Change and Natural Resource Science. Washington, DC.

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Guiding Principles and Recommended Practices for Co-Producing Actionable Science:

A How-To-Guide for DOI Climate Science Centers and the National Climate Change and Wildlife Science Center

Introduction

This how-to-guide is intended to help the staff of the U.S. Department of the Interior's Climate Science Centers and National Climate Change and Wildlife Science Center (CSCs and NCCWSC) — as well as the decision makers and resource managers with whom they work— effectively collaborate in developing scientific information that is useful and relevant to those who make decisions about how to conserve biodiversity and cultural resources in a changing climate. It was developed by the Advisory Committee on Climate Change and Natural Resource Science (ACCCNRS or the Committee), an advisory panel to the Secretary of the Interior.

Actionable Science provides data, analyses, projections, or tools that can support decisions regarding the management of the risks and impacts of climate change. It is ideally co-produced by scientists and decision makers and creates rigorous and accessible products to meet the needs of stakeholders.

The mission of the CSCs and NCCWSC is to help Department of the Interior entities, partners, and stakeholders manage the risks of climate change in a way that conserves biodiversity as well as other natural and cultural resources.[1] The CSCs and NCCWSC provide actionable science, which the ACCCNRS defines as, "data, analyses, projections, or tools that can support decisions regarding the management of the risks and impacts of climate change. It is ideally co-produced by scientists and decision makers and creates rigorous and accessible products to meet the needs of stakeholders." Most of the guide's content was adapted from four primary documents[2] augmented by the experiences of the ACCCNRS members and by case studies – many from the CSCs

[1] Managing climate risks to biodiversity requires both adaptation and mitigation (i.e., reducing emissions); the focus of this document is on actionable *adaptation* science.

[2] 1) National Research Council. (2009). Informing Decisions in a Changing Climate. Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Global Change. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.; 2) Science Policy Assessment and Research on Climate. (2010). Usable Science: A Handbook for Science Policy Decision Makers.; 3) Dilling, L, and MC Lemos. (2011). Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change* 21:680:689.;

and NCCWSC – demonstrating the principles and practices of actionable science. Among federal agencies, the CSCs and NCCWSC are emerging as exemplars in the co-production of actionable science. The Committee hopes to propagate best practices, and increase the rate at which they spread and are improved.

This guide offers five guiding principles that apply both to the NCCWSC-CSC enterprise and to individual projects of CSCs or the NCCWSC. Each guiding principle is followed by one or more recommended practices at the project level. In most cases, the program implications are obvious; in other cases, recommended practices for programs are included.

Some of the recommended practices include details intended to translate a vague principle (e.g. "Identify research needs collaboratively and iteratively.") into concrete actions, (e.g., the issues to be addressed at a meeting). These details are illustrative rather than prescriptive. The intent is to provide concrete guidance that will fit a typical situation; users should strive to meet the spirit of these recommendations, and adapt the specific details to their situations.

Why Actionable Science Should be Co-Produced by Scientists and Users

As defined above, *actionable science* "is ideally co-produced by scientists and decision makers and creates rigorous and accessible products to meet the needs of stakeholders." Although actionable science can, theoretically, be produced by scientists working alone, co-production is a more reliable route to actionable science for complex societal problems such as adapting to climate change and managing the risks of climate change. Co-production is key to producing actionable adaptation science because:

- *Decision makers* bring insights that are needed to co-define scientific questions and methods, precisely define the planning issues to be addressed, explain the downstream analytical tools, and explain how they plan to use scientific information to make decisions. They can explain the type of decisions that must be made, and the legal, political, social, and fiscal constraints affecting decision makers.

and 4) Kirchhoff, CJ, MC Lemos, and S Dessai. (2013). Actionable Knowledge for Environmental Decision Making: Broadening the Usability of Climate Science. *Annual Review Environmental Resources* 38:3.1-3.22.

- *Scientists* bring insights that are needed to ensure that the science is appropriately developed and then applied in decisions. At the project level, scientists provide decision support services more often than decision-support products.[3] Actionable science is not only actionable information, but also a process for the appropriate use of that information.

- *Collaboration between scientists and decision makers is often needed to define the research goal, methods, and products*. It is not always obvious what type of research is needed. For example, scientists and users may want research to resolve uncertainty about climate change and its impacts. However, in some cases, uncertainty cannot be reduced and decision makers may not need more information about future climate and its impacts. Rather they may need information about which alternative adaptation strategies are most robust to uncertainty or which actions can best manage risk. Sustained collaboration is needed not only to specify the research goals, but also to plan how the science will be used, and identify the most useful formats to interject scientific understanding and scientific uncertainty into specific decisions. Scientists acting alone or decision makers acting alone could come to this realization, but synergy between scientists and decision makers is more likely to ensure that the right questions are asked and addressed, producing useful outcomes with fewer delays and at a lower cost. For example, some decision makers have requested vulnerability assessments for particular species, and scientists have produced such assessments. Unfortunately, in many cases the parties had not discussed how the assessments would be used, what decisions would be informed by the assessments, the inherent model uncertainties, the format of model outputs, and how uncertainty and format of the outputs would affect actionability. Actionable science might have been produced if scientists and decision makers had spent more time co-defining the problem and identifying how the information would be used. For example, the assessments could have been designed to identify the anthropogenic factors affecting the adaptive capacity of the target species and ecosystems in a way that would suggest an appropriate adaptation strategy.[4]

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[3] National Research Council. (2009). Informing Decisions in a Changing Climate. Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Global Change. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.
[4] In short, Adam Smith's "invisible hand" does a poor job of regulating the supply of and demand for actionable science (SPARC 2010).

Effective and Sustainable Co-Production

Because both scientists and decision makers are essential to defining problems, developing approaches, making inferences, and guiding implementation, *ongoing* communication and relationships between the producers and users of information are central to producing actionable science. Effective information products are one result, but not the exclusive one, and they can rarely be produced by scientists and "handed off" to decision makers.

Co-production of actionable science is effective when:

- Scientists and decision makers engage in mutual learning that neither could have achieved alone, and when that engagement increases mutual understanding, respect, and trust as the parties work together.

- Interested stakeholders agree that the science products and processes led to (or could have led to) better decisions.

Co-production of actionable science is sustained when:

- Scientists, decision makers, and funders engage in attentive management to align the supply of actionable science with demand. Actionable science does not automatically occur whenever producers, users, and funders want it, but rather when these groups repeatedly interact in forums that are "owned" by all parties.[5]

- Scientists and program managers are rewarded for remaining engaged to ensure that decision makers make appropriate use of scientific information. Employers build co-production activities into job descriptions and staff reviews, and funders pay for these services.

[5] Dilling, L, and MC Lemos. (2011). Creating usable science: opportunities and constraints for climate knowledge use and their implications for science policy. *Global Environmental Change* 21:680:689.

Guiding Principles and Recommended Practices for Co-Producing Actionable Science

The five guiding principles for co-producing actionable science are presented here. They are paired with recommended practices, below.

1. **Actionable science is most reliably co-produced by scientists and decision makers or resource managers working in concert.**

2. **Start with a decision that needs to be made.**

3. **Give priority to processes and outcomes over stand-alone products.**

4. **Build connections across disciplines and organizations, and among scientists, decision makers, and other stakeholders.**

5. **Evaluate co-production products, processes, and the actionability of the science produced by projects.**

Guiding Principle #1: Actionable science is most reliably co-produced by scientists and decision makers or resource managers working in concert.

For many projects or programs, other stakeholders and funders may also be engaged. This overarching guiding principle underlies the other four guiding principles and recommendations.

Recommended Practice

1. Invest good will, respect, commitment, time, and resources to develop the interpersonal interactions that are critical to co-production.

    - The other recommended practices in this guide describe the actions needed to implement this overarching recommendation. Getting the relationships right – including relationships with downstream users – is crucial at every step of the project.

Guiding Principle #2: Start with a decision that needs to be made.

Research needs, which are rarely known (and almost never clearly specified) in advance, must be identified collaboratively and iteratively.

Recommended Practices

2. Decision makers: Approach scientists with a management need, goal, or problem, rather than a request for a product.

3. Scientists: Before suggesting specific products, make sure you understand the decision to be made, and the environment in which the decision will be made. Be open to a project that expands your research priorities and the types of products your team is comfortable producing.

    - Decisions about climate rarely hinge solely on more accurate predictions of impacts or assessments of vulnerability (although these can be important); most decisions require information on how well various options will reduce vulnerability and minimize risk. Although "project, assess, act" makes sense in many contexts, sometimes no-regret adaptation strategies can be devised that do not require projections. Even when projections are useful, they are almost never the end point.

4. Invest in at least one in-person meeting of several hours duration[6] to specify the decision to be made and reach consensus on the type of scientific information needed to support that decision.

Guiding Principle #2:
Case Study 2
Wildlife Refuge Durability on the Eastern Seaboard

National Wildlife Refuges (NWRs) are charged with protecting critical habitat for federally threatened and endangered species. In the southeastern United States the challenge is no longer limited to the species, but has expanded to the land itself, which is becoming threatened and endangered because of climate change. In 2014, Northeast and Southeast CSC researchers began working with Blackwater, Alligator River, and Cape Romain NWR managers to co-develop information products intended to support management of these lands that would continue to meet the NWRs' missions for as long as possible under the threats of sea level rise, habitat loss, and saltwater intrusion.

See also Case Studies 1, 2, 3, 4, 5, 6, & 8 in Section III.

[6] These details provide concrete (rather than generic) guidance that will fit a typical situation. Users should strive to meet the spirit of these recommendations, and adapt the specific details to their situation.

- Answer these questions before the in-person meeting:
  - What is the goal of the engagement (e.g., what need is the group attempting to meet)?
  - What timeframe is needed for completion?
  - Who are the stakeholders needed to begin the process?

- Invite diverse stakeholders to the first meeting, including the key decision makers, scientists in the appropriate disciplines, implementers (those who would be tasked to apply the science), and (when appropriate) funders and other stakeholders.
  - The invitation should state the goal of the meeting, the agenda, and what issues are off the table.
  - Concerned stakeholders with different values and objectives should be invited. Stakeholders might include land owners, community groups, business interests or others who affect or are affected by adaptation actions.

- At the first meeting produce a clear goal statement so that success can be assessed later. Refer to the goal statement throughout the process. If the goal must be revised during the process, seek concurrence of all parties for the change. Goals should be specific, measurable, achievable within time and budget constraints, and realistic.

- To clarify, ask questions like these at the first meeting: [7]
  - What question is being addressed? What factors are included or excluded from consideration?
  - Who will use the scientific information (including downstream uses) and how will they use it?
  - In what form, process, or product will the data be most useful to the users?
  - Given that decisions must be made before the science can be "settled," what is a realistic expectation of what is possible and needed within the available time and budget?
  - What is necessary to make data accessible to all projected users? Who will own the data or other products? Where will the products reside? A third party may be the appropriate owner

[7] Some questions may not apply in particular situations.

- What would success look like for all parties?
- What alternatives are available to achieve success? What is gained or lost by pursuing one alternative over another?
- What variables does the decision maker care about? What resolution of data? What spatial extent? What level of precision is realistic, achievable, and adequate for the decision that must be made? If such precision is not feasible, should the project be abandoned or modified?
- What is the planning time horizon? Is the planned time horizon appropriate? A decision about coastal infrastructure may depend crucially on whether sea level rise is projected for 50 years or 100 years.
- How will uncertainty be addressed? To what extent can multiple projections (e.g., emission scenarios, general circulation models) bracket uncertainty?

5. For a large, complex project, engage a subset of key people to serve on a technical advisory group that will tweak goals, review key methodological decisions, and co-produce inferences. A smaller steering committee may be needed to manage the project calendar, products, and workflows.

Guiding Principle #3: Give priority to processes and outcomes over stand-alone products.

The National Research Council Panel on Strategies and Methods for Climate-Related Decision Support admonished producers of actionable science to "give priority to process over products".[8] This rhetorical overstatement was intended to nudge scientists away from their traditional focus on products that are "thrown over the transom." Giving priority to process does not mean that shabby products will be tolerated – there is a dire need for quality scientific products relevant to management and adaptation. Rather it points out that facts (scientific products) do not speak for themselves, but require guidance on the proper interpretation and use of science. A focus on process, outcomes, and adequate communication and interaction – including the right expertise and the funds to pay for it – must be explicitly built into project design from the beginning. An emphasis on process not only affirms that "good process leads to good product," it points out that decision- support *services* are fundamentally different from decision-support *products*.

[8] National Research Council. (2009). Informing Decisions in a Changing Climate. Panel on Strategies and Methods for Climate-Related Decision Support, Committee on the Human Dimensions of Global Change. Division of Behavioral and Social Sciences and Education. Washington, DC: The National Academies Press.

Recommended Practices

6. Scientists, decision makers, and stakeholders should discuss all important issues, including spatial extent, focal species or processes, resolution of data, key assumptions involved in the scientific models and approaches, appropriate data sources, and criteria involved in key steps. In addition to the initial meeting (Recommended Practice 4), these discussions will typically require additional in-person meetings:

    - **Meeting 2:** Scientists explain the best scientific approaches (plural) to achieve the goal, discuss the key assumptions, data needs, and costs of each approach, and describe strengths and limitations (including uncertainties) of available data. All participants discuss these issues to reach consensus on one (or more) scientific approach that will be used. Pilot or demonstration work may be needed to evaluate competing approaches.

    - **Meeting 3:** Draft scientific products are presented and discussed in relation to the stated goals. The meeting should occur early enough to allow time for significant adjustments if needed.

    - **Meeting 4** (Optional): It may be advisable to have a "rollout" meeting at which scientists describe the information and appropriate use of the information in decision making, and decision makers explain how they intend to use the information.

7. Decision makers: Explain to scientists how risk (not just climate-related risk) is evaluated and managed in your organization. Explain the

Guiding Principle #3:
Case Study 3
Wisconsin Brook Trout in a Changing Climate

The Wisconsin Department of Natural Resources, which is tasked with protecting fish species, was concerned with the implications of climate change for the brook trout. To ensure the best possible outcome, researchers and managers in the Driftless area of Wisconsin, engaged stakeholders (governmental and nongovernmental organizations, academics, and community members) in two workshops to build an effective network for implementation, gather input on the design of actions, and instill a sense of ownership in the actions to be taken. This included beta testing an online tool (FishVis Mapper) for use in decision making. Nine public meetings and email surveys were used to gather information on habitat management issues, land acquisition recommendations, recreational preferences, and perceived future challenges.

See also Case Studies 1 & 3 in Section III.

specific decisions you need to make and the context in which decisions are made. Help scientists appreciate how you make informed decisions (not perfect decisions) despite uncertainty about current or future conditions and uncertainty about the outcomes of interventions. Describe how you manage uncertainty without eliminating it. Explain the limitations on your authority, and to whom you are accountable.

- Don't expect scientists to hear you on the first try. Explain it again.

8. Scientists: Honestly convey the meaning of uncertainty in your results, but (respecting the fact that decisions must be made) clearly convey the main implications of your research. In addition to providing information, an equally important task is to provide clear guidance on appropriate use of that information.

   - Don't expect decision makers to hear you on the first try. Explain it again.

   - Work with decision makers to develop a decision tree or table describing the most appropriate way to apply the information in each decision-making context.

Guiding Principle #4: **Build connections across disciplines and organizations, and among scientists, decision makers, and other stakeholders.**

Decisions related to climate adaptation can require combining information on available technological and policy options at different scales of decision-making, and information on the likely economic and societal costs and benefits of those options. This requires integration across disciplines, sectors, and scales. Linking information-producers and information-users is especially challenging because the cultures and incentives of science and practice are different, and those differences need to be respected.

Because they work in complex situations with multiple (and changing) decision makers, CSCs and NCCWSC serve an important role as "boundary organizations." A boundary organization is an entity that serves as a convener of science-producers, science users, and other affected parties, and as a translator and a facilitator of productive tension among these groups. Other exemplary boundary organizations relevant to managing risks of climate change include the Great Lakes Integrated Sciences and Assessments

center[9] and other centers in the National Oceanic and Atmospheric Administration's Regional Integrated Sciences and Assessment program.

Recommended Practices

9. Be explicit about the role of CSCs and NCCWSC as boundary organizations, and take steps to grow their capacity as boundary organizations.

    - Build support for boundary activities into the base funding of the CSCs and NCCWSC. Because these enterprises make commitments beyond the normal two- or three-year duration of individual projects, they should invest the time needed to establish trust and maintain good relationships with partner organizations.

    - Allocate money for travel and access to high-quality virtual-meeting facilities as needed to build a regional community of researchers and science users. Because each CSC has a broad geographic scope (especially compared with U.S. Geological Service Co-op Units, agricultural extension offices, Landscape Conservation Cooperatives, and some other boundary organizations), CSC staff will find it challenging to develop long-term relationships with managers and decision makers. Moreover, keeping up with leadership turnover in partner entities requires ongoing attention. But, because these long-term relationships are necessary for the success of projects and to generate the political support that will sustain the program, such expenses must be considered investments in the future of the NCCWSC-CSC enterprise.

Guiding Principle #4:
Case Study4
Crowd-Sourced Water Temperature Database

Stream condition is highly sensitive to climate change, with implications for not only water temperature but water quality, riparian condition, and species composition. To address the stream temperature piece of the puzzle in the northwestern United States, the NorWest project organized data collected by managers at dozens of resources agencies (federal, state, and local) in Oregon, Washington, Idaho, Wyoming, and parts of Montana, Colorado, Utah, and Nevada. The data was used to develop useful climate scenarios for local decision-making. This process not only created better information, but it also created a stronger social network for practitioners beyond their traditional jurisdictions.

See Case Studies 1, 2, 3, 4, 6, & 7 in Section III.

[9] GLISA. (n.d.). Retrieved January 12, 2015, from http://glisa.umich.edu/

- Train staff to serve as facilitators, conveners, and communicators.

- In some cases, it may be advisable to include another boundary organization in particular projects to increase the perception of objectivity, enhance outreach to new potential partners, advertise and translate products for diverse needs, or mediate disagreements between producers and users. This might be the case when a CSC or the NCCWSC lacks resources to tailor information to create value-added products, or lacks the trust of one or more users.

10. Scientists: Encourage a sense of ownership and engagement among decision makers and stakeholders. Because broad integrative assessments require an understanding of local environmental conditions and social processes, provide flexible guidance by which local knowledge and stakeholder values can be integrated with the information you provide.

    - Science is nothing more than an approach to knowledge that is transparent, evidence-based, logical, and open to correction. Make it easy for resource managers and decision makers to understand your key assumptions and the logical chain of your analyses. Your science is improved when you invite nonscientists to challenge your assumptions, provide local knowledge and other evidence, and offer alternative explanations.

    - Freely express your preferences. You increase your credibility by honestly disclosing your preferences, by insisting on transparency and rigor, and by being open to all evidence and inferences supported by evidence.

11. Decision makers: If multiple agencies are responsible for decisions, consider the following options:

    - Ask scientists to provide an array of scientific information, so that each agency has the information it needs to act independently.

    - Convene or participate in forums where multiple agencies can identify opportunities to use the information. In some cases, it may be appropriate to create interagency agreements or reorganizations to bridge divisions caused by different enabling laws, missions, procedures, budgets, and cultures; this requires motivation, initiative, innovation, and leadership.

12. Funders and users: Create incentives not only for CSCs, but also for academic scientists, to consider actionable science as a challenging and rewarding line of work. For example

    - Issue a request for proposals to generate competing ideas to address important decisions. Encourage applicants to partner with CSCs or the NCCWSC.

    - To scale up across projects, commission the NCCWSC to synthesize recommendations relevant to your industry or agency, drawing on CSC and NCCWSC experience from relevant projects.
    - Use the guidelines in **Section II** when issuing a request for proposals, and when evaluating submitted proposals.

Guiding Principle #5: Evaluate co-production products, processes, and the actionability of the science produced by projects.

Recommended Practices #13 and #14 focus solely on evaluations of particular projects.

Recommended Practices

13. Convene a meeting among scientists, decision makers, and selected stakeholders several months[10] after the contractual end of the project to determine how the recommended practices in this document (and practices used in the project) improved the project, and how the practices should be revised to better meet the goal of co-producing actionable science.

    - How well did scientists and decision makers specify the problem statement at the outset of the project? In retrospect, would different scientific information and processes have been more useful? What steps could have better set up the project at the outset?

    - Did the project give appropriate priority to process while also defining and delivering the right products? Was the process collaborative, communicative, and positive for both scientists and decision makers? Why or why not?

[10] This time frame is a suggestion. The key is to let enough time elapse so participants can provide meaningful answers to these questions. Many answers will not be evident until users have attempted to apply the new science to decisions and implementation actions.

- If scientists are providing continued (post contract) advice on the appropriate use of the information produced:
    - Was this continuing engagement properly budgeted in the project? Is the scientist appropriately rewarded in terms of salary, recognition by the employer, and the satisfaction of contributing to better decisions?
    - What practical steps could have been taken to provide better guidance on appropriate use of the scientific products?

- Did the scientific information and process lead to better decisions (or was it capable of leading to better decisions, even if overriding constraints precluded a better decision)?

- How should future projects be managed to better meet this goal?

- What obstacles to collaboration were encountered in shaping the goals and final results?

- Is the product being used in the way it was envisioned? If not, why not?

- How does the project (products and processes) support the strategic plan of the CSC or the NCCWSC?

- Was a mechanism created to insert new information (new scientific results, or learning that occurred by observing the outcomes of decisions made using the products) so that later decisions can use the latest information?

Guiding Principle #5:
Case Study 5
South Bay Salt Pond Restoration Project

Restoration in the face of climate change can be tricky. Things cannot be returned to their past condition since the climate is no longer as it was, and the future has more change in store. This continual change requires a management plan that changes as conditions change. One approach is onsite monitoring and adaptive management, which is just what the South Bay Salt Pont Restoration Project chose to do. Through a phased implementation approach, managers are able to assess change as it happens and modify the restoration and management accordingly.

14. Disseminate the lessons from the evaluation meeting.

- Communicate with colleagues via CSC or NCCWSC seminars.

- Communicate with colleagues in the broader professional community via presentations at scientific meetings (including those outside your discipline), publications, and reports.

- Submit a short written report as per the recommendations on program evaluation in Section V, Program Evaluation, of the ACCCNRS Report.

15. Revise this How-To Guide.

- After accumulating evaluations from individual projects (Recommended Practices 13 and 14), the NCCWSC should commission a revision of this guide to draw general lessons from evaluations of individual projects. The revision team should be vetted by the ACCCNRS and should include strong external reviewers and NCCWSC-CSC staff. Ideally, this effort should be subsumed under the Recommended Assessment described in Section II, Refining the Mission of the NCCWSC and CSCs, of the ACCCNRS Report.

- The revision team should use the recommended practices described here to co-produce the revision.

- The revision team should describe the extent to which CSC and NCCWSC staff engaged in ongoing sharing of lessons (e.g., Recommended Practice 14), and recommend how learning across the NCCWSC-CSC enterprise might be enhanced. Such enterprise-wide learning will help create an actionable science network that builds on the best of each unit.

- To the extent possible, the review should evaluate the hypothesis that co-production is the best route to actionable science.

Section II: How Funders Can Apply the Guiding Principles

The following questions are recommended for use in developing requests for proposals and in reviewing and evaluating proposals. These guidelines are intended for Climate Science Centers and National Climate Change and Wildlife Science Center (CSCs and NCCWSC) staff, and for partner agencies or industries wishing to fund co-production of actionable science.

Consider the Following Questions in Designing and Evaluating Project Proposals

What is the problem, question, or issue that the research needs to inform?

1. Has the need for a research product been articulated by users?
2. How will this research product be used by decision makers? If it will be used to inform a decision or action, explain specifically how it will be used to do so.
3. What activities or mechanisms are in place to ensure collaboration between those who will use this research (relevant decision makers) and the researchers conducting the project?
4. Does the project team have the appropriate expertise, or is there a plan to procure it, to effectively conduct the research activities?
5. What outreach is planned to disseminate the final product to those who need the information? Will users be trained on how to use the product? Will appropriate staff be assigned to make the products user friendly? What products are most useful to the users?
6. How will the project be evaluated for both process and product?

Guiding Principles for Co-Producing Actionable Science in Brief

1. Actionable science is most reliably co-produced by scientists, decision makers, managers, and implementers.

2. Start with a decision that needs to be made.

3. Give priority to processes and outcomes over stand-alone products.

4. Build connections across disciplines and organizations, and among scientists, decision makers, and other stakeholders.

5. Evaluate co-production products, processes, and the actionability of the science.

Section III: Actionable Science Case Studies

Guiding Principles for Co-Producing Actionable Science in Brief

1. Actionable science is most reliably co-produced by scientists, decision makers, managers, and implementers.
2. Start with a decision that needs to be made.
3. Give priority to processes and outcomes over stand-alone products.
4. Build connections across disciplines and organizations, and between scientists, decision makers, and other stakeholders.
5. Evaluate co-production products, processes, and the actionability of the science.

The following eight case studies illustrate how the guiding principles can be incorporated into projects.

CASE STUDY 1: DEVELOPING AND APPLYING OCCUPANCY MODELS AND DECISION FRAMEWORKS FOR THE ADAPTIVE MANAGEMENT OF GOLDEN EAGLES IN DENALI NATIONAL PARK

Co-Produce Actionable Science (Principle 1)
This project was initiated when biologists and managers from the National Park Service (NPS) started a collaborative process with scientists from the U.S. Geological Survey (USGS) in 2007. The goal was to develop an adaptive management strategy to deal with human disturbance of golden eagle nesting sites in Alaska's Denali National Park (Williams & Brown, 2012).

This project had involvement from the NPS inventory and monitoring coordinator for the Central Alaska Network, an NPS biologist responsible for the park's annual eagle monitoring program, a USGS Alaska Climate Science Center scientist, and two scientists from the USGS Patuxent Wildlife Research Center in Maryland (Williams & Brown, 2012).

Start with a Decision that Needs to Be Made (Principle 2)
The Denali National Park managers' objective is to maximize the number of golden eagle nesting sites open to recreational hikers while ensuring that the projected number of successful nesting sites during the next breeding season exceeds an established threshold. Park managers must determine how many nesting sites to close off to hikers

the following season based on information about golden eagle occupancy and reproductive success during the current breeding season (Williams & Brown, 2012).

Figure 1: Golden Eagle

Give Priority to Processes and Outcomes over Stand-Alone Products (Principle 3)

Researchers used several frameworks and models to understand the effect of recreational activity on golden eagle occupancy and reproduction. Multistate site occupancy models provided estimates of transition probabilities among nesting areas, taking into account recreational activities (hikers) and environmental covariates. An adaptive-management framework informed optimal management of hiking activities within Denali National Park. Threshold concepts were applied to recommend management decisions based on a minimum desired occupancy level for Golden Eagles (Eaton et al., 2014; Martin et al., 2011; Martin et al., 2009).

Monitoring surveys of potential nesting sites and prey (hare) abundance provided information for the models. Park managers can specify the current conditions of the Park (eagle occupancy, reproductive success, hare abundance) using results from the surveys. Based on current conditions, the models can identify optimal management plans and actions (Williams 2012).

Build Connections across Disciplines and Organizations (Principle 4)

Even though the golden eagle monitoring program at Denali has been ongoing for many years, the current management program between the NPS and USGS has introduced an explicit process for using monitoring and survey data to inform management decisions. This process can continue to be used for addressing various factors in Golden Eagle management and conservation (Williams 2012)

CASE STUDY 2: MAXIMIZING THE SOCIAL AND ECOLOGICAL VALUE OF COASTAL NATIONAL WILDLIFE REFUGES ALONG THE ATLANTIC COAST IN THE FACE OF GLOBAL CHANGE PROCESSES

Co-Produce Actionable Science (Principle 1)
The Northeast and Southeast Climate Science Centers (CSCs) are pursuing a management-research collaboration that would help coastal National Wildlife Refuge (NWR) managers make informed management decisions about how to plan for and adapt to sea level rise and related global change processes.

Figure 2: Fishing at Alligator River National Wildlife Refuge

In March 2014,
Northeast and Southeast CSC staff met with staff from the Blackwater, Alligator River, and Cape Romain NWRs to identify pressing climate-related problems for the refuges. During the meeting, CSC scientists listened and learned about the refuge managers' greatest challenges regarding adaptation to global change (e.g., sea level rise, habitat loss, saltwater intrusion) and thought about the type of science that could assist them with the management decisions they must make. Conversations with NWR staff have formed the basis for the proposed collaboration between the CSCs and NWR managers.

A follow-up workshop was scheduled for June 2014 at the National Conservation Training Center to develop a prototype decision structure and analytical approach for the Cape Romain NWR. Researchers from the Northeast and Southeast CSCs will provide coordination and decision science support for staff at the Cape Romain NWR, as well as the North Carolina Coastal Plain Refuges Complex and the Chesapeake Marshlands NWR Complex.

Start with a Decision that Needs to be Made (Principle 2)
Discussions at the March 2014 meeting resulted in the framing of the critical management issue faced by coastal refuges: How can we optimally allocate management resources over time to maximize the conservation value of refuges (i.e., achieve the refuge mission) as landscape conditions evolve?

Build Connections across Disciplines and Organizations (Principle 4)
In working directly with NWR staff at meetings and subsequent projects in 2015 and 2016, the Northeast and Southeast CSCs will assist in the development of an adaptation strategy to allow coastal NWRs to continue to provide social and ecological benefits in the face of climate and land-use changes. This process may involve tasks such as developing models to describe the relationship between stakeholders' values with respect to social and ecological benefits of the refuges and the existing ecological systems (e.g., habitat, wildlife, ecological services); and designing or redesigning monitoring programs to support learning and decision making.

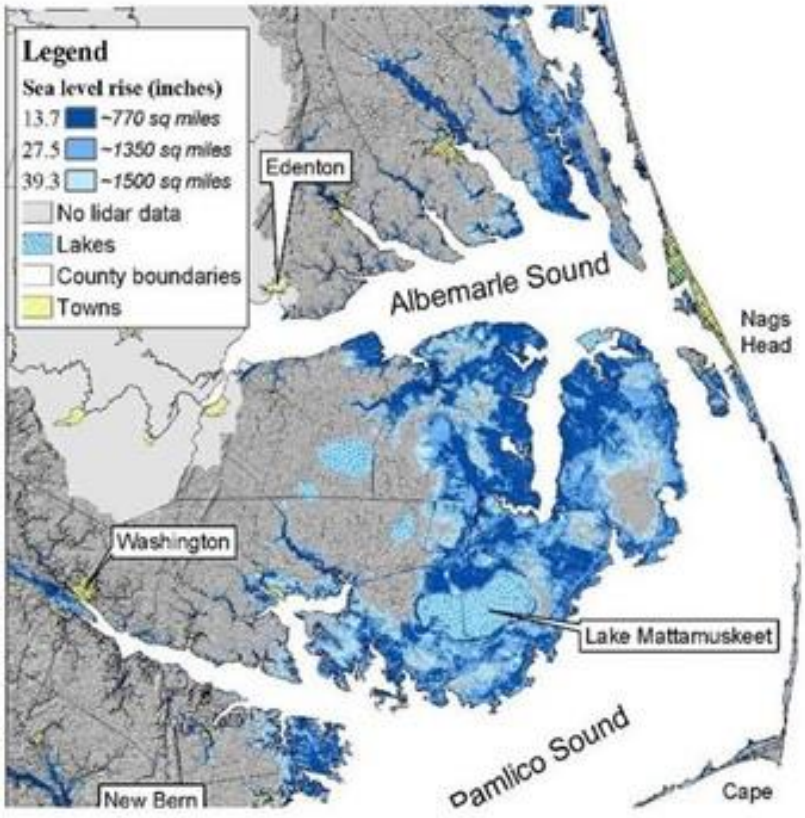

Figure 3: Sea Level Projections

CASE STUDY 3: BROOK TROUT VULNERABILITY TO PROJECTED CLIMATE CHANGES IN DRIFTLESS AREA STREAMS IN WISCONSIN

Start with a Decision that Needs to Be Made (Principle 2)
This project began with Wisconsin Department of Natural Resources (DNR) scientists reaching out to DNR managers to assess climate change impacts on different fish species. The problem was the potential loss of an important recreational fish, the brook trout.

Co-Produce Actionable Science (Principle 1)
A collaborative effort was undertaken by the U.S. Geological Survey, Wisconsin DNR, Michigan Institute of Fisheries Research, and Michigan State University. Funding was provided by the Great Lakes Restoration Initiative through the Upper Midwest and Great Lakes Landscape Conservation Cooperative. The FishVis website was developed, where data analysis and planning opportunities coincide to target vulnerable habitat, build flexibility into management practices, increase resilience for impacted species, and recognize future opportunities and limitations.

Give Priority to Process and Outcomes (Principle 3)
This case study focused on sound processes, which helped identify barriers early on, encouraged a sense of ownership among all parties, and built effective networks for the future. Two interactive workshops were held to get input from stakeholders. DNR researchers invited NGOs, federal and state agency managers, and others to gain feedback and increase accessibility to the data they had synthesized. The participants were tasked with beta testing the FishVis Mapper, an online tool that uses a number of models to present possible changes in fish species occurrence in response to climate change. These workshops developed connections with decision makers, which later led to the application of FishVis data in land use planning.

In addition to the workshops, nine public meetings were held and surveys were emailed to interested parties. Participants gave input on habitat management issues, land acquisition recommendations, recreational preferences, and perceived future challenges.

A background document was drafted to describe the features and attributes of the DNR properties included in the master plan and their surrounding landscape. The analysis presented science-based findings, which have the potential to become matters of department policy.

Build Connections across Disciplines and Organizations (Principle 4)

Now in its third generation of modelling, FishVis continues to help managers identify stream segments capable of supporting brook trout populations. Decisions about how to manage riparian zones and new acquisitions are based on projected effects of where brook trout will be able to survive in the future. The models and data can influence where to buy land, land rights, and how to manage DNR-owned lands. A Riparian Reforestation Working Group was formed to prioritize the most effective adaptation strategies, one of which is to build thermal resilience by reforesting riparian zones. Dialogue between scientists (fisheries researchers) and clients (managers and planners) has helped identify "no-regret" strategies that meet environmental, economic, and managerial goals.

Figure 4: Brook Trout
Photo by: Pete Yeomans

CASE STUDY 4: NORWEST: DEVELOPING HIGH-RESOLUTION STREAM TEMPERATURE FORECASTS IN THE NORTHWEST UNITED STATES FROM A CROWD-SOURCED DATABASE

Start with a Decision that Needs to be Made (Principle 2)

The goal of the NorWeST project is to organize stream temperature data collected in the Northwest United States by several resource agencies and use these data to create high-resolution models and maps of historical, current, and future stream temperatures. Over the last 20 years, stream temperature data has been collected to monitor state, federal, tribal, and private interests, yet was inaccessible, unorganized, and hard to access. The NorWeST project aims to coordinate access to historical and current stream temperature data in one comprehensive database.

Figure 5: Redfish Creek, Idaho

The database and model outputs cover Oregon, Washington, Idaho, western Montana, most of Wyoming, and parts of northern Colorado, Utah, and Nevada. All data pass through rigorous quality assurance tests. All data and models found on the NorWeST website are being used to develop high-resolution climate scenario maps, which are available to managers seeking to make better-informed local climate adaptation decisions.

Build Connections across Disciplines and Organizations (Principle 4)

The willingness to share data through interagency collaborations with many state, federal, tribal, and local agencies has made this project successful. Results are being shared with regional partners, managers, and other stakeholders through periodic workshops, project updates regarding use of the data, and the Climate-Aquatics blog. The workshops help practitioners understand management needs and demonstrate ways to use the information with complimentary decision support tools.

CASE STUDY 5: SOUTH BAY SALT POND RESTORATION PROJECT

Start with a Decision that Needs to be Made (Principle 2)

The South Bay Salt Pond Restoration Project, developed by the Center for Collaborative Policy, the U.S. Fish and Wildlife Service (USFWS), the California Department of Fish and Wildlife, and the California Coastal Conservancy, is the largest tidal restoration project on the west coast. The project intends to transform over 15,000 acres to a mosaic of tidal wetlands and managed pond habitats capable of providing complex habitat, recreational opportunities, and a critical natural buffer against sea level rise, coastal flooding, and erosion.

Evaluate Co-Production Products, Processes, and the Actionability of the Science (Principle 5)

The project evaluated three potential long-term alternatives to the restoration efforts, and ultimately settled on an adaptive management approach to determine how best to achieve project goals while avoiding adverse impacts to natural resources and ecosystem services. An Adaptive Management Plan was developed to implement the restoration efforts in multiple phases, allowing for monitoring and evaluation at each step to inform future phases and determine the final habitat configuration.

Figure 6: Salt Ponds in South Bay

The South Bay Salt Pond Restoration Project faces many challenges, such as the effects of sea level rise on sediment supply, possible establishment of invasive species, and the potential mobilization of mercury in the salt ponds' sediments. The adaptive management plan uses a scientific approach to generate information useful for decision-making, including monitoring, applied studies, and modeling. This adaptive management approach is based on restoration targets, and ensures science is always informing management decisions throughout each project phase. This allows project leads to assess progress and refocus activities if the system is not responding to the intended restoration goal.

CASE STUDY 6: INFORMING IMPLEMENTING THE GREATER YELLOWSTONE COORDINATING COMMITTEE'S WHITEBARK PINE STRATEGY BASED ON CLIMATE SCIENCES, ECOLOGICAL FORECASTING, AND VALUATION OF WHITEBARK PINE-RELATED ECOSYSTEM SERVICES

Start with a Decision that Needs to be Made (Principle 2)

The Greater Yellowstone Coordinating Committee Whitebark Pine Subcommittee has developed and is implementing a management strategy to protect and restore the whitebark pine, which is threatened by mountain pine beetles and blister rust. The whitebark pine strategy states that, as they become available, climate models and predictive mapping will be incorporated into management work plans. Yet, throughout the development of this strategy, little information was available to the subcommittee about how future climate change might influence the effectiveness of whitebark pine-related management decisions.

Figure 7: Whitebark Pines

Give priority to Processes and Outcomes over Stand-Alone Products (Principle 4)

In this project, researchers from Montana State University, with support from the North Central Climate Science Center, are working with the Greater Yellowstone Coordinating Committee's Whitebark Pine Subcommittee to inform future management decisions and implementation of the whitebark pine management strategy based on climate science. A subgroup of the full subcommittee will engage with the research team and coordinate with the full subcommittee. The research team plans to hold a "pre-implementation workshop" with members of the full subcommittee to review and refine the project methodology, climate scenarios, and timeline.

In addition to providing ecological forecasting models and analyses of paleoclimate data, the research team also plans to develop four management alternatives and evaluate them under different climate scenarios. These management options will be developed in workshops with coordinating committee managers. Management alternatives will be analyzed using cost-benefit analyses and other criteria for suitability (e.g., adequate survival and growth rates).

After the research and analysis components of the project are complete, the research team will hold a workshop with the full Greater Yellowstone Coordinating Committee Whitebark Pine Subcommittee to make recommendations for the whitebark pine management strategy, accounting for future climate change. The research team plans to develop recommendations within the context of the subcommittee's operating structure and history to allow immediate implementation.

Figure 8: Damage from Mountain Pine Beetles
Photo by: Don Becker, USGS

CASE STUDY 7: INTER-TRIBAL WORKSHOPS ON CLIMATE VARIABILITY AND CHANGE

Actionable science is most reliably co-produced by scientists and decision makers or resource managers working in concert (Principle 1)

The establishment of the South Central Climate Science Center (SCCSC) heralded new forms of partnership among Tribal nations and members of the climate science and conservation communities. But communicating key concepts such as risk and vulnerability is a culturally specific practice. So these new relationships call for pluricultural conversations about climate change and variability. To contribute to the goal of mutual understanding, this project developed and implemented a series of five workshops - four in Oklahoma and one in New Mexico - that introduced Tribal members and employees across the region to the SCCSC as a resource for their climate adaptation practices.

Build connections across disciplines and organizations, and among scientists, decision makers, and other stakeholders (Principle 4)

Figure 9: Comanche Horses
Photo by: Troy Sia

Not counting members of the research team 76 individuals participated in the workshops and 66 of them identified with 33 different Tribes. During and in relation to the workshops, the two Indigenous filmmakers on the research team interviewed 49 people. They incorporated this and related footage into a video titled *Listening for the Rain: Indigenous Peoples Perspectives on Climate Change*. Their 22.5-minute video documents climate impacts on Tribal nations and their Peoples, lands, resources, and economies in the Central U.S.A. Blending educational outreach with research on how Tribal members know and conceptualize weather and climate, as well as historically grappled with adapting to new climate conditions, *Listening for the Rain* provides lessons about adaptation that are useful for both Tribal and non-Tribal communities and businesses. Its production and subsequent circulation on the Internet, at conferences and by DVD, has prompted valuable dialogue that furthers previous relationships among Tribal and research communities while also fostering new ones.

CASE STUDY 8: ASSESSING CORAL REEF RESILIENCE TO CLIMATE CHANGE IN THE MARIANAS ARCHIPELAGO

Actionable science is most reliably co-produced by scientists and decision makers or resource managers working in concert (Principle 1) and start with a decision that needs to be made (Principle 2)

As coral reefs continue to decline in the face of both local and global stressors, managers are tasked with developing targeted actions that can reduce the impacts of these stressors, inform short- and long-term planning, and guide monitoring programs. Starting in 2012 in the lower Commonwealth of the Northern Mariana Islands (CNMI), a team effort involving local agencies such as CNMI Bureau of Environmental and Coastal Quality, NOAA Coral Reef Ecology Division, University of Guam Marine Laboratory, and the Pacific Marine Resources Institute began focused surveys of coral reefs to generate an extensive dataset used to identify attributes of these communities that were linked with low vs. high resilience to climate change. With Pacific Islands CSC collaboration, this information is being used to assess the efficacy of current management and protection efforts and justify additional actions that may be warranted to support resilience.

Figure 10: Divers Conducting Assessments of Reef Resilience Marianas Archipelago; Photo by: Jeff Maynard, USGS

Section IV: Case Study References

Case Study 1: Developing and Applying Occupancy Models and Decision Frameworks For The Adaptive Management Of Golden Eagles In Denali National Park

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Case Study 2: Maximizing the Social and Ecological Value of Coastal National Wildlife Refuges along the Atlantic Coast in the Face of Global Change Processes

This case study was based on the four-page project description, Maximizing the social and ecological value of coastal National Wildlife Refuges along the Atlantic coast in the face of global change processes, by Mitch Eaton, Fred Johnson, Jerry McMahon, and Mary Ratnaswamy.

Case Study 3: Brook Trout Vulnerability to Projected Climate Changes in Driftless Area Streams in Wisconsin

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Case Study 4: NorWeST: Developing High-Resolution Stream Temperature Forecasts in the Northwest United States from a Crowd-Sourced Database

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Case Study 5: South Bay Salt Pond Restoration Project

Kershner, J. (2010). South Bay Salt Pond Restoration Project. [Case study on a project of the California Coastal Conservancy]. Product of EcoAdapt's State of Adaptation

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Case Study 6: Informing implementing the Greater Yellowstone Coordinating Committee's Whitebark Pine Strategy based on climate sciences, ecological forecasting, and valuation of Whitebark Pine-related ecosystem services

The whitebark pine strategy can be found at:
http://fedgycc.org/documents/WBPStrategyFINAL5.31.11.pdf

This project was funded by the North Central Climate Science Center in 2013. Information for this case study was taken from the project proposal (available upon request).

Case Study 7: Inter-Tribal Workshops on Climate Variability and Change

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Case Study 8: Assessing Coral Reef Resilience to Climate Change in The Marianas Archipelago

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Or
https://nccwsc.usgs.gov/display-project/4f8c650ae4b0546c0c397b48/52165ec0e4b0b45d6ba39122

Image Links

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Figure 1: Golden Eagle
http://commons.wikimedia.org/wiki/File:Golden_Eagle_3c_(6447274107).jpg

Figure 2: Fishing at Alligator River National Wildlife Refuge
http://commons.wikimedia.org/wiki/File:Person_catching_a_fish_at_the_Alligator_River_National_Wildlife_Refuge.jpg

Figure 3: Sea Level Projections
http://commons.wikimedia.org/wiki/File:Sea_level_projections_at_Alligator_River_National_Wildlife_Refuge_(5687793984).jpg

Figure 4: Brook Trout
Photo by: Pete Yeomans
http://www.nps.gov/grsm/learn/nature/fish.htm

Figure 5: Redfish Creek, Idaho
http://commons.wikimedia.org/wiki/File:Redfish_Creek_Idaho.jpg

Figure 6: Salt Ponds in South Bay
http://earthobservatory.nasa.gov/IOTD/view.php?id=4877

Figure 7: Whitebark Pines
http://upload.wikimedia.org/wikipedia/commons/8/8f/Whitebark_pine_group.jpg

Figure 8: Damage from Mountain Pine Beetles
Photo by Don Becker, USGS
https://www.flickr.com/photos/usgeologicalsurvey/16612752984/in/album-72157638042731635/

Figure 10: Divers Conducting Assessments of Reef Resilience, Marianas Archipelago
Photo by: Jeff Maynard, USGS
http://gallery.usgs.gov/photos/03_11_2015_x1Sf73Iuu5_03_11_2015_3#.VZGUqflViko