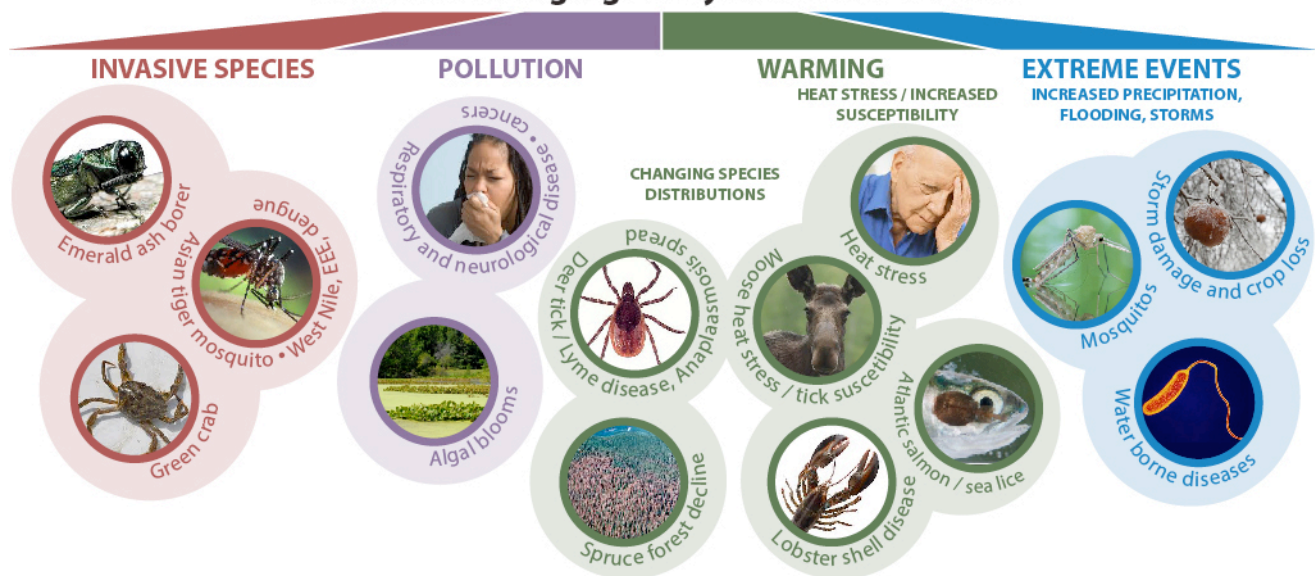


Emerging Research Area: Changing Ecosystems and Climate: Impact on Animal, Plant, & Human Health

The Problem

The dynamic history of the natural world is driven by climate and geologic change, bringing subsequent evolution, invasion, and sometimes extinction of species. Mankind has always influenced the environment through population growth, migration, and through technical, social and cultural changes. However, the *rate* of change and *scale* of human impacts that we are now experiencing, are unprecedented. All of the consequences of climate, ecosystem and human change are yet to be understood, but as our changing climate interacts with other human influences (e.g., pollution, introductions of exotic species) we are beginning to see significant direct and indirect effects on animal, plant and human health.

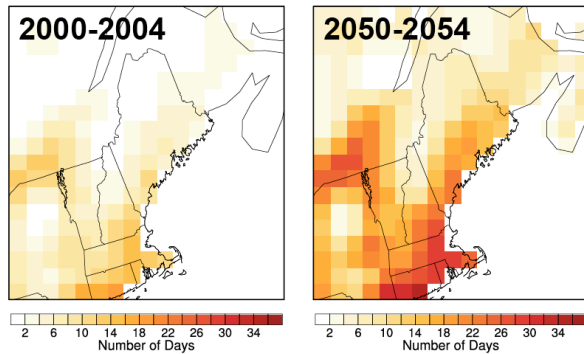
Effects of Changing Ecosystems and Climate



Global commerce has resulted in the introduction of exotic species, such as the green crab and the emerald ash borer, which threaten the health of our ecosystems, and the Asian tiger mosquito, which is increasing transmission of human (West Nile virus, Dengue) and animal diseases (Eastern equine encephalitis). Warmer temperatures have led to the northward shifts of disease vectors and other pests introducing human, plant and animal diseases previously unknown in Maine, which damage human health, and forest and agricultural productivity. Warmer temperatures are also increasing the frequency of days with unhealthy levels of air pollutants, adding to the health stress associated with high heat. Similar indirect deleterious effects of warming are being observed in our human and animal populations as heat stress has dramatically increased the impacts of parasites (ticks on moose/deer/humans, sea lice on Atlantic salmon) and disease (shell disease in lobster). Extreme weather events, becoming more common, introduce wind-blown pests into the state, contaminate surface waters, increase human injuries and fatalities and damage human structures, the natural landscape, forest and croplands. In Maine we stand to be particularly impacted by climate change effects on health, as the segments of the population most vulnerable to climate health outcomes, (heat stress, air pollution effects, water- and foodborne illness and vector-borne diseases), are children, outdoor workers and the elderly (which is a large and growing segment of our population).

The economic effects of animal, plant and human health losses are far-reaching in scale and scope. In-migration

**Average Number of Days Per Year
Heat Index ≥ 90 °F**



also lead to economic losses that are spread throughout the economy; for example, the invasive green crab or the emerald ash borer has the potential to cause decreased harvests in Maine’s marine- and forest-based economies. Increased presence of disease vectors in Maine’s forestland can also have large impacts on the health of outdoor workers (e.g., loggers, hunting guides, tippers) and outdoor recreationists (e.g., hikers, paddlers, anglers). These losses in harvests and increases in labor and insurance costs will lower the profitability of these resource-based industries, leading to lower wages and fewer jobs, which in turn, will have a ripple effect as they move through the local and state economies. These losses in economic activity will lead to lower tax revenues while raising the costs of income-support programs – which limit funds for other worthy activities supported by state and local governments (e.g. education, transportation improvements). Finally, the uncertainty of climate change and its associated impacts is costly to state and local agencies and to businesses that need to plan for the future. Planning activities take longer and are riskier, and financing for new and expanded infrastructure/activities and insuring against potential losses, become more expensive. All of this leads to a subtle, but potentially significant drag on economic activity.

Poised for Solutions

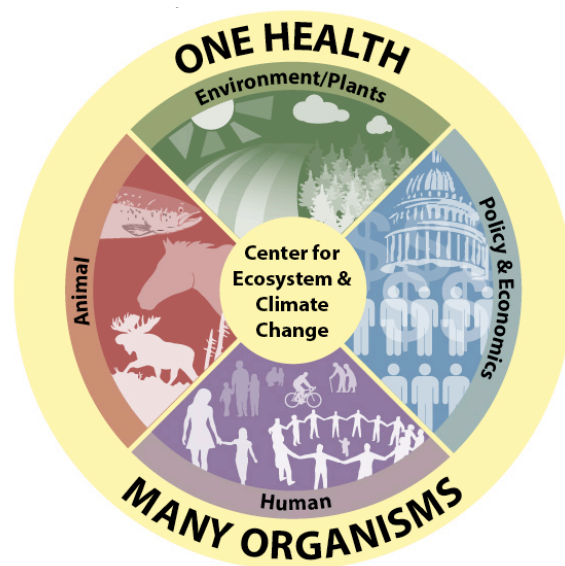
The University of Maine stands poised to address these emerging issues with the establishment of the “*Center for One Health and the Environment*”. Our proposed emerging, interdisciplinary research area, “*Ecosystem and Climate Change: Impacts on Plant, Animal and Human Health*”, builds on the theme of the *One Health Initiative*, “an international movement expanding collaborations and communications in all aspects of health care for humans, animals and the environment” in order to “advance health care for the 21st century and beyond” (<http://www.onehealthinitiative.com/>).

The *One Health Initiative* acknowledges that interdisciplinary collaborations between biophysical and social scientists working in human, animal and environmental health will accelerate discovery in biomedical research, enhance efficiencies in public health, and improve health education, communication and practice. Central to *One Health* is the concept that human, animal and ecosystem health are “inextricably linked”, and addressing the connections between health of all species and the environment is essential for the health of all organisms.

of invasive species (e.g., dengue virus) or increased prevalence of a host species (e.g., deer ticks which spread

Modern and predicted future incidence of high heat events. By 2050, parts of Maine could see 2X as many summer days with heat index values above 90 °F as compared to the early 2000s. Results from UMaine CCI regional climate modeling of IPCC Emissions Scenario A2.

Lyme disease) can lead to direct and severe economic losses to people through increased morbidity (i.e., economic losses through increased medical spending, and lower work productivity, for both the sick person and the caregiver), and mortality. They can

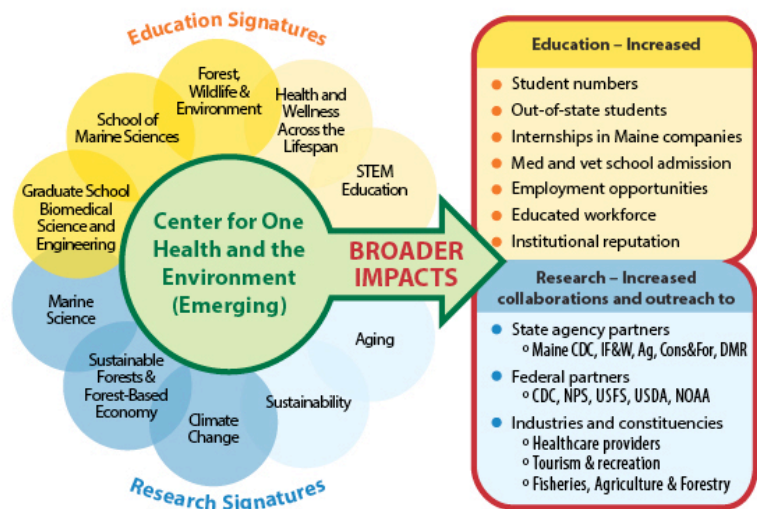


Center for ONE HEALTH and the ENVIRONMENT
at UMaine

At the University of Maine, we are particularly well positioned to contribute to and be recognized for a *One Health* focus in research and educational programs (Table 1). We have a depth of expertise in ecological and environmental sciences, and an internationally recognized research institute focusing on climate change (CCI), the largest threat of our time to animal, human and ecosystem health. We have faculty conducting biomedical research with model organisms such as zebrafish which directly translates and contributes to our understanding of susceptibility and disease development and manifestations across organisms, whether fish, cows, moose, or humans. We have a research and cooperative extension animal diagnostic laboratory (UM AHL), with a focus on health of domestic animals and wildlife and zoonosis (diseases passed between animals and humans), and we have faculty investigating the movement of animal carriers of disease. We have an aquaculture center (ARI) investigating a variety of links between temperature warming, coastal pollution, invasive species, and the interactions of these factors on shell- and fin-fish growth, reproduction and health. We have faculty investigating potential and current water-borne and food-borne pathogens. We have *many* faculty investigating the impacts of climate and other exacerbating environmental stresses (toxicants, invasive insects, pathogens and parasites) on fish, wildlife, plants, domestic animals, and humans, at the population, organism, cellular and molecular level. Finally, we have various social scientists that focus their research and teaching in environmental and health economics and policy. They measure the negative economic impacts of a changing health landscape, measure the economic benefits and costs of adopting climate-change adaptation and resilience policies, examine and evaluate alternative financing and risk-management policies, and assist in developing health communication strategies to help people adjust their behaviors to these emerging health risks. Hence, our moniker *One Health, Many Organisms* captures the breadth that we bring to the *One Health* concept; we develop and evaluate environmental and health management strategies and policies to solve the myriad of plant, animal and human health issues arising within the state as our climate and ecosystems change.

Our initiative is about “*making connections*” – connecting our strengths in ecosystem and climate change sciences with high-demand educational programs in animal and human health, and health economics and policy, to connect our health programs across organisms from marine fisheries to wildlife to domestic animals and humans and connecting between the economics, management and policy of health and the environment. This initiative builds on and connects with the current (proposed) research signature programs at the University of Maine in *Climate Change, Marine Science, and Sustainable Forests*, and (proposed) educational signature programs of the *Graduate School of Biomedical Science and Engineering, the School of Marine Sciences, and Forests, Wildlife and the Environment*. It dovetails and will synergize with the proposed emerging research areas of *Aging and Sustainability*, and the proposed emerging educational areas of *STEM Education and Health and Wellness Across the Lifespan*.

This initiative has already brought together faculty on campus, encouraging new collaborations and identifying links with state constituencies. Maine CDC collaborators and the state-wide Vector-borne Disease Working Group (pest management specialists, veterinarians, healthcare providers, and public health specialists) have both come to campus within the past two months to meet with researchers to discuss and share information on ecosystem and climate change related human health concerns. Further investment in this area will synergize opportunities to expand in a variety of critical areas for the state as well as position UMaine as a leader in “One Health and the Environment”. Specific examples of possible accomplishments and opportunities to highlight include research on:



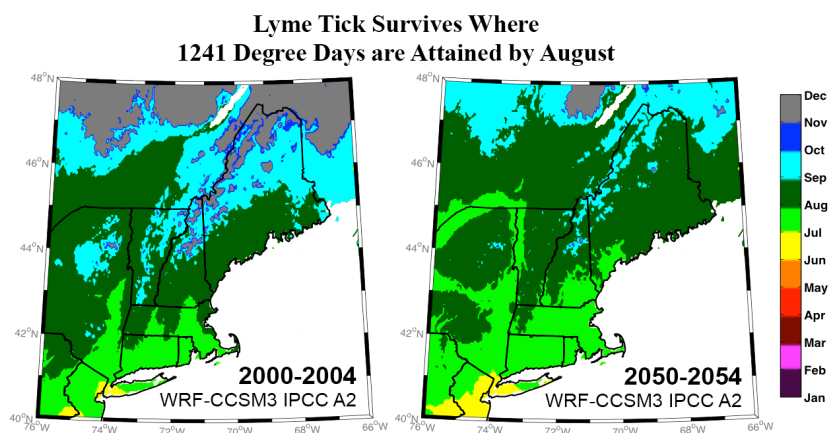
a) **Exposure to heavy metals/metalloids** (arsenic, lead, mercury): Heavy metals have numerous adverse health effects: increased risks of cancer, cardiovascular disease, neurological disorders, and reproductive problems. The breadth of heavy metal research at the University of Maine puts UMaine in a unique position to leverage current expertise to make significant inroads into heavy metal mitigation. Researchers at UMaine study not only the mechanisms underlying adverse health effects, but also how heavy metal partitioning in water and sediment affects bioavailability. The Center for One Health and the Environment will serve as a crucial nexus to coordinate and synergize multiple research programs and facilitate dissemination of research to inform watershed management and water/sediment remediation.

b) **Climate and fish health:** Climate models predict significant changes in the Gulf of Maine, affecting distribution of the resident flora and fauna, and increasing invasive species, parasites and disease. Currently, invasions of green crabs, Chinese mitten crabs, and the colonial tunicate *Didemnum* spp, along with intensifying sea lice infections of farmed salmon, threaten GoM aquaculture systems. Increased runoff importing nutrients, pollutants, and coliforms (e.g., from sewage) and decreasing light penetration, alters production of wild or cultured aquatic animals and increases public health risks of enteric disease. Native fishes that use inland waters, such as Atlantic salmon, brook trout, alewife, and sea lamprey, have also experienced range-wide decline as a result of human activities such as warming, damming, or deforestation. The Center for One Health and the Environment will team ARI and fisheries scientists, climate researchers and others for future modeling, field studies and laboratory studies on key wild or cultured species to evaluate climate impacts on reproductive success, growth and health. Studies will inform new management options for aquatic species.

c) **Lyme Disease** is an emerging vector-borne disease that tightly couples human health with ongoing ecosystem and climate change. The ticks first appeared in southern Maine in the 1980s and are projected to thrive throughout Maine by 2050 as climate changes. Lyme disease is now ranked among Maine’s top disease concerns and has potential to threaten Maine’s outdoor economy (forestry, tourism). From 2005 to 2013, cases increased from 265 to 1,376, costing \$14.2 million in medical expenses in addition to lost worker productivity and wellbeing.

Over 25 years of research on ticks infecting small mammals at UMaine’s Holt Research provides one of the longest and best datasets on invasion of Lyme carrying ticks. New research based on Dr. Sean Birkel’s (CCI) climate models are helping to predict future spread of ticks and Lyme in the coming decades (inset). The University’s wildlife pathology facilities provide an important resource for assessing infections in wild host systems. University expertise also include strengths in resource economics, policy and sustainability science, allowing an integration of environmental and human dimensions. Future hires in related areas would greatly strengthen our position. Adaptation to Lyme disease will require surveillance and management

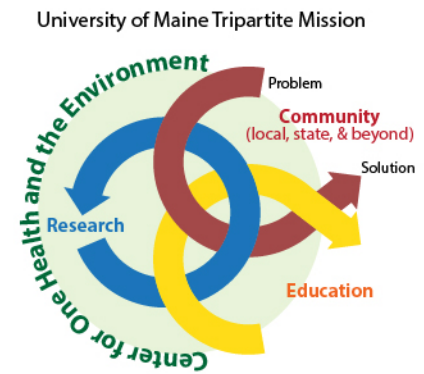
of complex, coupled human and natural systems. This will involve collaborators and stakeholders ranging from health care systems, state and federal agencies to industry and tourism. Holt Forest research collaboration with Maine Medical Center’s (MMC) Vector-Borne Disease Laboratory provides a great example of working with such partners. The UMaine Coop Extension IPM office has partnered with MMC Vector-Borne Disease Lab in state-wide monitoring of arthropod vectors, and has now taken over tick identification services for the state. Funding to support research in this area ranges from local to state contracts and major national funding sources, including NSF’s crosscutting program in the *Dynamics of Couple Natural and Human Systems*. UMaine has a remarkable track record with this program, ranking in the top 10 among all states for number of currently active awards (nearly \$4.5 million). Other sources include the National Institute of Allergy and Infection Diseases (within NIH) programs that support research on vector biology as well as pathogens themselves.



Predicted month of current and future attainment of degree day threshold for Lyme tick larval emergence. Spread of ticks depends on attaining this threshold by August (dark green) and it is likely ticks will thrive across Maine by 2050. (From UMaine CCI regional climate modeling of IPCC Emissions Scenario A2).

The Land-grant Tripartite Mission

Although we were requested to submit separate research and educational proposals, this initiative is specifically designed to meet the tripartite mission of the land grant university of research, teaching, and outreach. The research focus is aimed at addressing critical emerging issues for the state and beyond related to plant, animal and human health impacted by climate and other environmental factors affecting ecosystem change. This is an area that is impacting all of the major industries and constituencies within the state. As we build in this area in the future, we have specifically identified key positions that both: a) provide pivotal expertise for synergizing collaborations across biophysical and social science research faculty addressing these issues, and b) also meet critical teaching needs in high demand programs in health sciences. Our graduate AND undergraduate students contribute directly to our research programs and our research programs greatly enrich our undergraduate programs. Our faculty regularly involve both graduate and undergraduate students in research and outreach activities, which provides our students with valuable hands-on learning experiences through internships with state agencies, partners and industries.



1. Demonstrates a strong “fit to place” defined as: a.) meeting Maine’s cultural, workforce, and economic needs; and b.) actively building on Maine’s existing and future resource base. Maine’s economy and rich cultural history is tightly interwoven with the health of our farms, forests, rivers, lakes, shoreline, and ocean. Both work and recreation in Maine are intimately tied to our natural resource base, which is dependent on healthy ecosystems, workforce, and populace. Despite wise stewardship, the health of Maine’s animal, plant, and human systems are, and will increasingly be, subject to regional and global pressures of climate change, pollution, and invasive species. Maine’s landscape reflects a sharp transition between boreal and temperate biomes, and will be disproportionately affected by climate changes. Our state’s recent post-glacial history has resulted in ‘young’ natural communities, which are particularly vulnerable to invasive species and pathogens. Many of Maine’s signature species of vital importance to our economy, including balsam fir, moose, lobster, and Atlantic salmon, are threatened by climate-related health concerns. Pathogens and parasites invading under warming conditions are impacting forest, crop, animal, and human health. For example, lobster shell disease, MSX and Vibriosis in shellfish, and sea lice in salmon are all on the rise. The Maine CDC has identified the northward spread of arthropod vector-borne infectious diseases, including Lyme disease, Eastern Equine Encephalitis, Powassan virus, anaplasmosis, and West Nile Virus, as major public health concerns. In fact, with Maine’s aging population, an outdoor workforce supporting our natural resource based economy, and a tourist industry directly linked to outdoor recreational activities, our resident and tourist populations and a significant part of our economic foundation are particularly at risk from new diseases and their vectors moving into the state, as well as health complications resulting from rising temperatures, increased pollutants and greenhouse gases, and extreme storm events and flooding.

2. Distinctive and innovative. Investment in the emerging area of **Changing Ecosystems/Climate and Animal, Plant, & Human Health** supports and grows UMaine’s current (proposed) research signature programs (Climate Change, Marine Sciences and Engineering, Sustainable Forests & Forest-based Economy, and STEM Education Research) and (proposed) educational signature programs (Graduate School of Biomedical Science and Engineering, School of Marine Sciences, and Forests, Wildlife and the Environment, College of Engineering, and Honors College). It also dovetails with, and will synergize with, several other proposed emerging educational areas (STEM Education, Health and Wellness Across the Lifespan) and emerging research areas (Aging and Sustainability). This initiative will connect and strengthen research across campus in plant, animal, and human health through the focus on common ecosystem and climate drivers impacting the distribution and health of populations. It will strongly synergize research activities in climate and ecosystem change, infectious diseases, wildlife and fish responses to changing climates and to climate-associated disease vectors, and public health between existing and new faculty, creating a productive, nationally competitive, interdisciplinary team addressing local and global concerns. It invests in emerging growth areas in biomedical

sciences, zoonotic disease, conservation medicine, health policy and management, wildlife health, and holistic, ecosystem approaches to human, animal, and plant health.

Our state has an urgent need to train students in health-related areas and involve them in research. With the absence of medical or veterinary schools and associated extensive facilities, it is extremely important that UMaine capitalize on existing resources, and identify areas in which faculty can build successful collaborations to establish productive, health-related research programs that address critical needs within the state and the greater global community. Health dimensions of climate and ecosystem change provide just such a nexus opportunity for this campus to develop a unique strength and become a nationally-recognized leader in this fast-growing area. Building strategically in this emerging area over time will bring new expertise to campus that will bridge scientists currently in our signature programs in climate change, ecology, and environmental sciences, wildlife and fisheries science, with those investigating infectious animal, plant, and human diseases. This will provide opportunities for many collaborations within and between colleges and departments and new initiatives with established and successful faculty. New faculty will expand our current expertise in disease (plant, animal, and human), enabling us to address critical issues relevant to the state and the international science community in areas such as climate change and epidemiology of infectious diseases; ecosystem change and changing vector biology, parasitology, symbiosis; greenhouse gas warming, air and water quality, plant stress physiology; ecosystem change and public-health economics, management and policy. These emerging areas of science will provide faculty opportunities to integrate with the greater scientific community as well as many local interests within the state (i.e., public health interests and researchers; land managers, foresters and agricultural businesses; tourism; etc.). This initiative **aligns UMaine's research with Maine's Economic Improvement** initiatives through expansion of research addressing impacts, adaptation, and mitigation of climate and other ecosystem changes on human health impacting tourism and public health interests, and on plant and animal health impacting Maine's agriculture, tourism, and forestry sectors. It has the potential to significantly increase the number of PhD students through GSBSE, EES, Marine Biology, Marine Bio-Resources, Plant Sciences, Biological Sciences, Wildlife Ecology, and Anthropology and Environmental Policy, Civil and Environmental Engineering, as well as a potential future PhD in Public Health.

3. Builds on current strengths. As recognized in the UMaine Blue Sky Plan, primary areas of distinction at UMaine are its internationally recognized programs and research institutes, such as the Climate Change Institute, which focus on "Understanding, Managing, and Preserving Natural Resources". The University's strengths in areas of ecology, the environment, and natural resources are reflected in three of the five signature programs (Climate Change, Marine Research Solutions, and Sustainable Forests and Forest-Based Economy), several other research centers on campus (Sustainable Solutions Initiative, School of Marine Sciences, and Maine Agriculture and Forestry Experiment Station), and most units within NSFA (School of Biology and Ecology, School of Forestry, School of Food and Agriculture, Wildlife Ecology, School of Economics). This emphasis is aligned with the college's mission-based research in a state with a natural resource-based economy.

Faculty in the Climate Change Institute integrate transformational field, laboratory and modeling activities to understand the physical, chemical, biological and socio-cultural components of the climate system of the past and present, to better predict future changes in climate and their impacts here in Maine and across the globe. CCI investigations span the last 2 million years to the present - a time of multi-millennial to centennial scale climate changes punctuated by abrupt and dramatic (annual to decadal) shifts in climate. CCI investigations inform predictions for future climate change based upon an understanding of the full dynamic range of the natural climate system and the evolving significant influence of human activity. CCI has a legacy of major scientific contributions to understanding the timing, causes, and mechanisms of natural and human-forced climate change, and on the effects of physical and chemical climate changes on humans and ecosystems.

Faculty in biologically and ecologically related disciplines across NSFA have research emphasis and strength in basic and applied fields, across all hierarchical levels of the disciplines (populations, communities, ecosystems) and the range of ecosystems in the state (forests, freshwaters, marine) (Table 1). Our faculty are a resource for the study of basic and applied plant and animal biology and pathology for our Land Grant Institution. Faculty investigating plant, animal, and human health science and policy are represented in the Schools of Food and

Agriculture, Forest Resources, Biology and Ecology, and Economics, and Depts. of Molecular and Biomedical Sciences, Anthropology, and Psychology. We have faculty conducting biomedical research with model organisms such as zebrafish which directly translates and contributes to our understanding of susceptibility and disease development and manifestations across organisms, whether fish, cows, moose, or humans. We have a research and cooperative extension animal diagnostic laboratory (UM AHL), with a focus on health of domestic animals and wildlife and zoonosis (diseases passed between animals and humans), and faculty investigating the movement of animal carriers of disease. We have *many* faculty investigating the impacts of climate and other exacerbating environmental stresses (toxicants, invasive insects, pathogens and parasites) on fish, wildlife, plants, domestic animals, and humans, at the population, organism, cellular and molecular level.

The Graduate School of Biomedical Science and Engineering is intimately involved in many aspects of the effect of climate change on human health. Specifically, a subset of the 150 GSBSE faculty and 40 Ph.D. students are conducting research in environmental epidemiology with a specific focus on factors affecting the health or illness of populations and the progression of diseases in a population. A second and rapidly growing GSBSE research focus area is that of the biology of stress, including the responses and adaptations of a cell or organism to external challenges. Many of the stressors in question stem from climate change and impacts of the environment experienced by humans and animals. In recognition of the importance of this area, in 2011 the GSBSE created a Stress and Adaptation course that is mandatory for all of its students. As such the GSBSE is already working in aspects of the “One Health” arena-and in partnership with the other entities involved in the Emerging Research Area is poised to make significant and timely contributions.

4. Potential for sustainability regarding personnel, facilities, and funding. UMaine currently has a range of faculty and facilities for research in ecology, environmental sciences and policy, climate change, animal/wildlife ecology, and forest biology and ecology. Key investments for pivotal positions in the areas of epidemiology, vector biology, microbiology, animal and wildlife pathology, plant stress physiology, and health economics/policy would provide a “synergistic bridge” between ecological/environmental faculty and our current plant, animal, and human health sciences faculty. The new faculty positions would bring expertise that will contribute to critical teaching needs in high enrollment programs (Biology, Zoology, and Animal/Veterinary Science (including premed, pre-vet & other pre-professional health programs), Wildlife Ecology, Nursing, Microbiology, Graduate School for Biomedical Sciences and Engineering, School of Economics and SPIA-International Development). These faculty would be extremely competitive for funding from natural resources and forest industries directly impacted by environmentally related plant, animal, and human health concerns; foundations, such as Bill and Melinda Gates Foundation; Federal agencies such as USDA-NIFA (AFRI Programs), NSF (various programs on population, organismal and molecular and cellular biology), NIH, National Institute for Allergy and Infectious Disease, that regularly support innovative research addressing current and future issues relevant to plant, animal, and human health as high priority areas.

5. Leverages, or potential to leverage, existing resources.

These resources impact many research programs; conversely, most research areas use multiple resources. For example, the stress and adaptation research area of the GSBSE utilizes the spectroscopy, microscopy, sequencing and bioinformatics capabilities of UMaine and the GSBSE partner institutions to further our understanding of how climate and environmental change impact human and animal model health from the genetic to macroscopic level. Relevant research resources at the UMaine are discussed by general research area.

**Mammalian and Avian Biology and Health:* The School of Food and Agriculture (SFA) has strong linkages with agriculture and aquaculture in Maine. SFA is home to the University of Maine Animal Health Lab (UM AHL), which provides regional screening for diseases of livestock, wildlife and public health significance. The UM AHL is a member of the Northeast Wildlife Disease Cooperative, linking regional wildlife biologists with diagnostic resources. UM AHL is also a National Poultry Improvement Plan (NPIP) accredited salmonella laboratory, performs FDA-mandated regulatory testing for egg farms in New England, and provides domestic poultry diagnostic support for small farms in Maine. UM AHL’s aquatic animal research capacity is extensive, including facilities for disease and nutritional studies of aquatic animals ranging from lobster to salmonids. An \$8 million

expansion of the UMAHL is planned, pending the outcome of a bond in 2014. SFA also supports a large animal facility for preclinical studies of animal health products at the Witter Center, which includes a functioning dairy, equine center and small ruminant facilities. SFA is closely affiliated with Cooperative Extension, providing food safety and animal health information to a large clientele in New England, and has strong links with the Maine Center for Disease Control (CDC) and with Maine Department of Agriculture, Conservation and Forestry.

**Aquatic Animal Health from aquaculture to models of human disease:* Aquatic animals are a major food source, potentially impacted by climate change, yet mechanisms and potential mitigation options are not well understood. UMaine has many resources to leverage regarding aquatic animal health and ecosystem changes. Intellectual resources include the current expertise clusters on campus: (1) ecology of aquatic disease, (2) lower vertebrate vaccination, and (3) sea lice biology and pathobiology. Physical resources include the following: (1) The aquaculture aquarium facility (the Aquaculture Research Center or ARC; 13,000 sq ft) has salt and freshwater resources, including freshwater wells with approximately 75,000 GPM capacity for either recirculating or flow-through fish support systems. (2) The BSL2 Aquatic Animal Disease facility located in Hitchner Hall has salt and freshwater capacity up to 15 GPM and biosecurity adequate for smaller-scale fish pathogen research. (3) The University of Maine zebrafish facility, established in 2000 and producing over 30,000 embryos monthly, is a highly utilized resource for biomedical research. Current on-campus zebrafish expertise clusters include zebrafish models of fungal or viral infection, and of neurodegenerative or muscular disorders. The zebrafish facility is extensively used by faculty within multiple departments (SBE, SMS, MBS), and is funded by sources including NIH, the Muscular Dystrophy Association, NSF, and corporate sponsors. Upgrades to the facility within the last decade have greatly increased capacity, allowing recruitment of additional faculty (Rob Wheeler, Julie Gosse, Roger Sher) to UMaine. The current capacity of the zebrafish facility can accommodate at least one additional faculty, an excellent resource that can be leveraged during recruitment.

**Public Health:* Considerable opportunities exist to build on existing collaborations and to share resources with other medical laboratories and facilities throughout the state, including Eastern Maine Medical Center, Maine CDC, the six academic and research institutions in GSBSE, and others. In particular, state agencies concerned with water quality seek support for monitoring heavy metal/metalloid toxicants, and provide resources for studying environmental toxicants such as algal blooms. The SOE faculty have several research collaborations with Maine CDC related to heavy metal contamination of ground- (arsenic) and surface-water (mercury).

**Agricultural Sciences:* Agronomy facilities are critical for studying plant adaptation to climate change, including extreme environmental conditions, pest and pathogen dynamics. Current faculty investigate diseases affecting potatoes, blueberries, and vegetable crops, as well as landscape plants. Prolonged wet springs or droughts may stress plants, enhance disease pressure and decrease agricultural yields. Understanding the mechanisms underlying plant stress tolerance can facilitate developing innovative strategies for genetic improvement of agricultural crops. Extensive University of Maine facilities, supported in part by Cooperative Extension, include the Aroostook, Blueberry Hill, Highmoor and Rogers Farms; campus greenhouses, hoop houses, and plant growth chambers.

**Wildlife and Fisheries Science:* Three federally-funded scientists with the USGS Maine Cooperative Fish and Wildlife Research Unit (MCFWRU) are stationed at the University of Maine and are actively involved in studies of wildlife, fish, and aquatic and terrestrial system responses to changing climate. Collaborations with other state and federal agencies are facilitated through established agreements involving MCFWRU.

**Other University facilities:* The Orono campus houses a DNA sequencing facility, extensive microscopy resources (confocal, SEM, TEM, etc.), insect-rearing facilities (vital for vector biology), a pollen analysis laboratory, a wildlife necropsy laboratory, and an AAALAC-accredited Small Animal Research Facility (SARF) including surgical facilities for species ranging from lab mice to pigs. These facilities provide in-house support of complex projects; one example is the Wheeler laboratory, using animal models (zebrafish and rodents), confocal and electron microscopy to study the molecular and cellular aspects of host-pathogen (human-Candida) interaction. An additional Maine-based resource is the *Climate Reanalyzer* (<http://www.cci-reanalyzer.org/>), a web-based utility for visualizing meteorological data and models. The Climate Reanalyzer serves the UMaine research community and beyond, with a small but growing global audience of 300-400 users daily.

6. Interdisciplinary and/or multidisciplinary. Of critical importance, this initiative builds on and links existing faculty in climate change, ecology, aquaculture, marine and environmental sciences with those investigating plant, animal, and human health issues and their related public policy and management implications. Collaborations between ecological and environmental sciences and health scientists are rare. UMaine has the opportunity to foster a unique multidisciplinary group that spans from ecological and environmental, and wildlife and fisheries science scientists in the Climate Change Institute across multiple units including the School of Earth and Climate Sciences, Dept. of Wildlife Ecology, School of Biology and Ecology, School of Marine Sciences, Dept. of Molecular and Biomedical Sciences, School of Food and Agriculture, School of Forestry, School of Economics, Margaret Chase Smith Policy Center, Dept. of Anthropology, Dept. of Psychology, Dept. of Chemical and Biological Engineering, and GSBSE to study the impact of climate on public health, animal/veterinary sciences, wildlife ecology, and plant health, and associated policy issues.

7. Integrates (or potential for integration) with the teaching and service missions. The focus on health of humans and animals provides an immediate and salient problem focus, bringing the opportunity for applied research and service by faculty, research staff, and students.

TEACHING:

- Adds depth to our eroded teaching faculty in health sciences, enabling us to **further grow and increase our enrollments in undergraduate programs in the critical STEM areas serving popular, traditional pre-professional degrees (pre-med, pre-dental, pre-physician assistant, etc.), including the recently proposed CLAS minor in Health, Medicine and Society.**
- Combined with the Emerging Education Area of the same topic, the synergy and interdisciplinary stimulation will offer an opportunity to develop new climate-focused degree programs and concentrations in public health and public health management, Conservation Medicine, and Bioinformatics.
- Increased depth of faculty and course offerings for students in growing programs assures the availability of critical courses for health science related curricula, which will enhance retention in these programs. In particular, adding new faculty resources in epidemiology and health policy will bolster multiple programs.
- Provides greatly enhanced opportunities for undergraduate students in STEM disciplines to participate in hands-on research experiences with early career faculty actively engaged in cutting-edge research. The American Association for the Advancement of Science (AAAS) has identified student research engagement as the most important element for effective education in STEM disciplines.
- Provide students with internships in public policy, health economics, health communication, infectious disease methods, zoonotic disease investigational methods, control/prevention techniques, etc.

SERVICE: Problems associated with climate change can be expected to challenge policy makers and public agencies as they emerge. Agencies will need help identifying and defining problems associated with such major problems as the rise of infectious disease, population displacement due to rising sea levels and storms, and significant changes in fisheries. Having a robust, interdisciplinary research infrastructure at the University of Maine can provide invaluable support, current information, and research resources, and expand current service to Maine and federal agencies and healthcare facilities with collaborative projects and outreach (*Maine CDC, Board of Pesticide Control, Vector Mgmt. Programs, Maine Public Health Assoc., Maine Hospital Association, Depts. of Marine Resources, Inland Fisheries and Wildlife, and Agriculture/Forestry/Conservation, Maine Emergency Management Agency and Federal Emergency Management Agency.*

NPS, and EPA).

- Provides students with internships and research opportunities in public policy, infectious disease methods, zoonotic disease investigational methods, control/prevention techniques, epidemiology and disease surveillance, disaster planning etc.
- Student and faculty applied research projects associated with the above-mentioned agencies will provide new opportunities for extramural funding which will benefit both the University and the agencies.

Table 1 List of faculty expertise and research activities at the University of Maine addressing various aspects of climate change and their impact to human, animal and plant health.

Investigator information*	Research project	Funding sources	Broader impact
Aria Amirbahman (CIE) Expertise: Water chemistry, pollutant fate and transport	Basic, Applied: Trace metal and phosphorus cycling in sediment and water, photolysis and photocatalysis of organic compds	DoD, USGS, NPS, WRRRI, Maine DEP, foundations	Graduate student training, informing Maine DEP, water quality managers, water treatment plants, environmental consulting companies
Seanna Annis (SBE) Expertise: Plant pathology	Basic, Applied, Outreach: Impact of climate change on diseases of lowbush blueberries	USDA, private producers or grower groups	Undergraduate and graduate student training, informing blueberry industry on best IPM practices
Kathleen Bell (SOE) Expertise: Environmental and public economics	Basic, Applied, Outreach: Climate change threat to safety of coastal beach recreation, shellfish consumption, aquaculture prod; Designing, implementing, assessing health advisories	NSF, CDC, EPA, Sea Grant	Improved health, ecosystem, and climate change information and policies; improved public health; increased sales of healthy products and use of safe recreation sites; Graduate student training
RebeccaVan Beneden (SMS/MBS) Expertise: Molecular toxicol.	Basic: Impacts on adults of early-life arsenic exposure	USDA, EPA	Gene/environment interactions; aquatic models for human and environmental health
Sean Birkel (CCI) Expertise: Climate modeling and data visualization	Basic, Applied: Past, recent, and future climate modeling; earth systems data visualization and analysis.	NSF, ME-CDC, MEIF, private	Climate system evolution through time; models of climate influence on vector-born disease; visualization website for climate data and models
Erik Blomberg (WLE) Expertise: Wildlife population ecology	Applied: Demographic response of avian populations to climatic variability	ME-IFW, CFRU, ME-OHF	survival and recruitment responses of focal species (greater sage-grouse, ruffed grouse, spruce grouse) associated with variation in temp., precip., and other climate metrics; Grad education and training
Tim Bowden (SFA) Aquatic animal health, aquaculture	Basic, Applied: Influences of chronobiology on aquatic animal health. Impacts of climate change on aquatic animal health	NSF, private foundations, MAIC, industry	Environ'l impacts on aquaculture species, improving management strategies. Educ., training, outreach of aquatic animal health issues
Susan Brawley (SMS) Expertise: Algal reproduction, intertidal biology, sea vegetable aquaculture	Basic: The macroalgal microbiome; environmental effects on algal reproduction. Applied: Developing new crops for sea vegetable aquaculture, strain selection for changing climates.	NSF, Maine Sea Grant (NOAA)	Undergraduate/graduate training related to the algae, including effects of algae on climate; advising State government on rockweed biology; advising algal companies in Maine.
Ian Bricknell (SMS/ARI) Expertise: Fish Parasitology, Fish immunology, Aquaculture.	Basic, Applied: Sea lice biology, host parasite interactions, fish vaccines, aquatic disease ecology, pathobiology of aquatic pathogens	NSF, NOAA, USDA, Seagrant, MAIC, MTI, NRAC, foundations, MAIC, industry	Improving Maine's aquaculture based economy, Aquatic animal health management, welfare of research animals, testing biological models under field conditions
Aram Calhoun (WLE) Expertise: Wetland ecology and conservation	Applied: Population persistence of pool-breeding amphibians in urbanizing landscapes: conservation and policy	NSF	Creating conservation plans for municipalities that balance ecologic and economic sustainability
Robert Causey (SFA) Expertise: Equine reproduction, microbiology, infectious disease, composting of equine waste	Basic, Applied: Development and commercialization of new methods of detecting animal diseases. Equine management. Composting of equine waste.	MTAF, MAC	Effect of season and climate on diseases of importance to horses and their caretakers, and on management of equine compost
Xuan Chen (SOE) Expertise: Agricultural and resource economics, risk management	Applied: sustainability of dairy farms, risk assessment of pest/disease in potato production	USDA-NIFA, Maine Dept.Agric, Conser. & Forestry	Suggestions for sustainable agricultural productions. Education and training in economics.
Steve Coghlan (WLE) Expertise: Fisheries and aquatic ecology	Basic, Applied: Responses of coldwater fishes and their stream ecosystems to climate change	MAFES, NOAA, USFWFS, ME-IFW, PRRT, MDMR	Predicting how dam removal and habitat restoration affect resilience of Maine's native fishes in face of changing temp. and streamflow; Undergrad and grad educ.
Christopher Cronan (SBE) Expertise: biogeochemistry, ecosystems analysis, and landscape ecology	Applied: Strategic conservation planning and predicting stream vulnerability to land use changes and climate change	EPScoR-NSF, Sewall Foundation, and MAFES	UMaine alternative futures landscape spatial models that provide framework for examining potential effects of changing land use and climate on ecol. and social systems
Benildo de los Reyes (SBE) Expertise: Plant stress physiol, gene regulation, genomics, epigenomics	Basic: Genetic and epigenetic regulatory networks involved in plant responses to abiotic and biotic stresses	NSF, USDA-NIFA, International agencies	Breeding the next generation of climate resilient crops; Education (graduate, undergraduate), training, and outreach in genomics; International partnerships and outreach

Frank Drummond (SBE) Expertise: Conservation, pollination, pop. genetics, agric.	Applied, Outreach: Decline of bumble bees; Cold tolerance in lowbush blueberry	USDA-NIFA, SCRI	Climate change and pollination
Adria Elskus (SBE/SMS) Expertise: Aquatic toxicology	Applied: Effects of pesticide mixtures (fungicides), on basic functions of aquatic ecosystems	USGS	Implications of global increase in fungicide use with climate change; Education and training in toxicology
Eric Gallant (SFA) Expertise: Sustainable agriculture and ecological weed management	Basic, Applied, Outreach: Assessing potential for emergence of new cropland weeds in the Northern New England (NNE) region as result of climate change	Maine Agricultural and Forestry Experiment Station, NSF, USDA-AFRI	Potential impact on farmers' short-term management and longer term investments in infrastructure related to weed management
Jacquelyn Gill (SBE/CCI) Expertise: Paleoecology, plant ecology	Basic, Applied, Outreach: Novel climates and ecosystems, climate-driven extinctions, biotic interactions and climate change	Startup, NSF (pending), National Geographic (pending)	Graduate student training, blogging and Twitter, seabird conservation,
Julie Gosse (MBS) Expertise: Biochemical, molecular, and cellular toxicology	Basic, Applied: Effects (and underlying mechanisms) of toxicants and other stressors on signal transduction pathways	NIH, NSF, USDA-NIFA, EPA, Private foundations	Cellular and molecular studies to aid in human and wildlife environmental health risk assessments; Graduate and undergraduate education and training in molecular toxicology
Hamish Greig (SBE) Expertise: Climate change ecology, freshwater ecology	Basic, Applied: Impacts of warming on plant-herbivore interactions. Effects of hemlock decline on aquatic ecosystems	NSF-NCEAS, USDA-HATCH, CIEE	Effects of climate change on plant pest damage and biocontrol; International interdisciplinary synthesis
Eleanor Groden (SBE) Expertise: Entomology, insect ecology	Basic, Applied: Microbial symbionts associated with invasive insects and their parasites	USDA-AFRI, NSF, NPS, USDA-FS	Work with state and national agencies relative to monitoring, ecology and management of invasive insects, biocontrol, development of microbial controls.
Jianjun Hao (SFA) Expertise: Plant pathology, soil microbiology	Basic, Applied: Structural, functional and genomic studies of soil microbial communities associated with potato common scab	USDA-NIFA	Help disease management in organic production; Improve sustainable agriculture by better understanding the ecosystem, and improving soil health and plant health
Clarissa Henry (SBE) Expertise: Muscle development in zebra fish model	Basic: Impact of disease burden on muscle wasting	NIH	Education, training in genetics and muscle biology, implications for muscle wasting in myriad of cond.
Malcolm Hunter (WLE) Expertise: Conservation biology	Applied: Conservation strategies in response to climate change	Doris Duke Charitable Foundation	Developing landscape-scale conservation strategies that are resilient to climate change
Carol Kim (MBS) Expertise: Innate immune response to bacterial and viral infection using zebrafish model	Basic: Effects of emerging pathogens and environmental factors on the innate immune response	NIH, NSF, NASA, DOE	Effects of emerging pathogens resulting from climate change and environmental stress
Michael Kinnison (SBE) Expertise: Applied evolution	Basic, Applied, Outreach: Synthesis of applied evolution across environmental, food and health sectors	USDA, NSF	Public awareness of evolution as appl'd science, improved outcomes through knowledge transfer, solutions (e.g. disease) that link sectors
Anne Lichtenwalner (SFA) Expertise: Animal and wildlife diseases	Applied, Outreach: Moose health in a changing ecosystem; Emerging zoonoses in wildlife, livestock and man	USDA-NIFA, NESARE, NOAA	Improved livestock/wildlife health; reduced public health risks; student integration into research and service; improved vet school admissions
Cynthia Loftin (WLE) Expertise: Systems and landscape ecology (freshwater focus)	Basic, Applied: Conservation and restoration of perturbed systems; spatial assessment of system response to landscape conditions	USFWS, NSF, USGS, MDIFW, USDA	Graduate student training; resource management information for agricultural interests and land management agencies
Shannon McCoy (PSY) Expertise: Social psychology	Basic, Applied: Consequences of stress for the general well-being (i.e. physical, mental, cognition) of humans	NSF	Implications of stress of climate change to human health; Undergraduate and graduate training in psychophysiology
Brian McGill (SBE/SSI) Expertise: Large-scale ecology	Basic, Applied: Range shifts and conservation implications of climate change and land use change	NASA, NSF	Improved forecasts for conservation planning
Shawn McKinney (WLE) Expertise: Terrestrial comm. ecology	Basic, Applied: Responses of plant and animal communities to climate change	DOI, NPS, USFWS, ME-IFW, OHF	Forecasting distribution, abundance, and composition of montane communities under climate change scenarios; Grad educ and training
Paul Mayewski (CCI, SECS, SPIA, SMS) Expertise: Climate science, glaciology	Basic, Applied: Global climate change including global impacts on Maine	NSF, NOAA, private foundations	Translating climate science, climate adaptation and sustainability planning

David Neivandt (CHB, GSBSE) Expertise: Biomedical engineering	Basic, Applied: Impact of stress on plasma membrane transport of signal peptide-less proteins	NSF, NIH, DOD, Industry	Understanding molecular and cellular responses to stress and the pathways to human diseases and disorders
Caroline Noblet (SOE) Expertise: Environmental economics and psychology	Basic, Applied, Outreach: Information processing; preferences for resource use; threats of climate change to the safety of coastal beaches, shellfish and aquaculture products	NSF, EPA, FDA	Improved understanding of citizen preferences and reaction to information; Graduate student training
Brian Olsen (SBE/CCI) Expertise: Avian ecology, conservation biology	Basic, Applied: movement patterns and habitat use of migratory birds under climate change (vectors of human disease)	NPS, USFWS	Mapping the likely pathways and timing of spread for bird-borne human illnesses (e.g., Avian Influenza, West Nile Virus)
Gregory Porter (SFA) Potato breeding and variety development, crop management and physiology	Applied: breeding and selection of potato varieties for adaptation to diverse climates, biotic and abiotic stress, management practices for optimizing crop productions	USDA-NIFA, USDA-ARS; ME Potato Board, private companies	Breeding for improved productivity, quality, and tolerance to abiotic and biotic stresses, release and commercialization of new potato varieties development of crop management practices; Education (graduate and undergraduate), training, and outreach.
Paul Rawson (SMS) Expertise: Marine biology, aquaculture	Basic, Applied: Impacts of climate change and ocean acidification on shellfish health and productivity	USDA-NIFA, NSF, NOAA	Stress tolerance mechanisms and breeding in marine bivalves; Informing the aquaculture industry in Maine and northeastern U.S.
Jonathan Rubin (MCS) Expertise: Economics	Applied: Mitigation of GHG emissions from transportation, Adaptation of transport systems from climate change; consideration of impacts on humans	NSF, DOE, EPA	Mitigation and adaptation, with a focus on regulatory design and transportation energy and human systems
Jasmine Saros (SBE/CCI) Expertise: Freshwater ecology	Basic, Applied, Outreach: Threats of climate change to drinking water quality in Maine	Water Resources Research Institute, water districts	Graduate student training; Informing water districts and water management
Roger Sher (MBS) Expertise: Gene by environment interaction, neurodegeneration	Basic: Impact of harmful algal bloom neurotoxins in neurodegeneration	NIH, NSF, DOD, EPA, Private foundations	Effects of climate change to neurodegenerative diseases; Education and training in toxicology
Mario Teisl (SOE) Expertise: Environmental and health economics	Basic, Applied, Outreach: Threats of climate change to the safety of drinking water supplies, coastal beaches, shellfish and aquaculture products; Measuring effectiveness of health advisories	USDA, NSF, EPA, CDC, FDA	Improved health information strategies, regulation of health-related information and Increased sales of healthy products; Graduate student training
Mary Tyler (SBE) Expertise: Developmental biology, histology, introductory biology, educational materials	Applied: Developing educational materials for intro and advanced biology classes to examine effects of the environment on health, biodiversity, and energy costs	NSF (previously), ADVANCE Award	Education of undergraduate and graduate students at UMaine and worldwide.
James Weber (SFA) Expertise: Reproductive physiology, veterinary parasitology.	Basic, Applied: Environmental effects on free-living stages of parasitic nematodes, mgemt. in small ruminants.	USDA-NE SARE, previously NIFA	Develop management strategies that take advantage of environmental conditions to reduce parasitism-related losses in New Eng. livestock
Robert Wheeler (MBS) Expertise: Microbiology, immunology	Basic: Molecular aspects of host-pathogen interactions in mycoses of human, mouse and zebrafish	NIH, NASA, Foundations, Pharmaceutical companies, USDA-NIFA	Molecular aspects of innate immunity-relevant to resistance to Lyme disease, babesiosis, West Nile EEE; Fish immunity relevant to aquaculture developmt.
Vivian Wu (SFA) Expertise: Food safety	Applied: Nanotechnological tools for the detection of major food-borne human pathogens	USDA-NIFA, food industry	High-resolution technology for detecting pathogens (and its climate-driven dynamics) in fresh farm produce; Graduate and undergraduate student training; International outreach
Gregory Zaro (ANT/CCI) Expertise: Archaeology of agricultural landscapes, urbanism, and human-environment interactions	Basic, Applied, Outreach: Landscape evolution and human agency surrounding the city of Zadar, Croatia, 3000 years ago to present	NSF, National Geographic Society	Delineate human agency in environmental change; train students in problem oriented, interdisciplinary environmental research; community outreach and education

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