Under EPA’s overarching mission to protect human health and the environment, one of the major research priorities of the EPA’s Office of Research & Development (ORD) Sustainable and Healthy Communities (SHC) National Research Program is to promote and build healthy and resilient communities (description of both programs available online). Many communities and their supporting ecosystems face high pollutant exposures and risks. Human exposure and effects can be exacerbated by nonchemical stressors (also known as modifying factors) such as poverty, limited access to services, pre-existing health conditions, and aging infrastructure that undermines pollution-control efforts. Nonchemical stressors that may intensify ecosystem exposures and effects include, for instance, habitat disturbance and destruction, life-stage-specific vulnerabilities and invasive species in addition to aging infrastructure. Fig. 1 illustrates a conceptual model for how environmental stressors, ecosystem services, and human health and well-being are inter-related and influence one another (EPA 2016). Impacted communities often lack the technical expertise, environmental knowledge, and community capacity to address these risks. EPA is making efforts to better evaluate, quantify, and incorporate cumulative impacts both quantitatively and qualitatively, and seeks to foster better integration of ecosystem services and human health and well-being by providing the knowledge, data, and tools needed.
while supporting local communities build capacity to become more sustainable and resilient. In order to successfully address this problem, understanding scientific framework for how ecosystem services may support human health and well-being (Millennium Ecosystem Assessment 2005) is important (Fig. 2).

Fig. 1. Example Conceptual Model: Stressor, Ecosystem Services, and Human Health and Well-Being (EPA 2016).
In 2015, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) has presented the IPBES Conceptual Framework—connecting nature and people, illustrating complex inter-relationships connecting ecosystem services and human well-being (Fig. 3; Diaz et al. 2015).

In 2017, EPA, under the STAR RFA, “Integrating Human Health and Well-Being with Ecosystem Services” has provided $2 million funding for four collaborative, community-based research projects (EPA STAR Grants, RD836938, RD836939, RD836942, and RD836946) that will foster better understanding of how ecosystems support human health and well-being. Specifically, the major goals were to examine how communities can integrate ecosystem services with human health and well-being to (1) inform their...
decision-making and management practices; (2) develop information that allows communities to integrate environmental, societal, and economic information; (3) better manage multiple stressors and their cumulative impacts on humans and ecosystems; and (4) help communities achieve their own objectives.

In this ESA 2019 Symposium Session, the four EPA STAR projects examined how communities could promote human health and well-being in their decision-making and management practices regarding some of their most vitally important ecological systems:

1. Exploring the links between harmful algal blooms and human well-being: How and why communities take action (University of Vermont, PI: Rachelle Gould).
2. Human health, ecosystem services, and their economic value as part of sustainability assessment for the Sacramento region (UC-Davis, PI: Patrick Huber).
3. Integrating human well-being and ecosystem services into near-term action planning in the Puget Sound (Oregon State University, PI: Kelly Biedenweg).

4. Community-level management of human health risks from concentrated animal feeding operations (CAFOs) with defensive natural capital investments (East Carolina University, PI: Jacob Hochard).

A common goal of these projects was to develop scientific evidence-based tools, models, or approaches to better enable communities to integrate environmental, societal, and economic information for optimal outcomes. The four research presentations, along with two EPA tools, EnviroAtlas and DASEES: Decision Analysis for a Sustainable Environment, Economy, and Society (Dyson and Canfield 2018) presentations aimed to integrate, synthesize, and generalize these different challenges into solutions for communities that can use for a variety of environmental/ecological problems. The main purposes of the symposium were to present compelling case studies and examples on how communities may make the most optimal decisions regarding its important ecology and human residents; to have open discussion with ESA members on how a community can bring about meaningful and impactful changes to bridge ecosystem and human health; and to have open dialogue about how scientific research results can be applied to real-world issues in actual communities, narrowing the gap between theory and practice in achieving the optimal ecological health and human health.

Here are the summaries and results of each presentation:

1. EnviroAtlas—EPA’s mapping tool for building community resilience and sustainability by visualizing community ecosystem services and their linkages to human health and well-being

Human health and well-being are closely tied to the environment, which provides benefits such as clean water, clean air, and protection from natural hazards, also known as ecosystem goods and services.
EnviroAtlas provides geospatial data, easy-to-use tools, and other resources related to ecosystem services, their chemical and nonchemical stressors, and human health. Ecosystem goods and services, often shortened to ecosystem services (ES), are the benefits that humans receive from nature. These benefits underpin almost every aspect of human well-being, including our food and water, security, health, and economy. Many of the decisions we make, from how to develop community infrastructure, to managing the land surrounding our communities, impact the provision of ES. We are not always conscious of the links between our surrounding environment and our well-being, and thus, we may not always take the true value of ecosystems into account in our decision-making processes. Considering the true value of ES in our policies and decision-making could help us better manage our resources in a way that would benefit us economically, environmentally, and socially. EnviroAtlas uses seven broad benefit categories to organize its information and data on ecosystem services: (1) Clean Air, (2) Clean and Plentiful Water, (3) Natural Hazard Mitigation, (4) Climate Stabilization, (5) Recreation, Culture, and Aesthetics, (6) Food, Fuel, and Materials, and (7) Biodiversity Conservation.

EnviroAtlas contains over 400 map layers spanning the conterminous United States with about 100 additional layers at a finer resolution for almost 1,200 cities and towns across the United States. It features two primary tools: (1) an interactive map which makes environmental resources, policy implications, stressor, and demographic and other data discovery available to anyone with an internet connection and (2) an Eco-Health Browser which allows users to readily investigate the many linkages between ecosystems, ecosystem services, and human health and well-being as well as the pointing to the literature supporting those relationships. We discovered that while researchers do not seem to have any problems finding and using EnviroAtlas resources, the sheer amount and novelty of geospatial data can be overwhelming for decision-makers. Some decision-makers require explicit guidance on how to use the data in a decision context. One of the ways in which EnviroAtlas has met this need is by developing "use cases" which walk the user through the steps of a specific decision using EnviroAtlas resources. The case studies in this Symposium demonstrate how tools such as EnviroAtlas could successfully aid multidirectional engagements among decision-makers and communities trying to make the most optimal use of their ecosystem services and goods for promoting human health (see Presentations 3 and 4).

2. Decision Analysis for a Sustainable Environment, Economy, and Society (DASEES): A tool for better decision-making by integrating community values with scientific understanding

DASEES is an application for structured decision-making (SDM), a process for evaluating scientific assessments with stakeholder objectives and preferences. A central insight of SDM is that environmental management may be more fruitfully accomplished as a decision to be made, rather than a problem to be studied. This shift in thinking provides opportunities for integration of the social, economic, and ecological issues facing communities such as ecosystem restoration and human well-being. The DASEES approach helps identify technical/scientific expertise and data needs for integrated multi-objective evaluation of decision alternatives.

DASEES was used supporting a component of ongoing research into integrating human well-being and ecosystem services into near-term action planning in the Puget Sound (see Presentation 5). Through a combination of online and in-person support, various watershed restoration groups in Puget Sound were trained on the concepts of SDM and their implementation via DASEES. DASEES was then used by these groups to investigate the effectiveness of including human well-being measures into
strategic funding decisions regarding watershed restoration. The analysis of decision consequences in DASEES is performed with supplied tools such as consequence tables and Bayesian networks. Consequence tables are suited for quicker screening evaluations where there is minimal uncertainty, while the use of Bayesian network evaluations is more suited for characterizing socio-ecologic causal linkages with uncertainty. These tools can be used separately or together depending on decision problem specific conditions. These tools provide the basis for prioritization and trade-off analyses among alternatives and yield examples for other watershed groups interested in better inclusion of social and ecological data for resource management.

Direct engagement with group wrestling with these multifaceted funding decisions has resulted in useful feedback and insight on potential improvements to DASEES design and application with similar groups in the future.

3. Exploring the links between harmful algal blooms and human well-being: How and why communities take action

Harmful algal blooms (HABs) impede ecosystem services and enhance ecosystem dis-services. This study, conducted in a Vermont lakeside community, elucidates links between HABs and human well-being, and investigates how and why a community has taken action based on data about those links. The study has multiple objectives: to (1) determine relationships between HABs and the nutritional value of fish; (2) understand the impact of aerosolized neurotoxins from HABs on human health; (3) explore community members’ mental models of HABs, including HABs’ impact on nonmaterial benefits from human-lake relationships; (4) analyze 50+ years of local media coverage of HABs to understand messaging and treatment of scientific data; and (5) assess the effectiveness of informational framings to motivate action to reduce HABs. Overall, the study develops nuanced understanding of how communities accept, process, and understand scientific information related to HABs, and how they feel empowered or disempowered to affect change.

Each component of the study employs an approach appropriate to its objective and the discipline(s) from which it draws. To test hypotheses about the links between HABs and multiple components of human well-being, we analyze the fatty acid and toxin content of fish, sample ambient aerosols within the community, and conduct an experiment to determine whether visual exposure to HABs leads to increases in stress. To elucidate how a community responds to information about HABs’ impacts, we work with community partners to analyze historical media sources for factors influencing the failure of past initiatives to combat HABs, conduct an experimental survey that frames HAB impacts in multiple ways and observes motivations to take action, and conduct a community-based study of how people absorb, process, and (do not) act upon the increasing amount of HAB-related data with which they are presented. We also describe the use of EnviroAtlas outputs in our community engaged discussions of scientific information.

This study will be completed in July 2021. Preliminary results include that fatty acid content is lower in fish tissue sampled during HABs; analysis of neurotoxins in aerosol samples is ongoing. Mental models research demonstrates that people of different backgrounds (e.g., farmers vs. lakeside property owners) understand the HABs and the actions required to address them differently. Media analysis demonstrates that the framing of and responses to HABs have changed dramatically over five decades and that they respond to scientific understanding in complex yet patterned ways.
Ecologists and geologists provide increasingly unequivocal data about HABs and their deleterious impacts. This study will help communities to draw on these data to effectively reduce HABs.

4. Human health, ecosystem services, and their economic value as part of sustainability assessment for the Sacramento region

Systematic land-use planning for ecological sustainability does not typically include human health and well-being as explicit inputs. We tested the effects of including issues related to human health, ecosystem services, and community well-being on the outputs of a standard land use planning process which is primarily focused on environmental variables. We interviewed regional stakeholders to identify the health issues that have environmental links in the Sacramento, California region, and to identify potential indicators and datasets that can be used to assess and track these issues. We developed formal ontologies describe the relationships between individuals, organizations, sustainability issues, indicators, datasets, and legal mandates that influence sustainability planning in the region. Marxan planning software was used to identify efficient land-use patterns to maximize both ecological conservation and human health outcomes. Economic valuation of ecosystem services and health indicators associated with alternate land-use patterns allowed comparisons between these land-use scenarios. Economic valuation of ecosystem services was used to quantify changes in people’s well-being—as measured by their own preferences—due to incremental changes in their environments.

In particular, we assembled a database of 780 environment- and health-related actors of particular relevance in the region including organizational affiliation and areas of expertise. This was developed into an “expertise ontology.” Health-focused issues, indicators, and datasets were integrated with a growing Environment Issues and Indicators ontology representing classes of regional environmental information. Interviews, online searches, and other information were used to assemble an ontology of people, projects, organizations, and datasets. Finally, a “mandates & guidelines” ontology was developed to formally track the linkages from policies and guidelines to regional sustainability issues and data. Encoding these data and information sources into interlinked ontologies permits query across multiple entry points and perspectives. A focus of the resulting databases and ontologies was the linkage of EPA tools and data to the region. For example, data found in EnviroAtlas were linked to regional sustainability issues to provide capacity to identify useful data sources in regional sustainability assessments. Marxan outputs were derived for four different land-use scenarios that varied in thematic focus. Ecosystem service valuations explicitly quantified trade-offs between scenarios. Preliminary results indicate likely co-benefits to be realized for both ecological and human health outcomes when both are included in regional planning processes.

5. Integrating human well-being and ecosystem services into near-term action planning in the Puget Sound

State and regional governments in the Puget Sound of Washington State are increasing their attention to the social and ecological benefits of ecosystem restoration, largely because it fulfills their dual mandates of protecting public goods and protecting the public. Natural resource managers, however, have little training in integrating social and ecological data to prioritize multi-benefit restoration strategies. This study sought to (1) understand how watershed restoration groups in the Puget Sound basin make strategic funding decisions and in what ways they considered human well-being in their planning and (2)
experiment with three pathways for integrating human well-being and ecosystem service data to prioritize restoration activities that cumulatively contribute to both ecosystem service and human well-being outcomes. We answered the first question by conducting semi-structured interviews that included a cognitive map activity with 37 individuals from nine watershed boards that make biennial funding decisions for restoration priorities. The second component was addressed using participatory research with four of the nine boards, taking detailed notes as the research team facilitated the use of three tools to structure decisions: consequence tables (from DASEES), Bayesian networks (from DASEES), and spatial overlays of human well-being trends and ecosystem services (from EnviroAtlas and regional data).

We found that while social and economic benefits were embedded as evaluative criteria within agency-prescribed decision-making tools, none of the nine watershed groups explicitly emphasized human well-being in their decision-making because they did not have the resources, stakeholders, understanding, or support to adequately do so. All recognized common factors needed for such integration: (1) access to and knowledge of data, (2) experience and understanding of human well-being and social science more broadly, (3) understanding socio-ecological linkages, (4) the presence of structures or systems that inform their decision-making (e.g., planning processes, prescribed decision-making tools), and (5) stakeholder inclusion and equity. While most watershed groups expressed similar enabling factors to human well-being integration, there were some distinctions, reflecting place-based variations. The use of both consequence tables from DASEES and spatial overlays from EnviroAtlas and regional monitoring data will be used by some, but not all of the groups due to limit capacity in their annual workplans, technological confidence of the lead restoration planner, and willingness to engage with new planning terminology.

All projects will be wrapped up in fall of 2020, with full data analyses and documentation available by the end of 2021. Our hope is that this study may guide institutions in this and other regions that are still grappling with how to integrate social and ecological benefits into resource-management decisions.

6. Community-level management of human health risks from concentrated animal feeding operations (CAFOs) with defensive natural capital investments

Intensive agricultural practices can lead to trade-offs between economic benefits and environmental and human health costs. For example, Concentrated Animal Feeding Operations (CAFOs) support local economies but are associated with air, surface, and groundwater pollution. Community-level management of pollution-related health risks requires (1) identifying neighborhoods that are vulnerable to contaminants and (2) understanding how community investments into physical capital and natural capital relate to one another in their capacity to reduce human exposure to contaminants.

Examination of nearly 50,000 well water samples from 2013 to 2018 and over 1.3 million birth outcomes from 2007 to 2019 reveals that major hurricane events impair birth outcomes, such as reducing birthweight and increasing the likelihood of a preterm birth, near animal agriculture facilities. However, these birth impacts appear unrelated to the contamination of private wells and are driven primarily from stress and the disruption of access to prenatal services in rural underserved areas. Further analysis of private well water sampling and well construction trends reveals two behaviors that understate the social cost of groundwater pollution downstream of swine lagoons. First, we discover a uniform sampling schedule but a highly variable risk of bacterial contamination within each calendar year. We document a
Threshold of 90° Fahrenheit where total coliform and *E. coli* detection spikes in private wells near swine lagoons. The high-temperature bacterial contamination is absent during cooler temperatures suggesting that “cold-weather sampling” is unlikely to reflect year-round groundwater contamination risk. The annual gap between sampling and maximum air temperatures implies that annual total coliform and *E. coli* contamination rates near swine lagoons are 25% and 103% higher than prior thought. Alternative contamination sources cannot explain the contamination spike that is also absent in nearby wells upstream from swine lagoons. Second, for each 1-km increase in CAFO proximity, homeowners extend their well casing depth by 30 feet. We show that this avoidance-of-risk effect is isolated on wells known to be drinking water sources and is robust to a variety of specifications including controlling for soil profiles.

Together, these findings suggest that the social cost of groundwater pollution from swine lagoons (human health cost + private adaptation cost) is likely to be larger than prior thought. Findings highlight that atmospheric stressors near animal agriculture operations influence local human health through many channels. State regulations and federal guidelines that coordinate domestic well water sampling with a seasonally fluctuating risk of groundwater contamination have the potential to improve public health by closing a gap between perceived and actual risks of drinking water contamination. Given the lifespan of wells, the distributional burden of private adaptation, and the size of the local animal agriculture industry, targeted and agriculture-funded subsidies for well construction and public water supply expansion may generate tremendous social benefits. Such a program should (1) account for spatially and temporally varying contamination risks and (2) be weighed against similar investments that ensure public health services to vulnerable populations, such as prenatal care, are undisrupted during severe weather events.

Lessons learned/future directions (based on discussions and Q&A with attendees)

1. The case studies demonstrate that the concept and framework of integrating human health/well-being with ecosystem services could enable communities to identify management practices pertaining to ecological conservation, restoration, or land use that are consistent with their values.
2. Developing and understanding a community’s scientific knowledge base, perceptions, and their information sources regarding environmental, societal, economic, cultural, and health benefits is an essential part of developing an effective and transparent decision-making process.
3. EPA tools such as EnviroAtlas and DASEES could streamline analysis of management interventions on multiple environmental stressors and assess their cumulative impacts on humans and ecosystems. Their visual interactive platforms could enhance collaborations and engagement among decision-makers and community stakeholders.
4. Integration of human health/well-being with ecosystem services for effective community decision-making is a complex and multidimensional effort. Careful and thorough examination of different case studies may reveal patterns that can inform other places, especially those with communities that share similar characteristics (environmental, societal, economic, cultural, etc.), challenges, and needs.

More information about this ESA Symposium can be found on the 2019 ESA Annual Meeting website.
Notes

1 https://www.epa.gov/aboutepa/about-sustainable-and-healthy-communities-research-program
2 https://www.epa.gov/research/sustainable-and-healthy-communities-strategic-research-action-plan-2019-2022
3 https://www.epa.gov/eco-research/ecosystem-services
4 https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/display.rfatext/rfa_id/616#Introduction
5 https://cfpub.epa.gov/ncer_abstracts/index.cfm/fuseaction/recipients.display/rfa_id/616
6 https://www.epa.gov/envirotas
7 https://eco.confex.com/eco/2019/meetingapp.cgi/Session/15411

Literature Cited

Diaz, S., et al. 2015. The IPBES Conceptual Framework — connecting nature and people. Current Opinion in Environmental Sustainability 14:1–16.
Dyson, B., and T. Canfield. 2018. DASEES: Decision Analysis for a Sustainable Environment, Economy, and Society. EPA Region 7 and the State of Iowa Conference on support tool DASEES, Cincinnati, Ohio, November 16, 2018.
Millennium Ecosystem Assessment. 2005. Ecosystems and human well-being: Synthesis. Island Press, Washington, D.C., USA.
U.S. EPA (Environmental Protection Agency). 2016. Science-To-Achieve-Results (STAR) RFA: Integrating Human Health and Well-Being with Ecosystem Services. USEPA, Washington, D.C., USA.