SUSTAINABLE and HEALTHY COMMUNITIES RESEARCH PROGRAM

Linking Ecosystem Services to Human Health to Inform Estuary Management in Puerto Rico




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Project Goals

San Juan Bay Estuary Program
Puerto Rico

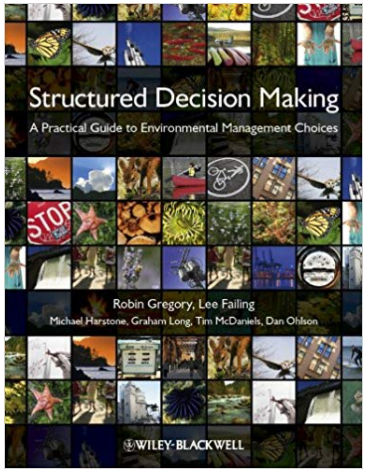
- Develop transferable approaches to integrate ecosystem services into community decision-making
- Identify what kind of information and tools needed to quantify ecosystem services and their benefits

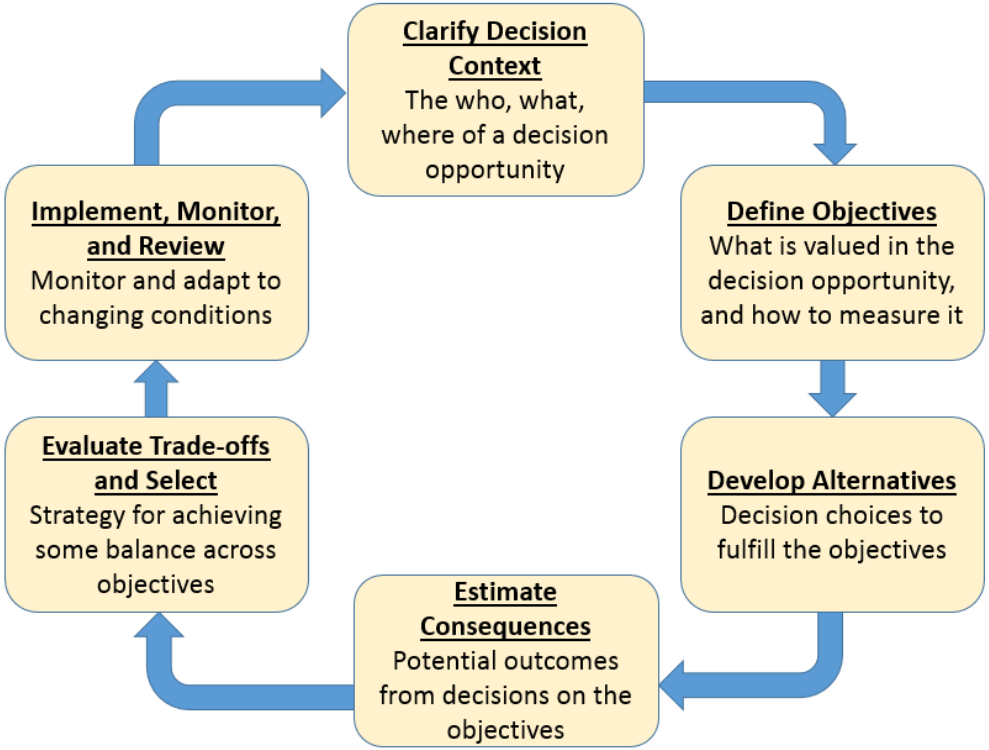
Most highly urbanized NEP: 7000 persons/mi^2

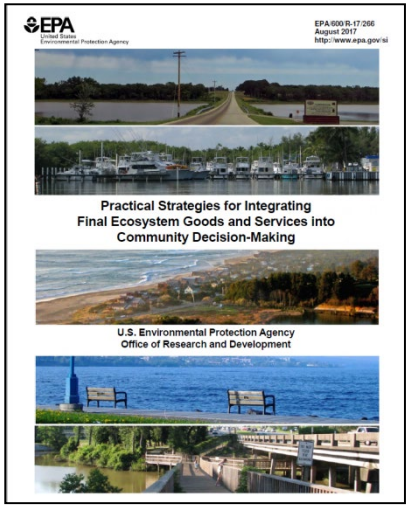
- 67% Urban, 11% Surface waters
- 22% Forest, wetlands, and green areas

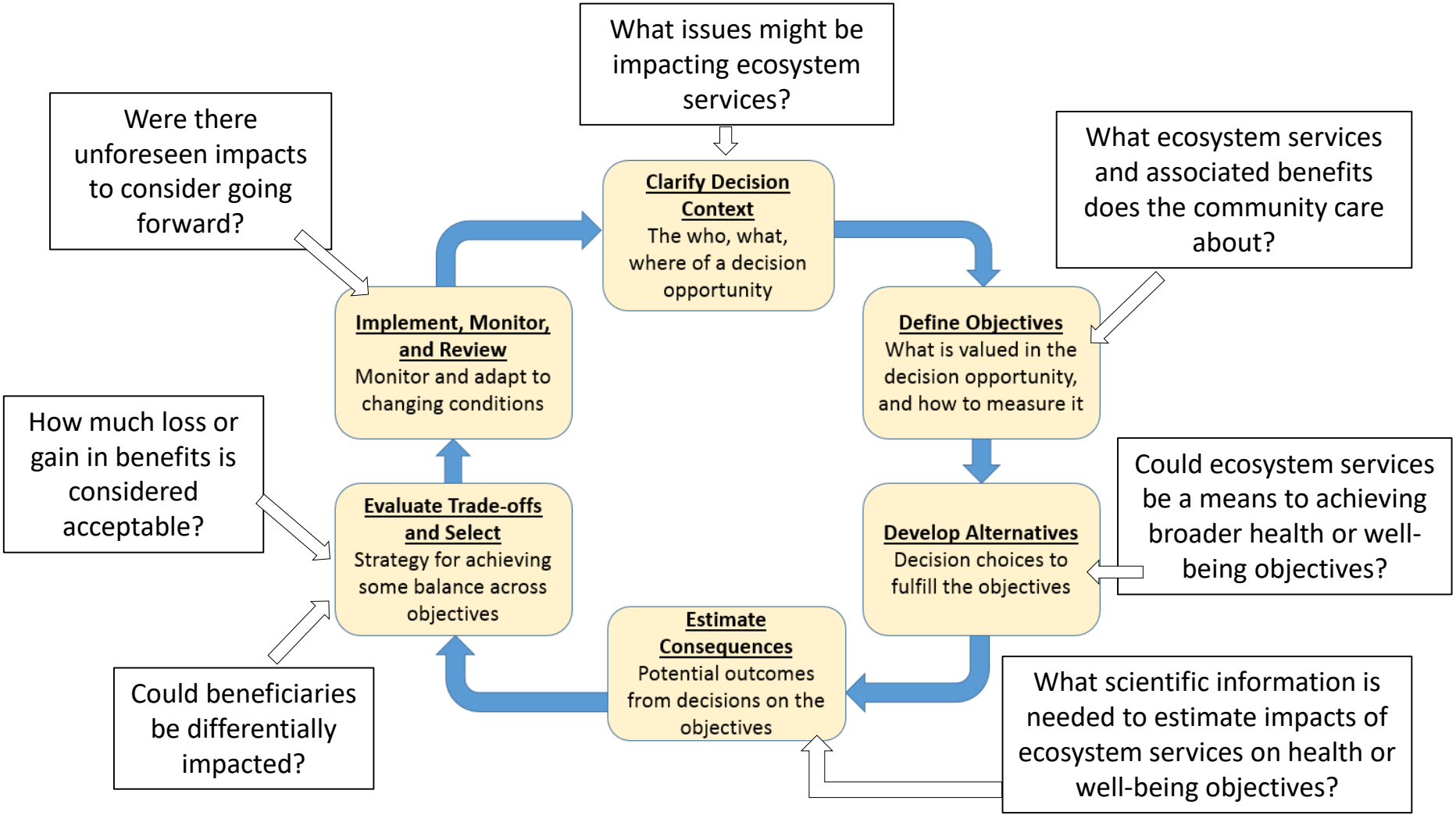
Structured Decision Making

A process to identify ***scientific knowledge*** that is linked to ***stakeholder values*** and relevant for making decisions








What issues might be impacting ecosystem services?
Were there unforeseen impacts to consider going forward?
What ecosystem services and associated benefits does the community care about?
Clarify Decision Context
The who, what, where of a decision opportunity
Implement, Monitor, and Review
Monitor and adapt to changing conditions
Define Objectives
What is valued in the decision opportunity, and how to measure it
How much loss or gain in benefits is considered acceptable?
Could ecosystem services be a means to achieving broader health or well-being objectives?
Evaluate Trade-offs and Select
Strategy for achieving some balance across objectives
Develop Alternatives
Decision choices to fulfill the objectives
Estimate Consequences
Potential outcomes from decisions on the objectives
Could beneficiaries be differentially impacted?
What scientific information is needed to estimate impacts of ecosystem services on health or well-being objectives?

Decision Context

Key Question:

How can we ensure the sustainable delivery of ecological, economic, and social benefits from the estuary?

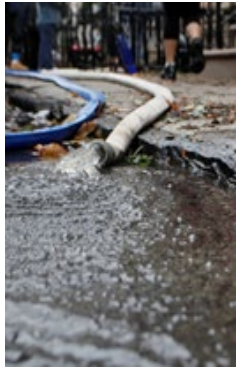
Urbanization

Aquatic debris

Habitat Loss

Stormwater runoff

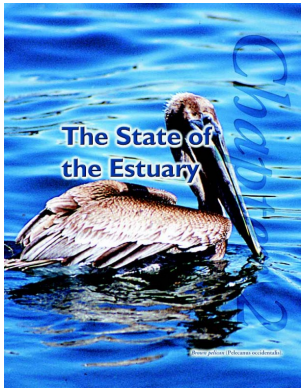
Sewage discharges

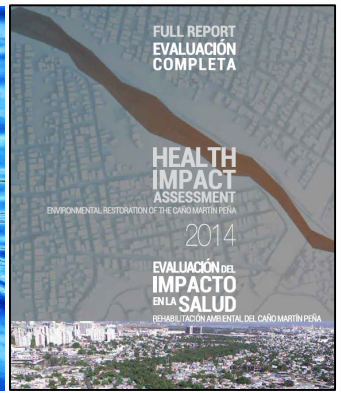


Flooding

Climate events

Objectives of SJBEP Management





Approach: Review existing plans to identify objectives related to ecosystem services and their benefits

Ecosystem Services

- Contaminant & nitrogen processing
- Habitat and biodiversity for aesthetic, existence, and recreational value (mangroves, coral reefs, manatees, birds, sea turtles)
- Water quality for recreation (boats, swimming)
- Recreational & artisanal fish harvesting
- Flood protection of homes

Community Well-being

- Health concerns
  - Seafood contamination
  - Waterborne gastrointestinal diseases
  - Asthma-related incidences
  - Vector-borne illnesses
- Economic and Leisure opportunities
  - Tourism and Recreation
- Social concerns
  - Safe housing
- Stewardship
  - Community connection to the estuary

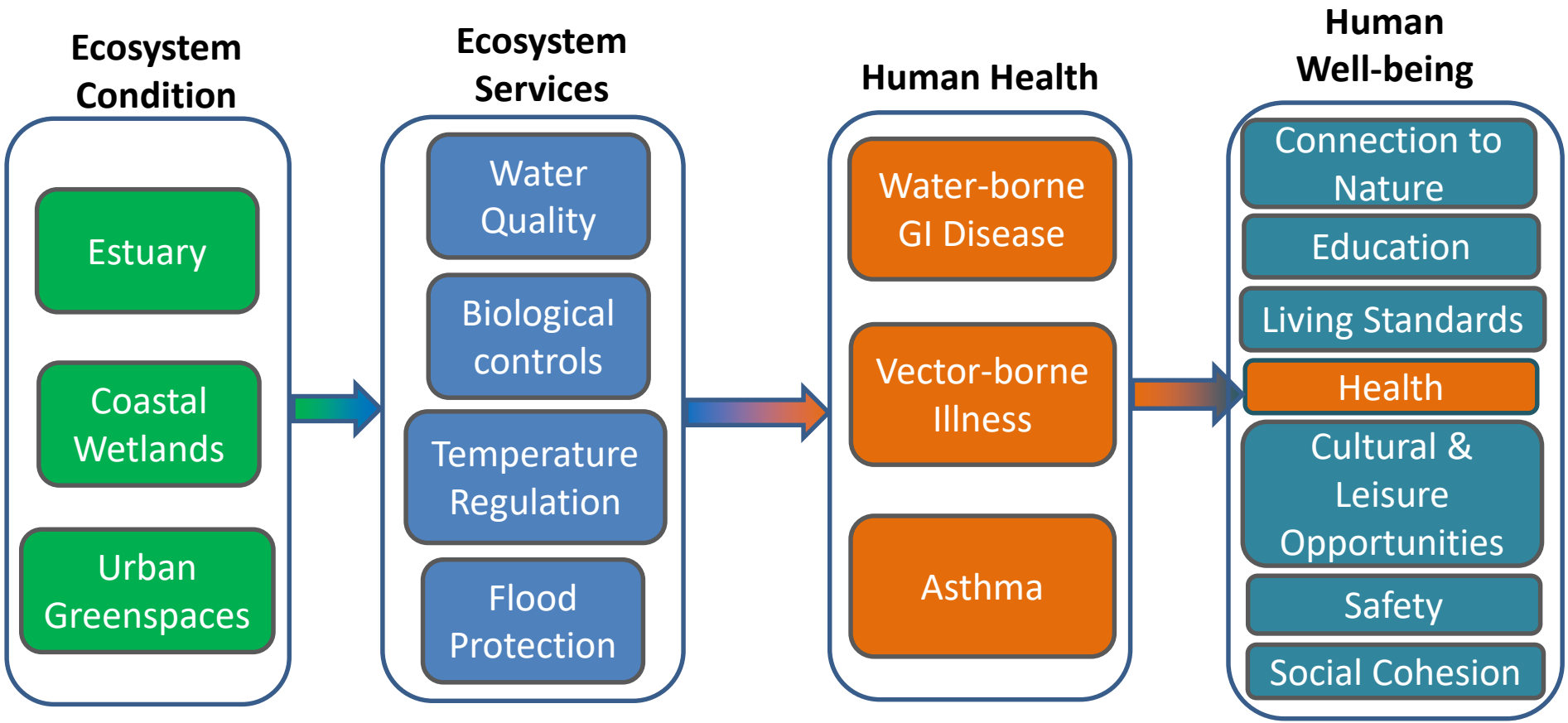
Management Alternatives

- Dredging to improve water flow and restore natural hydrology
- Mangrove restoration
- Sewage discharge interventions
- Stormwater and waste management
- Education and outreach
- Beautification & greenspace

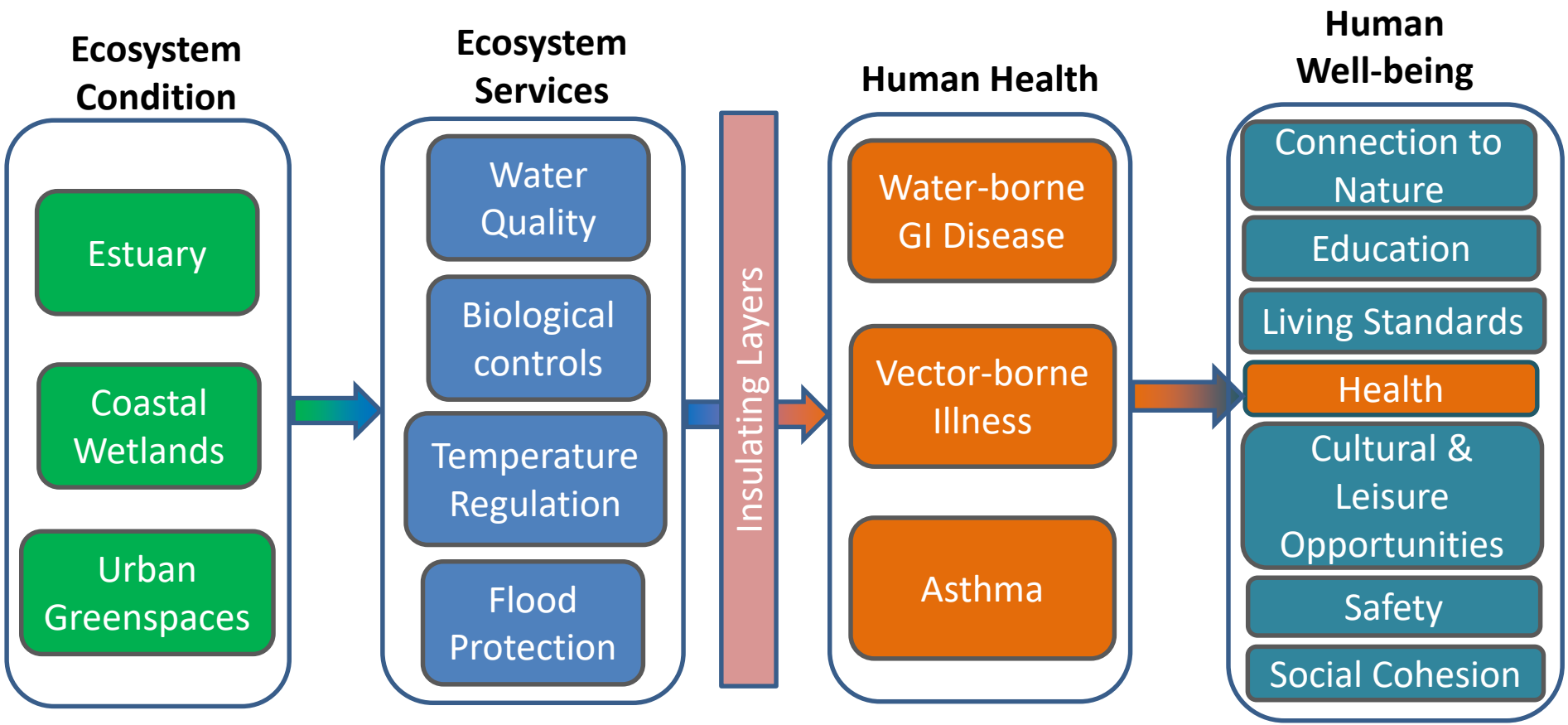
Management Alternatives

Key Question:
Could actions to restore estuary hydrology, wetland habitat, and greenspace lead to potential benefits for human health and well-being objectives?

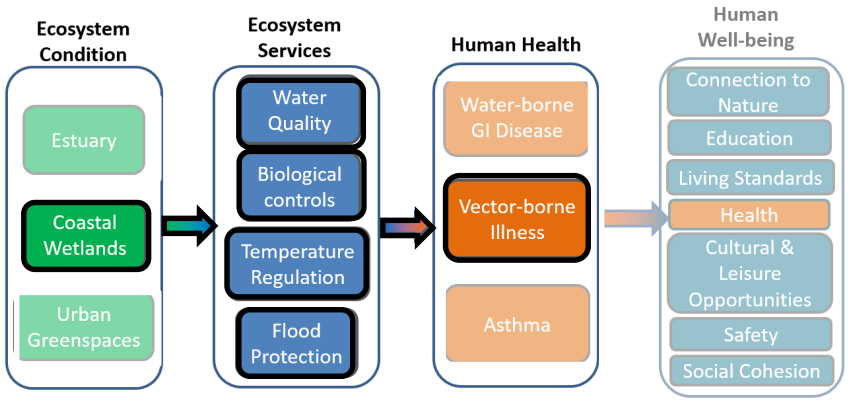
Estimate Consequences



Estimate Consequences



Vector-borne Illness - Dengue



Key Question:

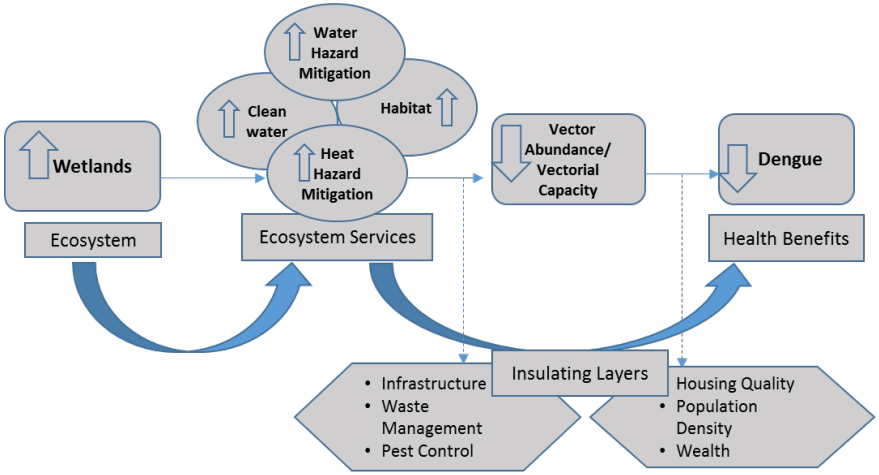
Can wetland ecosystem services help mitigate dengue prevalence?

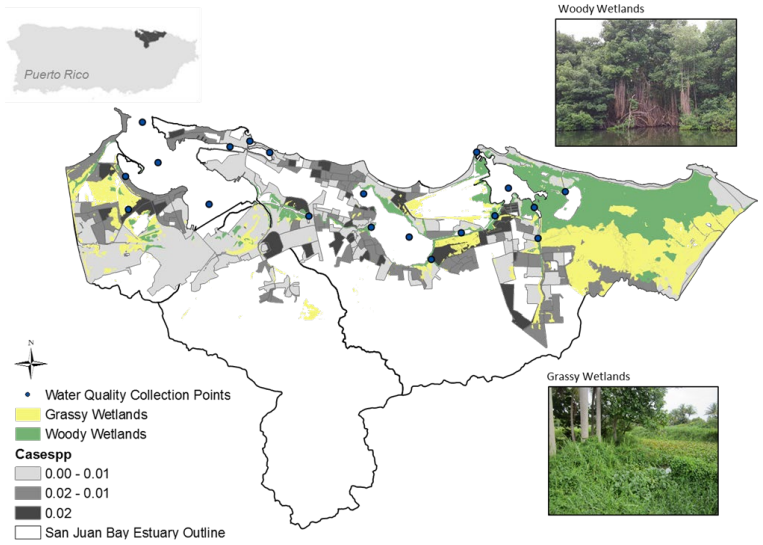
Background

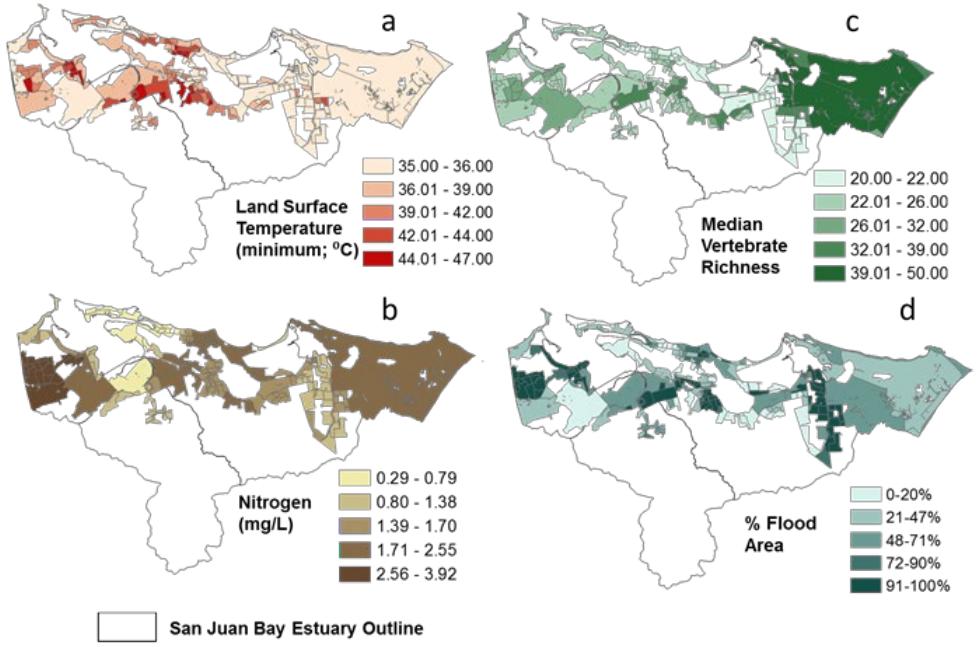
- High temperatures may increase mosquito biting, oviposition rate, viral load
- Floods may increase larval habitat availability
- Clean water and wetland habitat may favor bio-control

Approach

Response Variable: Dengue Prevalence 2010-2013
Scale: Census Block Groups/Flood Prone Areas (N=170)
Analysis: General Linear Models using Model Averaging





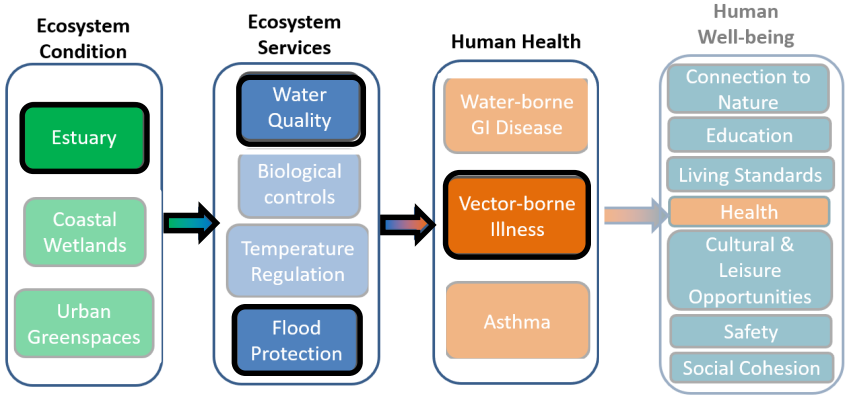


Results

Model Variables	Model Averaging Results		
	Coefficient Estimate	P (>z)	Relative Importance
%Woody Wetlands	**-0.12**	**0.03**	**0.29**
% Grassy Wetlands	-0.04	0.44	^0.00
Min LST (°C)	**0.18**	**0.002**	**0.62**
Nitrogen (mg/L)	**0.12**	**0.01**	**0.17**
Vert.Rich.(Median)	n/a	n/a	n/a
Roads (m/m2)	n/a	n/a	n/a
Sewage (m/m2)	n/a	n/a	n/a
Median Income	-0.03	0.60	^0.00
% Teenagers	0.03	0.51	^0.00
Population per m^2	-0.12	0.06	^0.00
Salinity (ppm)	**-0.10**	**0.02**	**0.70**
% Flood Area	**0.10**	**0.02**	**0.28**

- Dengue prevalence positively associated with flood zones, air temperature, water nitrogen
- Dengue prevalence negatively associated with woody wetlands and water salinity
- 10% increase in woody wetlands associated with 1 fewer dengue case per 1000 people (175 cases over study period and extent)
- 19% of variance explained by woody wetlands could also be explained by reduced temperatures

Vector-borne Illness - Zika



Key Question:

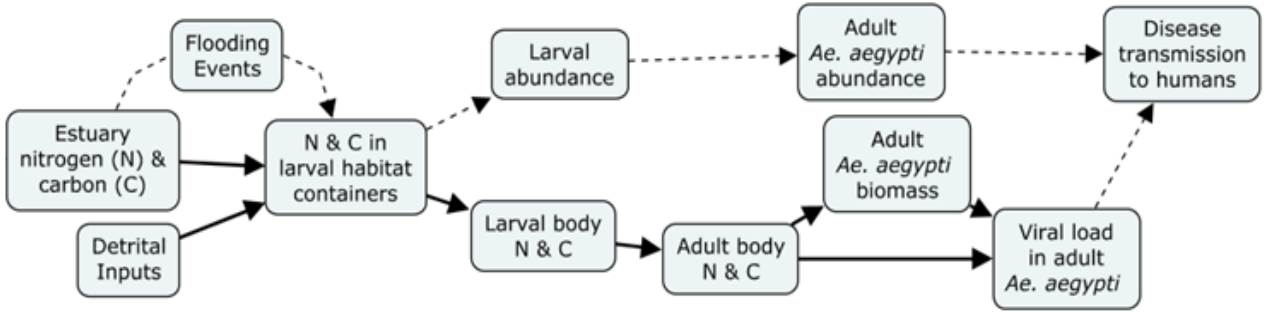
Can estuarine flood waters provide nutrient inputs to larval habitats, and influence viral capacity in adult mosquitos?

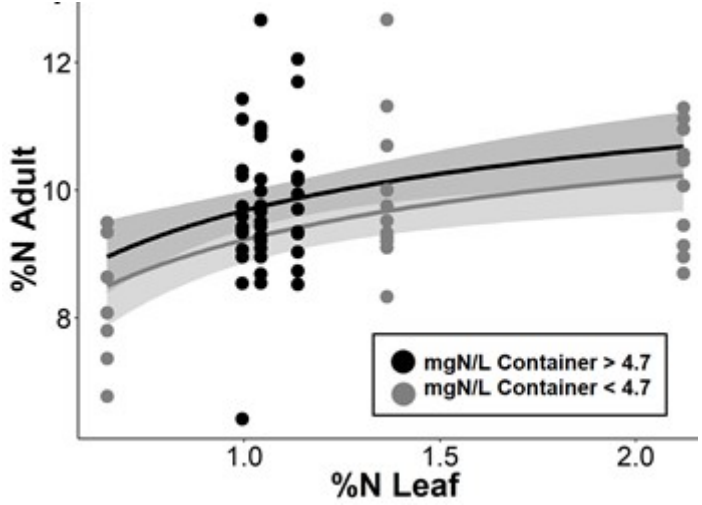
Background

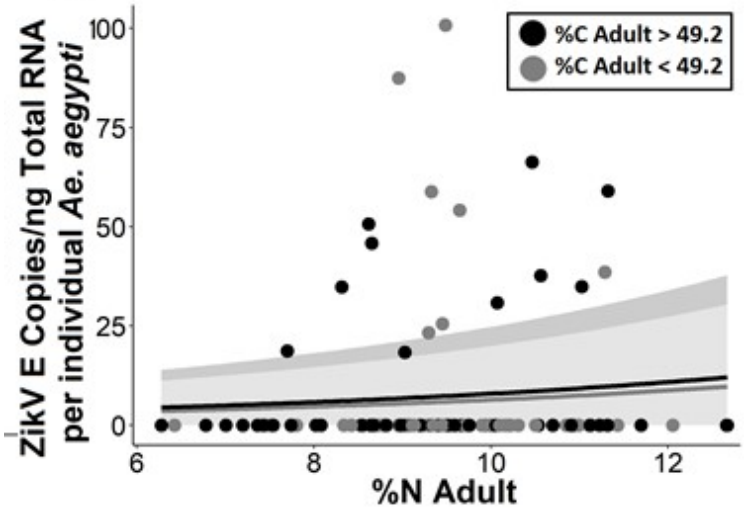
- High nitrogen where poor estuary water flow
- Frequent flooding and leaf detritus could provide nutrient inputs to larval containers
- Nutrient-enriched larvae produce bigger adults
- Bigger adults may take bigger blood meals, produce more virus

Approach

- Field sampling of 6 neighborhoods in flood zones across a range of estuary nitrogen levels
- Sampled estuary water, leaf detritus, container habitats, larval and adult *Aedes aegypti*
- All samples tested for nutrient content; adults also for ZIKV
- Relationships analyzed using General Linear Models



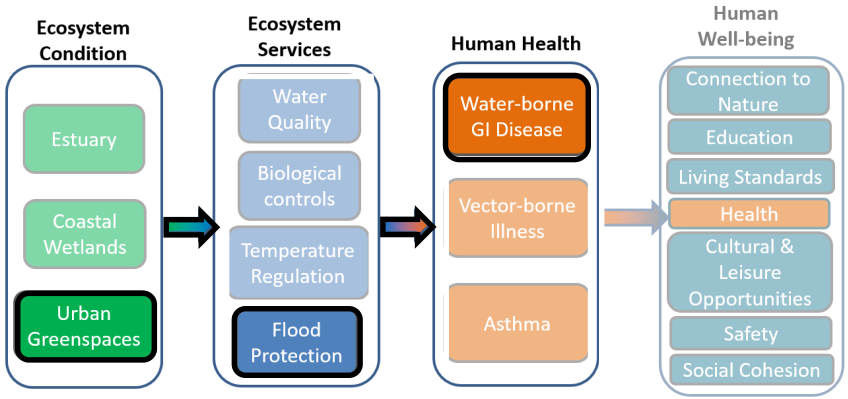




Results

- Sites with high nitrogen in containers or leaf detritus tended to have adults with higher % body nitrogen
- Adults with higher % body nitrogen tended to have higher zika titer
- Establishes a pathway by which nitrogen processing in the environment may influence viral capacity in mosquitos

Water-borne Gastro-Intestinal Disease



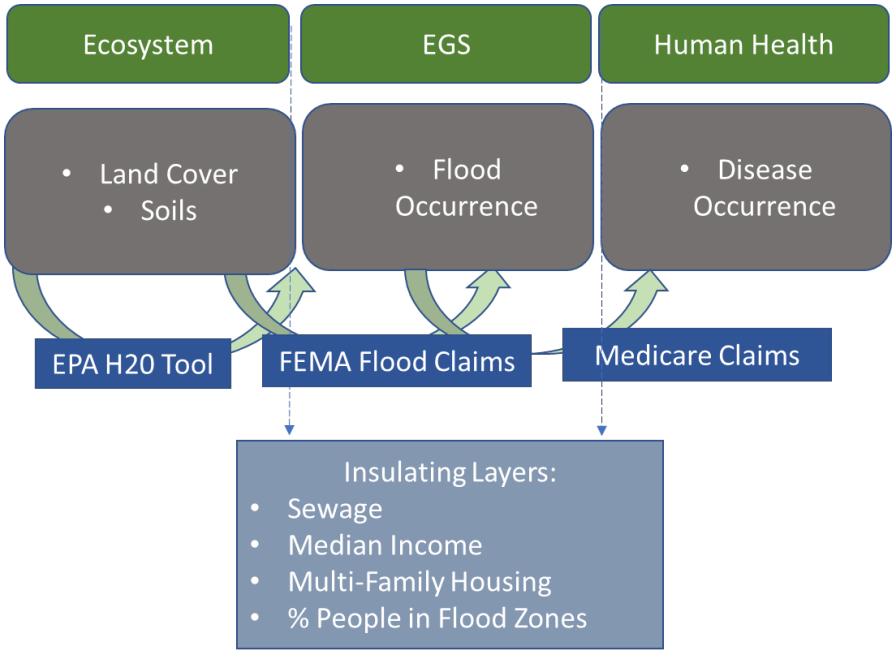
Key Question:

Does rainwater retention by urban greenspaces and soils help mitigate water-borne GI diseases?

Background

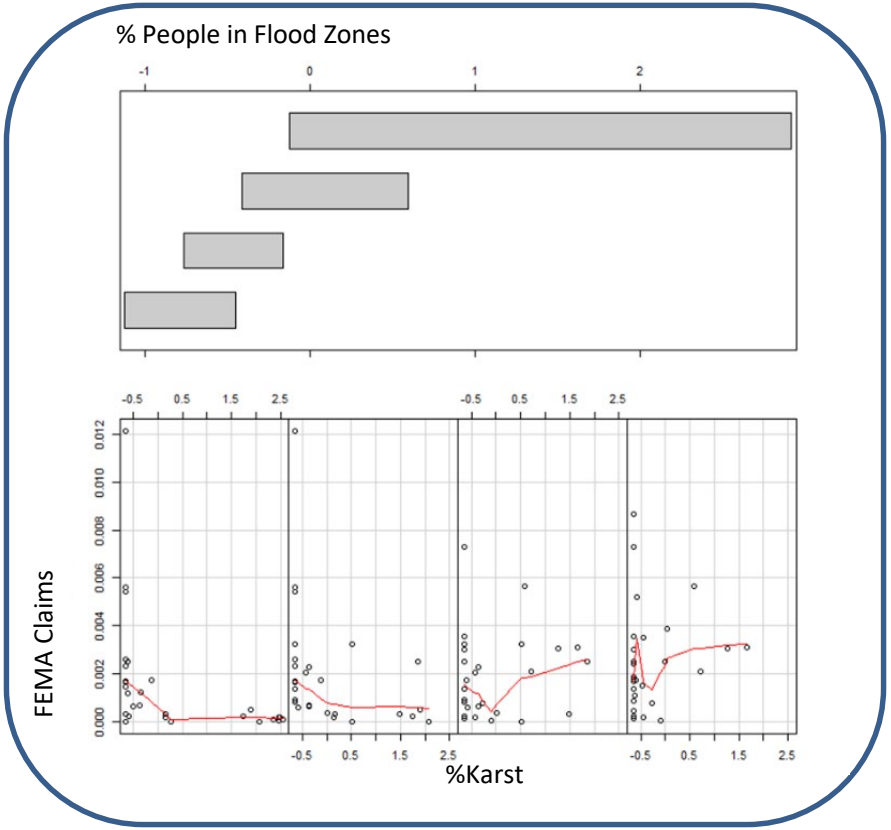
- Precipitation events may wash pathogens from sewage or domestic animal waste into surface waters
- Periodic flooding events may wash pathogens into drinking or recreational water, streets, or homes
- Vegetation and soil may help to absorb rainwater

Approach



- Test whether FEMA Flood Claims are associated with Rainwater Retention, Greenspace Cover, or Soil (% Karst)
- Top predictors for Flood Claims were then tested for association with Medicare GI Disease Claims (1999-2013)
- General Linear Models for Flood Claims using Model Averaging; INLA SPDE model for Medicare Claims

Results



- Rainfall retention, primarily by karst soils, may have a protective effect against gastrointestinal illnesses

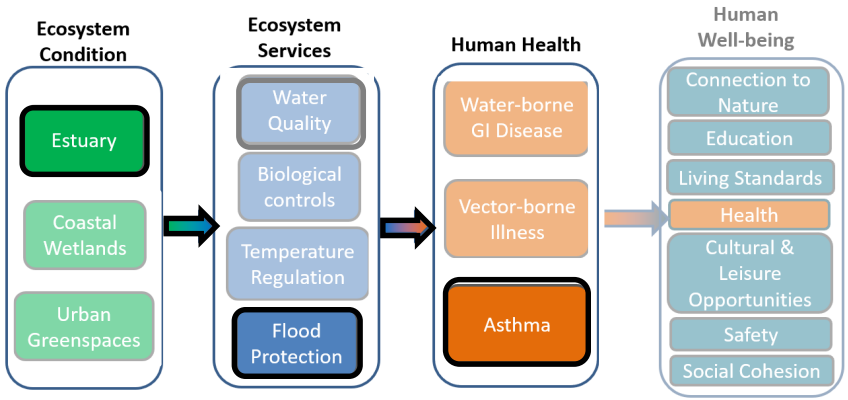
<u>Flood Claims were best explained by</u> :

1. 99% Rainfall events (+)
2. % People living in flood zones (+)
3. % karst soils (-)
4. Interaction:
   %Karst * % People living in flood zones

<u>Medicare Claims were best explained by</u> :

1. 90% Rainfall events one week prior (+)
2. % People living in flood zones (+)
3. % karst soils (-)
4. Interaction:
   %Karst * % People living in flood zones

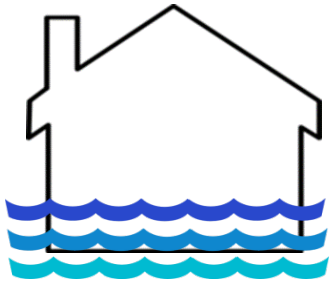
Mold and Asthma



Key Question:
How do flooding events impact mold and bacterial populations in homes?

Background

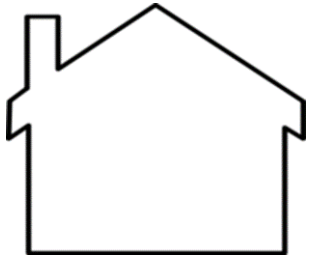
- High incidence of asthma appears to be associated with deterioration of homes with flooding events and mold exposure



Homes at flooded sectors

Phase 1

Collect air and dust samples from houses with flooding and non-flooding events



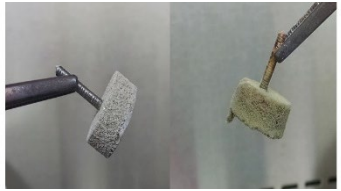
Homes at non-flooded sectors

DNA extraction and analysis

Determination of predominant fungal and bacterial populations at homes in flooded sectors

Phase 2 & 3

Insulating Layers
- **Building Material**
- **Antimicrobial Cleaners**

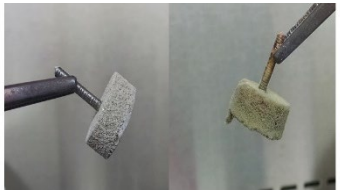


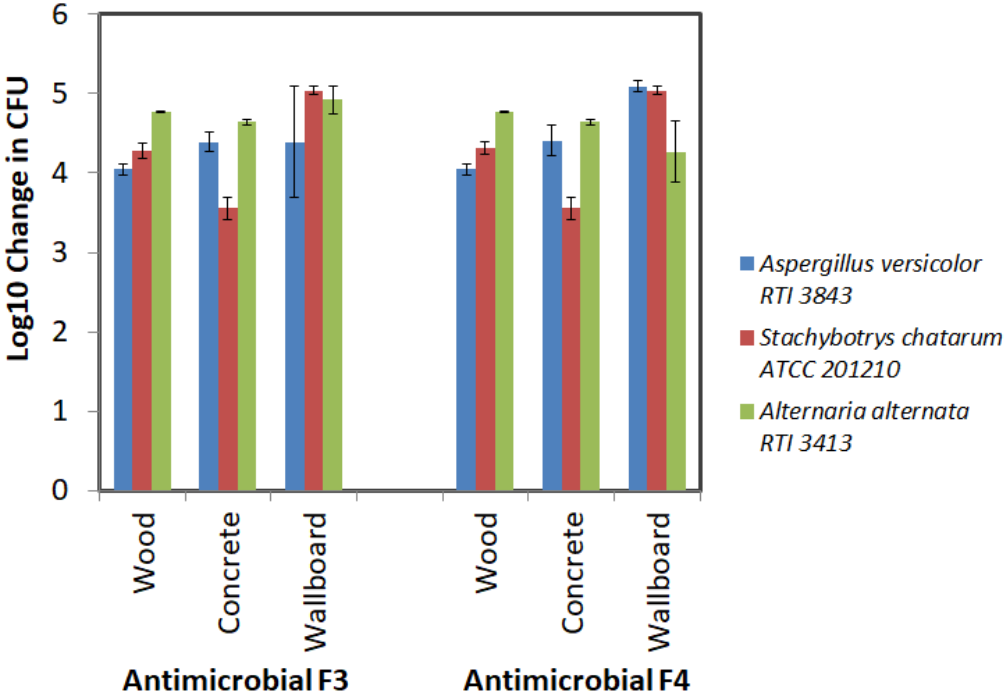
Approach

- Phase 1: Assess differences in mold and bacteria populations in homes within and outside of flood zones
- Phase 2: Expose common building materials to predominant mold spores
- Phase 3: Test new antimicrobial technology for mold remediation

Results

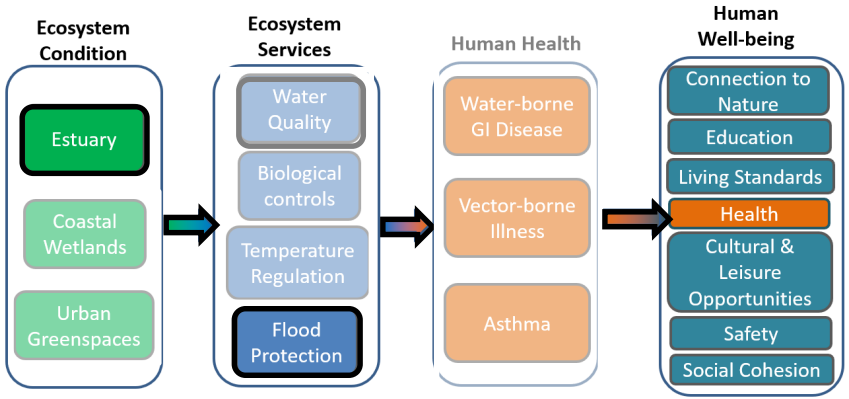
Log_{10} difference calculated using:
Log_{10}reduction =
$Log_{10}CFU_{Positive} - Log_{10}CFU_{Exposed}$





- Building materials have different susceptibilities to various molds
- Efficacy of antimicrobial technology depends on both building material and type of mold
- Field study is still ongoing
- Impacts of flooding on mold populations likely depends on the type of building materials in homes

Human Well-being

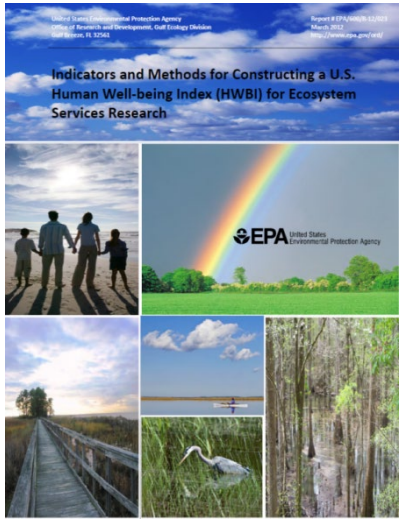


Key Question:

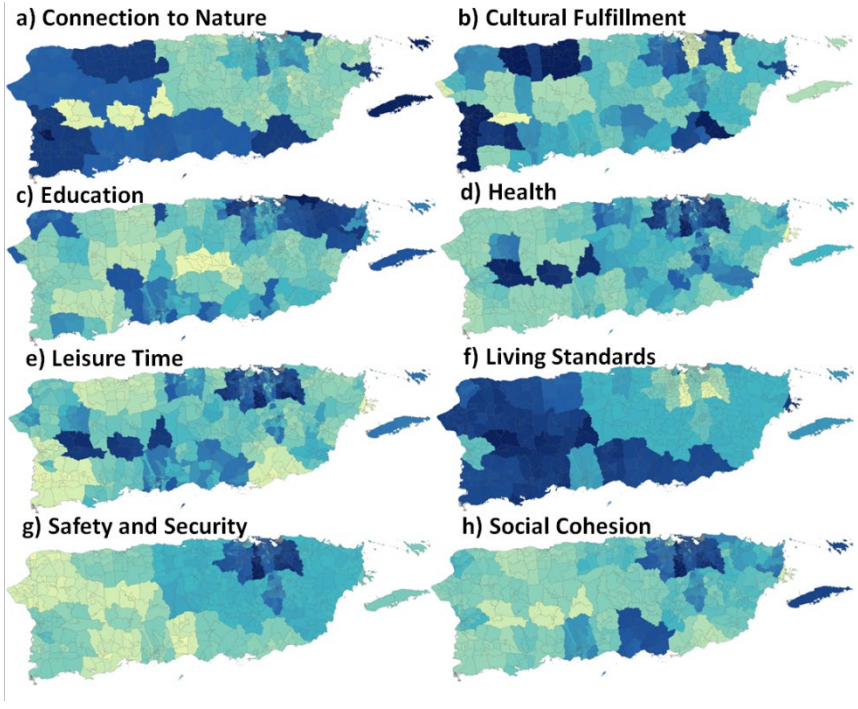
How do flooding events impact overall health and other components of well-being?

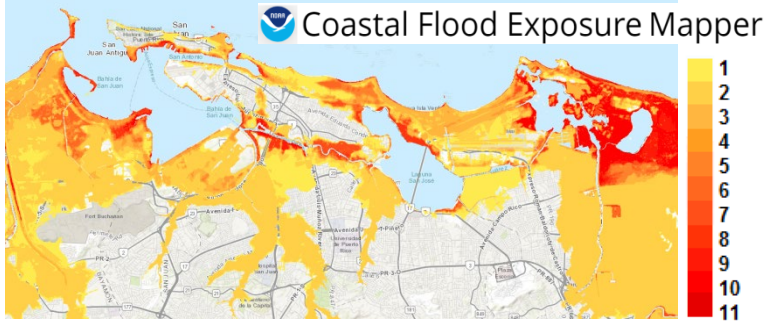
Background

- Human Well-Being Index developed for U.S. and Puerto Rico (county-scale)
- Eight domains of well-being defined by hierarchical sets of metrics and indicators



Approach





- Metric data at census-tract scale → Indicators → Domains → Composite HWBI
- Relate scores to flood exposure (GLM)

Connection to Nature
Biophilia
Connection to all of life (1)[1]

Cultural Fulfillment
Cultural Activity Participation
Performing arts attendance (1)[2]
Belonging to religious denomination (1)[1]

Education
Basic Knowledge/Skills of Youth
Standard math test achievement (2)[3]
Standard reading test achievement (2)[3]
Standard science test achievement (2)[3]
Participation and Attainment
Adult literacy rate (2)[4]
High school graduation rate (5)[5]
Post-secondary education enrollment (5)[5]
Post-secondary education graduation (5)[5]
Social, Emotional, Developmental Aspects
Children feeling unsafe at school (3)[6]
Children's health (4)[7]
Children's social behavior (3)[6]

Health
Healthcare
Regular doctor visits (13)[8]
Satisfaction with hospital care (1)[8]
Life Expectancy and Mortality
Asthma mortality rate (11)[9]
Cancer mortality rate (11)[9]
Diabetes mortality rate (11)[9]
Heart disease mortality rate (11)[9]
Infant mortality rate (14)[9]
Life expectancy at birth (13)[10]
Suicide mortality rate (11)[9]

Lifestyle and Behavior
Alcoholic beverage consumption (13)[8]
Healthy Behaviors Index (7)[8]
Teen pregnancy rate (14)[8]
Teen smoking rate (3)[6]
Personal Well-being
Happiness (1)[1]
Life satisfaction (6)[8]
Perceived health (14)[8]
Physical and Mental Health Conditions
Lifetime adult asthma rate (14)[8]
Lifetime adult cancer rate (4)[8]
Lifetime child asthma rate (9)[8]
Lifetime adult depression rate (5)[8]
Lifetime adult diabetes rate (14)[8]
Lifetime adult heart attack rate (10)[8]
Lifetime adult heart disease rate (10)[8]
Adult obesity rate (14)[8]
Lifetime adult stroke rate (10)[8]

Leisure Time
Leisure Activity Participation
Physical activity participation (14)[8]
Time spent on vacation (7)[11]
Time Spent
Time spent on leisure or relaxing (1)[12]
Working Age Adults
Long work hours (8)[13]
Regular daytime work hours (8)[13]

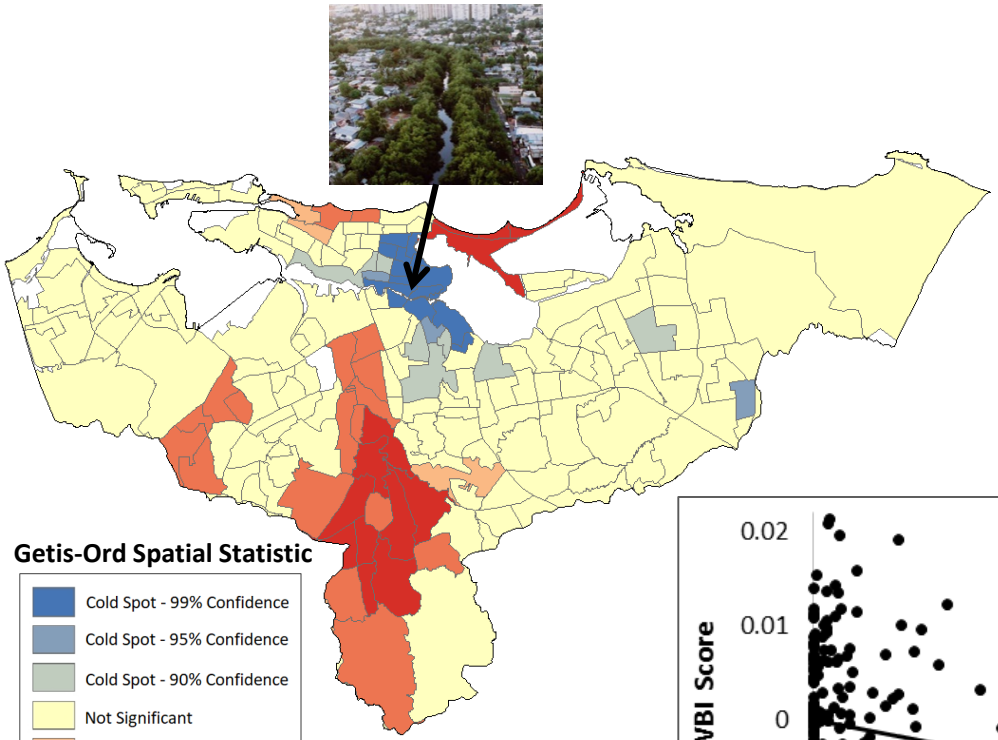
Living Standards
Basic Necessities
Food security (1)[14]
Home affordability (5)[5]
Income
Median household income (5)[5]
Poverty rate (3)[5]
Persistent poverty rate (2)[5]

Wealth
Median home value (5)[5]
Mortgage debt (5)[5]
Work
Fear of job loss (13)[15]
Job satisfaction (1)[16]

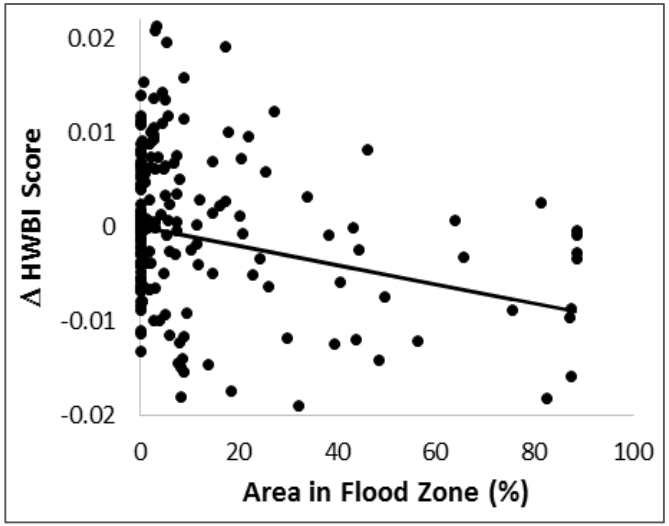
Safety and Security
Actual Safety
Accidental death rate (11)[9]
Natural event injury and death rate (14)[17]
Property crime rate (13)[18]
Violent crime rate (13)[18]
Perceived Safety
Perceived safety (1)[19]
Risk
Social Vulnerability Index (1)[20]

Social Cohesion
Attitude toward Others and the Community
Trust in people (1)[1]
City satisfaction (2)[21]
Feeling close to one's town or city (1)[22]
Perception that others are helpful (1)[1]
Democratic Engagement
Interest in politics (1)[1]
Registered voters (3)[23]
Satisfaction with democracy (1)[1]
Trust in government (1)[1]
Voice in government (1)[1]
Voter turnout (3)[23]
Family Bonding
Time spent watching television (3)[6]
Social Engagement
Child organized activity participation (3)[6]
Participation in organized group (1)[1]
Volunteer rate (1)[1]
Social Support
Having close family or friends (1)[1]
Getting emotional or social support (6)[8]

Results



- Neighborhood adjacent to impacted canal had significantly lower well-being
- HWBI in each census tract, and most domain scores, declined with % area in flood zone



Dependent variable	Slope
HWBI Score	-0.010***
Connection to Nature	-0.021***
Cultural Fulfillment	-0.034***
Education	-0.002
Health	-0.008*
Leisure Time	-0.010***
Living Standards	-0.002
Safety and Security	-0.003*
Social Cohesion	-0.012*

Integrating EcoHealth Information into Management

- Management actions to restore wetland habitat, improve estuarine hydrology, and reduce flooding could have benefits for human health and well-being:
  - Greenspace (temperature regulation) associated with reduced dengue
  - Nitrogen regulation associated with zika titer in adult mosquitos
  - Rainwater retention associated with reductions in gastrointestinal disease
  - Flood exposure associated with lower well-being (health, safety, social cohesion)

- Insulating layers (building materials; living outside of flood zone) can help buffer negative health effects
  - Environmental Justice communities next to impacted canal have significantly lower human well-being & would likely see the greatest benefits of management

- Potentially broader relevance as Puerto Rico looks for opportunities to improve resilience post-hurricane Maria

Acknowledgments

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Mold and Asthma
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Vector-borne Illness
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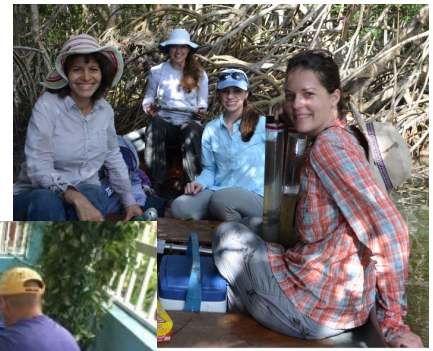
Fengwei Bai (University of Southern Mississippi)
Stephanie Friedman (US EPA)
Roberto Barrera (CDC)

Human Well-being
Elizabeth Paulukonis (US EPA)
Jessica Orlando (US EPA)
Lisa Smith (US EPA)
Kyle Buck (US EPA)
Linda Harwell (US EPA)



Linking Ecosystem Services to Human Health to inform Estuary management in Puerto Rico

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Estuary management programs are increasingly framing management issues within the context of ecosystem services benefits to the well-being of stakeholders. However, assessments and monitoring are still often limited to measures of ecological condition. When benefits assessments are conducted, they overwhelmingly focus on monetary valuation of economic resources such as fisheries, while under-representing potential social benefits to human health and well-being. A key challenge is that the methods, data, and models needed to quantify health impacts are generally less developed than monetary valuation approaches.

For example, the San Juan Bay estuary, Puerto Rico, comprises a connected system of bays, lagoons, and canals in a highly urbanized watershed. Habitat alterations and land-use development have disrupted the natural flow of water throughout the estuary system, subjecting some neighborhoods to frequent flooding events and exacerbating the effects of wastewater discharges, including untreated sewage, and stormwater runoff into areas of the bay. In addition to restoring habitat and water quality of the estuary, objectives of the San Juan Bay estuary management program include many social elements of human well-being, including cultural opportunities, education, public safety, a social connection to nature, good governance, and human health. However, the degree to which estuarine management actions to improve wetland condition and restore natural hydrology could improve human health and well-being is largely unknown.

Here, we overview several research studies aimed at assessing how restoration of estuarine ecosystem services could benefit human health and well-being. First, we developed a holistic index of human well-being to assess inequalities among neighborhoods in human health and well-being. Second, we developed a conceptual model to identify how ecosystem services might convey potential benefits to human health. Third we conducted a number of field and modeling studies to evaluate whether changes in ecological condition could be quantitatively linked to human health impacts. In particular, we evaluated i) the potential impacts of flood regulation on indoor mold and bacterial populations that might be associated to asthma and other respiratory illnesses, ii) the potential impacts of water quality regulation, temperature regulation and flood regulation on vector-borne illnesses, and iii) the potential impacts of floodwater retention on waterborne gastro-intestinal diseases. Taken together, results indicate health disparities in communities that border the estuary could in part be mitigated by estuary management actions largely aimed at improving water quality and restoring habitat. As data and models linking ecosystem services to human health continue to grow, environmental management programs will be increasingly empowered to communicate benefits to stakeholders.

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Eco-Health linkages: assessing the role of ecosystem goods and services on human health using causal criteria analysis

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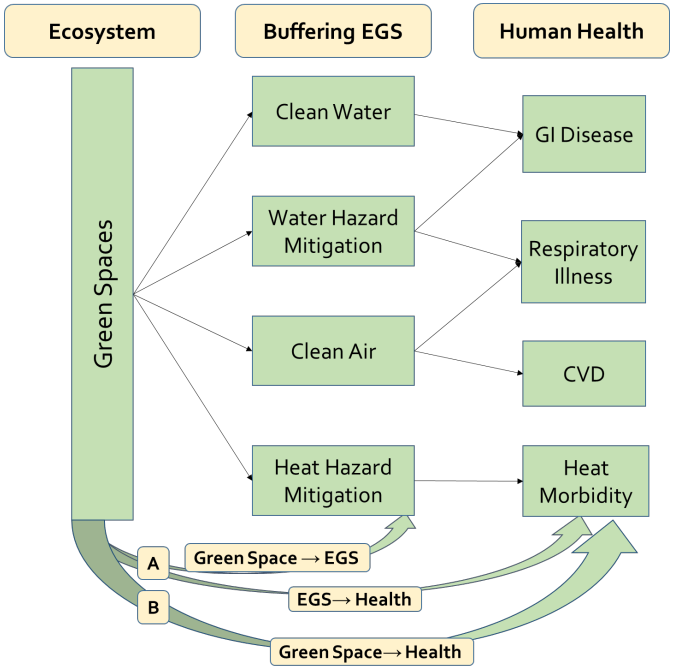

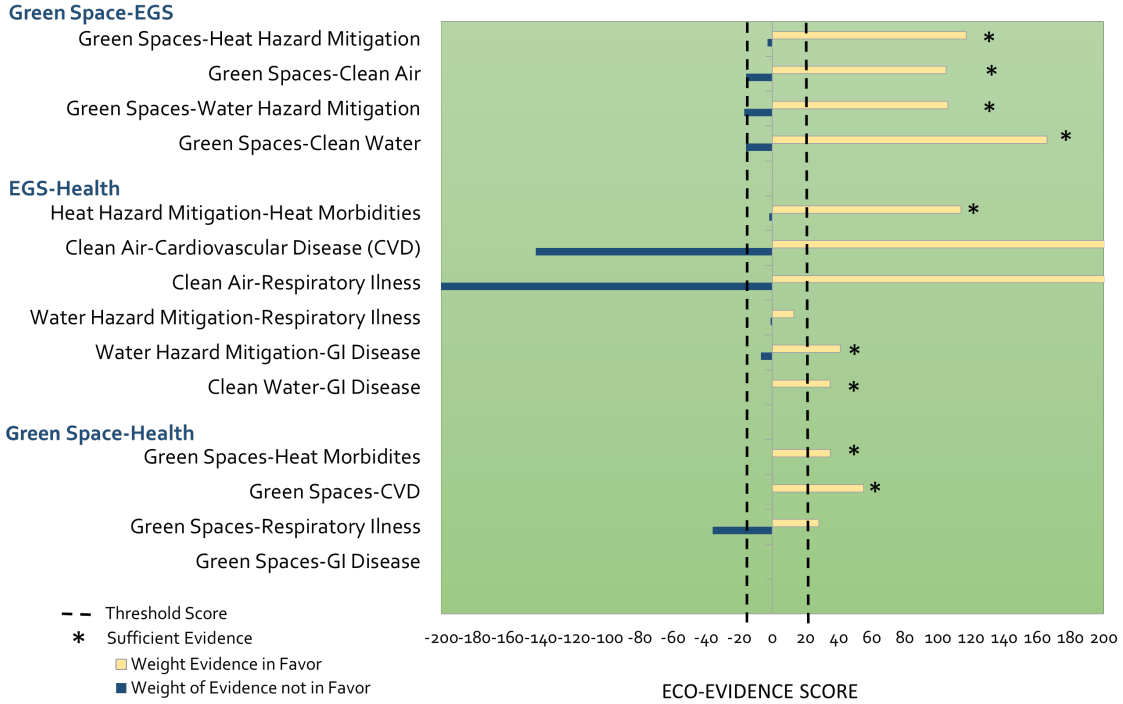

Data Sources for HWBI Metrics on Slide 24

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