Thomas K. Frazer is a Professor and the Director of the School of Natural Resources and Environment at the University of Florida. Dr. Frazer holds a Bachelor's Degree in Fisheries Biology from Humboldt State University and a Master's Degree in Fisheries and Aquatic Sciences from the University of Florida. He earned his Ph.D. in Biological Sciences from the University of California, Santa Barbara. His research addresses contemporary and emerging environmental issues, and it is, by nature, interdisciplinary. His work involves collaborators from disparate disciplines, and it includes sampling and experiments conducted across a wide range of spatial and temporal scales. During his tenure at the University of Florida, Dr. Frazer has garnered substantial research funding to address topics pertaining to water quantity and quality, nutrient dynamics, biogeochemical processes, fish population dynamics, food web interactions, and ecological restoration of degraded ecosystems. He has conducted field research in both freshwater and marine systems around the globe, and he is intimately familiar with a broad suite of environmental and natural resource issues (e.g., eutrophication of fresh, estuarine, and coastal waters; invasive species; and the ecological impacts of contemporary environmental change, including coral bleaching, ocean acidification, and sea level rise). Dr. Frazer has authored and/or co-authored more than 175 peer-reviewed publications, technical reports, and book chapters. He serves as Chief Specialty Editor for the Coral Reef Research section of Frontiers in Marine Science, currently holds an at-large seat on the Gulf of Mexico Fishery Management Council, and is a member of APLU's Board on Oceans, Atmosphere and Climate.

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Professional Preparation

Humboldt State University	Marine Fisheries (cum laude)	BS, 1986
University of Florida	Fisheries and Aquatic Sciences	MS, 1990
UC Santa Barbara	Biological Sciences	PhD, 1995

Appointments

2012-present	Director, School of Natural Resources and Environment, University of Florida
2015-2016	Acting Director, University of Florida Water Institute
2008-2012	Associate Director, School of Forest Resources and Conservation, University of Florida
2008-2012	Program Leader, Fisheries and Aquatic Sciences Program, University of Florida
2008	Associate Chair, Department of Fisheries and Aquatic Sciences, University of Florida
2010-present	Professor, School of Forest Resources and Conservation, University of Florida
2007-2009	Research Foundation Professor, University of Florida
2004-2009	Associate Professor, Department of Fisheries and Aquatic Sciences, University of Florida
1998-2004	Assistant Professor, Department of Fisheries and Aquatic Sciences, University of Florida
1996-1998	Research Assistant Professor, Department of Fisheries and Aquatic Sciences, University of Florida
1990-1995	Graduate Research/Teaching Assistant, Department of Biological Sciences, University of California at Santa Barbara
1988-1990	Biological Scientist II, Department of Fisheries and Aquatic Sciences, University of Florida
1987-1988	Biological Scientist, Department of Fisheries and Aquatic Sciences, University of Florida
1986	Fisheries Biologist, U.S. Fish and Wildlife Service, Arcata, California

Administration and Leadership Experience

University of Florida

2012 – Present: Director of the School of Natural Resources and Environment

Administrative Scope – The Director provides leadership and administrative oversight of all aspects of the SNRE's academic programs. The School's degrees access more than 300 affiliate faculty and courses delivered across 13 different UF colleges and college level units. The Director plans, implements and administers innovative, interdisciplinary degree programs and serves as Graduate and Undergraduate Coordinator for the Interdisciplinary Ecology and Environmental Science degree programs, respectively. The Director has fiscal oversight of the School and is responsible for planning and managing the academic programs budget. The Director also is responsible for attracting extramural support for the SNRE's academic programs and private donations in support of the broader suite of activities carried out within the School.

2015 – 2016: Acting Director of the UF Water Institute

Administrative Scope – The Director leads and guides the establishment of interdisciplinary research, education and outreach programs conducted under the auspices of the University of Florida Water Institute. The Director is expected also to identify and foster externally funded research programs and strategic opportunities for UF to deliver valued outcomes to stakeholders confronting water-related issues. Within UF, the Director works with faculty, department chairs, directors of on-campus and off-campus research and education centers, and county extension directors to focus, coordinate, and integrate the water-related programs in existing disciplinary departments, centers, and interdisciplinary programs.

2008 – 2012: Associate Director of the School of Forest Resources and Conservation and Leader of the Fisheries and Aquatic Sciences Program

Administrative Scope - Provide school-wide leadership in Research, Teaching and Extension and with the SFRC Director manage a facility that houses over 250 faculty, staff and graduate students. The Associate Director reports directly to the Director of the SFRC and assists with fiscal, administrative and personnel matters.

2008: Associate Chair, Department of Fisheries and Aquatic Sciences

Administrative Scope – Provide leadership in Research, Teaching and Extension and with the FAS Chair manage an academic unit that comprises 15 tenure track/tenured faculty, 10 resident scientists, and ~ 25 graduate students. The Associate Chair assists with all fiscal, administrative and personnel matters.

Research Narrative

The overarching goals of my individual and collaborative research efforts are to develop and transfer into management a mechanistic understanding of the effects of anthropogenic activities on the ecology of both freshwater and marine ecosystems. My research is, by nature, interdisciplinary, involves collaborators from disparate disciplines and is carried out across broad space and time scales to most effectively address contemporary and emerging environmental issues.

Publications

Refereed Publications

In Preparation

Guan, J., C.A. Jacoby, T.K. Frazer. In Prep. Light attenuation by epiphytes on *Vallisneria americana*.

Hilsenroth, J., S.M. Baker and T.K. Frazer. In Prep. Temperature effects on fouling assemblages: implications for the mariculture industry.

Laing, J., T.K. Frazer, C.A. Jacoby and M.J. Cohen. In Prep. Sediment redox conditions in Florida spring systems.

Lauretta, M.V., W.E. Pine, C.W. Walters and T.K. Frazer. In Prep. Plant mediated community structure within spring-fed, coastal rivers.

Miller, N., P. Maneval, T.K. Frazer and J.L. Meyer. In Prep. Spatial distribution of microbial communities associated with nursery-reared *Acropora cervicornis.*

Takoukam, A.K., M.V. Hoyer, L.W. Keith-Diagne, M.K. Hunter, T.K. Frazer, R.K. Bonde, R. Francis-Floyd. In Prep. Assessing lake trophic state models in predicting submerged aquatic vegetation and its implications for manatee conservation at Lake Ossa, Littoral, Cameroon.

In Review

Brown, A.L., T.K. Frazer, G. Li, J.R. Hilsenroth, J.S. Shima and C.W. Osenberg. In Review. Hidden predators on coral reefs: muricid consumption of vermetids. Marine Ecology Progress Series.

Hyman, A.C., T.K. Frazer, J. Frost and M. Kowalewski. In Review. Long-term persistence of structured habitats: Seagrass meadows as enduring hotspots of elevated biodiversity and faunal stability. Proceedings of the Royal Society.

Liebowitz, D.M., M.J. Cohen, J.B. Heffernan, C. Hartmann and T.K. Frazer. In Review. Experimental evidence for grazer-control of alternative algal stable states in Florida's spring-fed rivers. Freshwater Science.

Reaver, N.G.F., D.A. Kaplan, R.A. Mattson, E. Carter, P. Sucsy and T.K. Frazer. In Review. Hydrodynamic controls on primary producer communities in spring-fed rivers. Geophysical Research Letters.

2019

Littles, C.J., R.K. Bonde, S. Butler, C.A. Jacoby, S.K. Notestein, J.P. Reid, D.H. Sloan and T.K. Frazer. 2019. Behavior of Florida manatees encountering reduced food provisions in a prominent winter refuge. Endangered Species Research. 38:29-43 [https://doi.org/10.3354/esr00933]

2018

Adler, J., S.C. Barry, J. Johnston, C.A. Jacoby and T.K. Frazer. 2018. Aggregation of turtles in a Florida spring yields insights into dietary preferences and grazing rates. Freshwater Science. 37(2):397-403 [https://doi.org/10.1080/00036846.2018.1458196]

Alvarez-Aleman, A., J.A. Austin, C.A. Jacoby and T.K. Frazer. 2018. Cuban connection: regional role for Florida's manatees. Frontiers in Marine Science. 5:294 [https://doi.org/10.3389/fmars.2018.00294]

Alvarez-Aleman, A., E. García, Y. Forneiro Martin-Viana, Z. Hernandez Gonzalez, R. Escalona Domenech, A. Hurtado, J. Powell, C.A. Jacoby and T.K. Frazer. 2017. Status and conservation of manatees in Cuba. Bulletin of Marine Science. 94(2):313-327 [https://doi.org/10.5343/bms.2016.1132]

Barry, S.C., T.S. Bianchi, M.R. Shields, J.A. Hutchings, C.A. Jacoby and T.K. Frazer. 2018. Characterizing blue carbon stocks in seagrass meadows subjected to different long-term phosphorus supplies: a lignin biomarker approach. Limnology and Oceanography. 63(6): 2630-2646 [https://doi.org/10.1002/lno.10965]

Barry, S.C., C.A. Jacoby and T.K. Frazer. 2018. Resilience to shading influenced by differential allocation of biomass in *Thalassia testudinum*. Limnology and Oceanography. 63(4):1817-1831. [https://doi: 10.1002/lno.10810]

Hilsenroth, J.R., S. Larkin and T.K. Frazer. 2018. The price of pretty: characteristics of black Tahitian pearls and their implicit values. Applied Economics. 50(2):4582-4591. [https://doi.org/10.1080/00036846.2018.1458196]

Mintzer, V.J., K. Diniz and T.K. Frazer. 2018. The use of aquatic mammals for bait in global fisheries. Frontiers in Marine Science. 5:191 [https://doi: 10.3389/fmars.2018.00191]

Newkirk, C.R., T.K. Frazer and M.Q. Martindale. 2018. Uptake and proliferation of *Symbiodinium* in polyps of the upside-down jellyfish, *Cassiopea xamachana*. Journal of Experimental Marine Biology and Ecology. 508:44-51 [https://doi.org/10.1016/j.jembe.2018.08.010]

2017

Barry, S.C., C.A. Jacoby and T.K. Frazer. 2017. Environmental influences on growth and morphology of *Thalassia testudinum.* Marine Ecology Progress Series. 570:57-70 [https://doi.org/10.3354/meps12112]

Hotaling-Hagan, A., R. Swett, L. Rex Elllis and T.K. Frazer. 2017. A spatial model to improve site selection for seagrass restoration in shallow boating environments. Journal of Environmental Management 186:42-54 [doi: 10.1016/j.jenvman.2016.10.005]

2016

Brown, A.L., T.K. Frazer, J.S. Shima and C.W. Osenberg. 2016. Mass mortality of the vermetid gastropod *Ceraesignum maximum*. Coral Reefs 35: 1027–1032 [doi: 10.1007/s00338-016-1438-8]

Nifong, J.C., T.K. Frazer and C. Mojica. 2016. *Alligator mississippiensis* (American alligator). DIET. Herpetological Review 47(1):130-131.

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2015

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2014

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Camp, E.V., C.L. Staudhammer, W.E. Pine III, J.C. Tetzlaff and T.K. Frazer. 2014. Replacement of rooted macrophytes by filamentous macroalgae: effects on small fishes and macroinvertebrates. Hydrobiologia 722:159-170.

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Camp, E.V., D.C. Gwinn , M.V. Lauretta , W.E. Pine and T.K. Frazer. 2011. Use of recovery probabilities can improve sampling efficiency for throw traps in vegetated habitats. Transactions of the American Fisheries Society 140:164-169.

Lazar, K.L., T.K. Frazer, C.A. Jacoby and C.M. St. Mary. 2011. Reproductive strategy of *Siderastrea radians* (Pallas 1766) in the St. Martins Keys, Florida. Bulletin of Marine Science 87:91-111.

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Duarte, C.M., R. Martinez, Y.T. Prairie, T.K. Frazer, M.V. Hoyer, S.K. Notestein and D.E. Canfield. 2010. Rapid accretion of dissolved organic carbon in the springs of Florida: the most organic-poor natural waters. Biogeosciences 7:4051-4057.

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Heffernan, J.B., M.J. Cohen, T.K. Frazer, R.G. Thomas, T.J. Rayfield, J. Gulley, J.B. Martin, J.J. Delfino and W.D. Graham. 2010. Nitrogen dynamics in a spring-fed Florida river. Limnology and Oceanography. 55(1):249-263.

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2009

Tetzlaff, J.C., W.E. Pine III and T.K. Frazer. 2009. Comparison of bioenergetics parameters from two spring-fed riverine largemouth bass populations. The Open Fish Science Journal 2:1-14 [ISSN: 1874-401X/09]

Ortega-Retuerta, E., T.K. Frazer, C.M. Duarte, S. Ruiz, A. Tovar-Sanchez, J.M. Arrieta and I. Reche. 2009. Biogeneration of chromophoric dissolved organic matter by bacteria and krill in the Southern Ocean. Limnology and Oceanography 54(6):1941-1950.

Tomasko, D.A., E. Hyfield-Keenan, L. De Brabandere, J.P. Montoya and T.K. Frazer. 2009. Assessment of water quality responses to sediment removal in Lake Hancock. Florida Scientist 72(4):346-366.

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De Brabandere, L., M. J. Catalano, T.K. Frazer and M.S. Allen. 2009. Stable isotope evidence of ontogenetic changes in the diet of gizzard shad (*Dorosoma cepedianum*) with implications for biomanipulation of a shallow eutrophic lake. Journal of Fish Biology 74:105–119.

2008

Moline, M.A., T.K. Frazer, R. Chant, S. Glenn, C.A. Jacoby, J.R. Reinfelder, J. Yost, M. Zhou and O.M.E. Schofield. 2008. Biological responses in a dynamic, buoyant river plume. Oceanography 21:70–89.

Frazer, T.K. and C.A. Jacoby. 2008. Estimating rates of microzooplankton grazing. Oceanography 21:79.

Chant, R.J., J. Wilkin, W. Zhang, B.J. Choi, E. Hunter, R. Castelao, S. Glenn, J. Jurisa, O. Schofield, R. Houghton, J. Kohut, T.K. Frazer and M.A. Moline. 2008. Dispersal of the Hudson River plume on the New York Bight: synthesis of observational and numerical studies during LaTTE. Oceanography 21:148–161.

Moline, M.A., N.J. Karnovsky, Z. Brown, G.J. Divoky, T.K. Frazer, C.A. Jacoby, J.J. Torres and W.R. Fraser. 2008. High latitude changes in ice dynamics and their impact on polar marine ecosystems. Annals of the New York Academy of Sciences 1134:267–319. [Book Series: Year in Ecology and Conservation Biology]

Grober-Dunsmore, R., T.K. Frazer, J.P. Beets, W.J. Lindberg, P. Zwick and N. Funicelli. 2008. Influence of landscape structure on reef fish assemblages. Landscape Ecology 23:37–53.

2007

Greenawalt-Boswell, J.M., T.K. Frazer, C.A. Jacoby and W.S. Arnold. 2007. Estimates of mortality and exploitation rates for the recreational bay scallop fishery off the Gulf coast of Florida, USA. North American Journal of Fisheries Management 27:1230–1242.

De Brabandere, L., T.K. Frazer and J.P. Montoya. 2007. Stable nitrogen isotope ratios of macrophytes and associated periphyton in two subtropical, spring-fed streams. Freshwater Biology 52:1564–1574.

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2006

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2004

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2003

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Contracts and Grants Awarded

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A Seawater System for Enhancing the Nature Coast Biological Station's Research and Education Programs. 2018 – 2019, $238.987, National Science Foundation, M.S. Allen, T.K. Frazer, C. Angelini, C. Martin and L.K. Reynolds.

Historical Ecology of Seagrass Meadows: Assessing Multi-Centennial Dynamics of Threatened Biodiversity Hotspots. 2016, $127,300, UF/IFAS Seed Fund, T.K. Frazer and M. Kowalewski.

SJRWMD-UF Springs Protection Initiative – *Collaborative Research Initiative on Sustainability and Protection of Springs (CRISPS)*. 2014 – 2017, $3,000,000, St. Johns River Water Management District - this effort involves multiple UF investigators and multiple projects; T. Frazer is the lead investigator for the biology group.

Technical Review of Options to Move Water from Lake Okeechobee to the Everglades. 2014, $250,000, Florida Senate, W. Graham, K. Havens, T. Frazer, R. Reddy, M. DeAngelo and P. Frederick.

Peer review: proposed minimum flows and levels for lower Santa Fe and Ichetucknee rivers. 2013, $45,000, Suwannee River Water Management District, W.D. Graham, M. Clark, M.J. Cohen, T.K. Frazer and J.B. Martin.

Marine and Coastal Sciences – Assistant Research Scientist Position. 2012 – 2016, $250,000, Florida Aquarium, T.K. Frazer.

Marine and Coastal Sciences – Assistant Research Scientist Position. 2012 – 2016, $125,000, Florida Fish and Wildlife Conservation Commission, T.K. Frazer.

Spatial patterns of coral-vermetid interactions: short-term effects and long-term consequences. September 2011 – August 2016, $800,000, National Science Foundation, C.W. Osenberg and T.K. Frazer.

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Management and restoration of Kings Bay: control of undesirable submersed aquatic vegetation by macroinvertebrate grazers. January 2012 – June 2015, $369,375, Southwest Florida Water Management District, T.K. Frazer and C.A. Jacoby.

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Defending reefs from invasive lionfish. October 2011-September 2012, $20,000, Disney Worldwide Conservation Fund, T.K. Frazer and C.A. Jacoby.

A pre-spill assessment of seagrasses along Florida's Gulf coast, July 2010 – December 2010, $9,997, Florida Sea Grant, T.K. Frazer and C.A. Jacoby.

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Assessment of Florida's marine and freshwater hatchery programs. January 2010 – December 2014, $827,500, Florida Fish and Wildlife Conservation Commission, T.K. Frazer and K. Lorenzen.

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Linking seagrass performance measures to water quality. January 2010 – December 2012, $150,000, Florida Fish and Wildlife Conservation Commission, T.K. Frazer and C.A. Jacoby.

Quantifying pathways of nitrate removal in spring-fed rivers. January 2010 – December 2012, $298,375, Southwest Florida Water Management District, T.K. Frazer, M.J. Cohen and C.A. Jacoby.

Compilation and synthesis of existing data in support of the determination of minimum flows for Crystal River. January 2010 – December 2010, $63,200, Southwest Florida Water Management District, T.K. Frazer.

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Teaching

Undergraduate, graduate, and post-doctoral training are critical to my professional goals. I have served on more than 140 Ph.D. and M.S. committees, involved numerous undergraduates in my research programs, and sponsored 2 international PhD-level students and 7 post-doctoral scholars.

Service

I regularly review manuscripts for a broad suite of scientific journals and frequently serve as a panelist to review research proposals submitted to state and federal agencies. Other recent and/or current service related activities are as follows:

University of Florida – current* and recent

- Member, UF Graduate Council (2015-2018)
- Member, UF Diving Control Board (2014 – present) *
- Member, UF International Outreach Advisory Council (2014 – present) *
- Member, UF Tropical Conservation and Development Program, Steering Committee (2017 – present) *
- Chair, UF Environmental Science General Education Committee (2014 – 2016)
- Past-Chair and member, Faculty Advisory Committee, UF Water Institute (2007-17)
- Faculty Advisory Committee, UF Climate Institute (2013 – present) *
- Chair, Climate Science Faculty Committee (2014 – present) *
- Past-Chair, University of Florida Oil Spill Task Force (2010 – 2011)
- Search and Screen Committee, Chair – Soil and Water Sciences Department (2018)
- Search and Screen Committee, Director - Whitney Marine Laboratory
- Melnick Fund Advisory Board
- QSE3 IGERT Advisory Council
- Member, UF Hydrologic Sciences Academic Cluster*
- Search and Screen Committee, Dean – UF College of Veterinary Medicine
- Founding Member – UF Marine Sciences Committee
- Chair, SNRE Coordinating Committee (2012 – 2013)
- Center for the Environment Working Group (2012 – 2103)
- Chair, Search and Screen Committee, Assistant Research Scientist in Marine Conservation, School of Forest Resources and Conservation
- Curriculum Committee, College of Agriculture and Life Sciences (2012 – 2019)

- Search and Screen Committee, Assistant Professor in Coastal Biogeochemistry - Soil and Water Science Department
- Search and Screen Committee, Assistant Professor in Restoration Aquaculture – School of Forest Resources and Conservation
- Search and Screen Committee, Estuarine Ecologist – UF/IFAS Nature Coast Biological Station*
- Graduate Curriculum Committee, School of Forest Resources and Conservation
- Proposal Review Panel, UF Office of Research

External Activities - current* and recent

- Member and current Chair, Gulf of Mexico Fishery Management Council *
- Member, Atlantic Highly Migratory Species Advisory Panel, NOAA Fisheries *
- Member, Board on Oceans, Atmosphere and Climate, APLU *
- Specialty Chief Editor, Frontiers in Marine Science, Coral Reef Research *
- External Reviewer, Great Barrier Reef Marine Park Authority
- Delegate, Organization for Tropical Studies
- Oil Spill Research Strategy Review Panel, US EPA
- Indian River Lagoon Observatory Science and Technology Advisory Committee (IRLO-STAC)
- LOICZ working group on Global Environmental Change in the Coastal Zone
- Technical Advisory Committee on Marine Numeric Nutrient Criteria, Florida Department of Environmental Protection
- Executive Committee, National Association of University Fish and Wildlife Programs
- Peer-review panel for Dissolved Oxygen Criteria, Florida Department of Environmental Protection
- Advisory Council, Office of Water Policy and Ecosystem Restoration, Florida Department of Environmental Protection
- Board Member, Central Caribbean Marine Institute
- Science Advisory Board, Central Caribbean Marine Institute
- External Review Team, University of Idaho
- External Review Team, California Polytechnic University
- Oil Spill Academic Task Force, Florida State University System
- Kings Bay Working Group, Southwest Florida Water Management District
- Florida Aquaculture Interagency Coordinating Council, Florida Department of Agriculture and Community Services
- External examiner, Imperial University, United Kingdom
- External examiner, Murdoch University, Australia

Other Professional Affiliations

- Current Member, American Association for the Advancement of Science
- Current Member, International Society for Reef Studies

Statement of

Thomas K. Frazer
Professor and Director, School of Natural Resources and Environment
Institute of Food and Agricultural Sciences
University of Florida

before the

Committee on Science, Space, and Technology
U.S. House of Representatives
February 27, 2019

Good morning, Madam Chair and members of the committee. Thank you for affording me this opportunity to speak with you today. My name is Tom Frazer. I am a Professor and Director of the School of Natural Resources and Environment in the Institute of Food and Agricultural Sciences at the University of Florida.

I understand, based on the background information provided by staff, that the committee has received substantial testimony focused on the causes of climate change, as well as its consequences, both realized and potential. You have heard from internationally renowned scholars and experts that climate change is real and that humans are responsible for it. I agree. You have heard also that marked reductions in global greenhouse gas emissions are essential and urgently needed to stabilize the earth's climate and avoid significant detrimental effects. Again, I agree. In fact, I would argue that the substantial, long-lasting opportunity costs associated with delaying reductions in greenhouse emissions outweigh any short-term benefits. The climate-related challenges that we face today are certainly not going away in the near future, and they will only be exacerbated by further increases in greenhouse gas emissions [1,2]. For example, if current conditions were stabilized, we will still see a 1.1°F (0.6°C) increase in global temperatures over the next century [2], and a scenario with continuing increases in emissions and no mitigation yields a 5.0° – 10.2°F (2.8° – 5.7°C) increase during the same time frame [2]. Given these projections,

reducing greenhouse gas emissions and staying on that course for the foreseeable future should be major investments.

With that said, we also should be compelled, as a society, to invest aggressively in the science needed to inform effective adaptation and mitigation. Reducing emissions is key. It is essentially the equivalent of feeding, clothing and housing your children today. Investing in science, on the other hand, is equivalent to saving for their college education. In fact, consistent, long-term investment in science makes the most sense because many valuable insights can only be gained by observations and experiments conducted over time. In other words, good science can take a while to come to fruition.

The science I am talking about is needed to incrementally adapt existing management to the new norm so that we are able to conserve and safeguard natural resources that sustain livelihoods and economies of communities in the United States and around the globe. In addition, science drives technological innovation and advancement or transformational change, and given the challenges that we will experience due to past actions and potential challenges that depend on current and future actions, I suggest to the committee that the call for transformational change has never been as strong as it is today.

My background is in the arenas of marine ecology and fisheries science, and I draw on my academic training and other professional experiences to provide here some examples of how and where investments in science would yield substantial value.

Wild caught fisheries yield approximately 90 million metric tons of fish and shellfish per year, with the bulk of this production being consumed by people, including those who have little access to other sources of protein [3]. However, this bountiful natural resource is already threatened, with about one-third of stocks classified as overfished [3], and changing climate introduces new challenges.

Among those challenges are changes in the ranges of exploited species, both expansions and contractions, and changes associated with alterations to habitats. As sea surface temperatures increase, some warm-water species can expand their ranges northward, but some cold-water species will be forced to contract their ranges. As global climate changes, we will also see changes in habitats. These changes range from shifts in major ocean currents that will alter patterns in

movement and recruitment to potential loss of inshore, structural habitats, such as seagrass meadows, that provide food and shelter for a large number of exploited fishery species. As a less drastic, but still significant example, a "flashier" environment caused by more frequent, and larger storm events can alter the salinity regime in estuaries, which could make them less hospitable for juveniles of many fished species. Furthermore, warmer temperatures have added stress to the world's coral reefs, which were already challenged by coastal development and associated human activities (I'll talk about this in more detail in just a minute).

In response to such challenges, managers will have to adapt their strategies, with the key thrust being a commitment to ecosystem-based fishery management as proposed by NOAA Fisheries [4]. For example, managers will need to be able to differentiate between range expansions driven by increased stock abundances that result from effective management actions and range shifts driven by changes in water temperatures and ocean currents. Fisheries managers will also need to factor habitat and other environmental variables into stock assessments and stock projections because altered habitats appear to be an inevitable consequence of climate change. Overall, managers will need to move from harvest quotas established primarily on the basis of historical landings to quotas that account for a changing or non-stationary environment. This flexibility is not explicitly articulated in the current version of the Magnuson-Stevens Fisheries Conservation and Management Act. In addition, fisheries managers will need to consider ways to help, and potentially even fund, adaptation by the recreational and commercial fishing industries, such as moving access points and wholesale and retail outlets. Without such incremental adaptations, we, in the U.S., stand to lose a substantial portion of the 1.7 million jobs, $212 billion in sales and $100 billion in gross domestic product generated by these industries [5].

Science comes into play because it is the best base for designing and implementing the necessary adaptations to existing management of our nation's fisheries. One way that science can help is by providing timely and accurate information on the status and trends of stocks and habitats. Our existing monitoring of recreational and commercial catches and our tracking of critical habitats are insufficient, and we will only fall further behind given the pace of change we will experience in the coming decades. In addition, our understanding of the interactions between fished species and their habitats and our ability to employ models to provide early warnings of detrimental consequences are inadequate. A second way that science can help is to transform the tools and

techniques needed to mitigate undesirable changes in fished stocks or the habitats that support them. Given the time constraints imposed as part of this hearing, I will focus on one example of mitigating loss of habitat, rehabilitating coral reefs.

Coral reefs occupy a relatively small proportion of the ocean realm, but harbor more than 25% of marine biodiversity. Coral reefs also support important recreational, commercial and subsistence fisheries around the globe. In fact, coral reefs yield approximately 25% of the total fish catch in developing nations and contribute substantially to the economies of more than 100 countries that promote reef-related tourism [6]. They are, however, one of the most imperiled habitats on the planet due to nutrient pollution, physical damage, overfishing and other local stresses. Recent reports suggest that greater than 60% of the world's reefs are threatened due to these stresses and climate change only heightens this percentage [6,7].

Managers must continue to address local stresses, and, as already indicated, we need to reduce emissions of greenhouse gases to address global stresses. Regardless of our efforts, nearly all coral reefs will be threatened by conditions generated from existing levels of climate change by the year 2050 [6]. In fact, managers should prepare to mitigate both existing damage and the damage that will occur from the inevitable changes in global climate that already have been initiated.

Rehabilitating or restoring damaged and degraded reefs will require transformational innovations and advancements based on sound science. Key questions to be addressed include the following:

- How do we create a supply chain for coral reef rehabilitation that does not consist solely of transplanting survivors?
- Can we identify and culture genotypes that exhibit increased resistance and resilience to local or global stressors?
- Can we identify genes that encode increased resistance and resilience in the symbiotic algae that sustain reef-building corals and what are the risks and rewards associated with manipulating those genes?
- How might we increase survivorship of transplanted corals?
- What characteristics do rehabilitated reefs need to possess to ensure they provide most if not all of the ecosystem services derived from natural coral reefs?

Answering these questions and transferring the new knowledge into effective and efficient innovations and advancements will take time and a consistent stream of resources. In fact, it is an investment that we should begin now.

In conclusion, I reiterate my agreement with much of what you have heard from others. Climate change poses significant threats, and now is the time to begin addressing the human activities that drive it. My goal today was to introduce a potentially new topic: the need for consistent investment in science that will support incremental adaptation to the effects of climate change and build the basis for transformational change in mitigating existing and future effects. My hope is that this initial contribution might persuade you to include discussions of the risks and rewards associated with long-term investments in science in your future deliberations regarding the essential and urgently needed efforts to reduce greenhouse gas emissions. I will close by saying that I am happy to participate in those discussions.

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