Environmental Stressors: Effects on Aquatic Ecosystems

S. Marshall Adams
Environmental Sciences Division
Oak Ridge National Laboratory

Outline

Concepts of environmental stressors and stress

Assessing effects of stress using multiple response measures

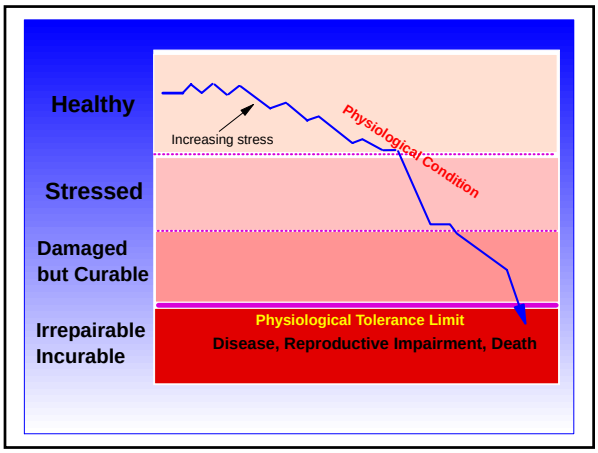
Examples of Stress effects in aquatic systems
- **stream polluted by multiple contaminants**
- **coastal estuary experiencing eutrophication**
- **ponds on Air Force Base affected by military activities**

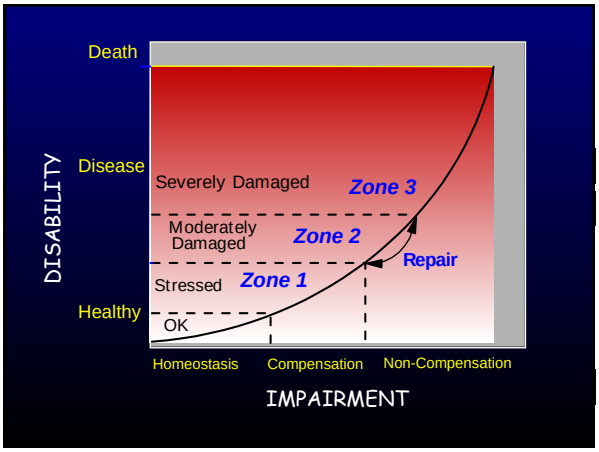
Relevance and Application

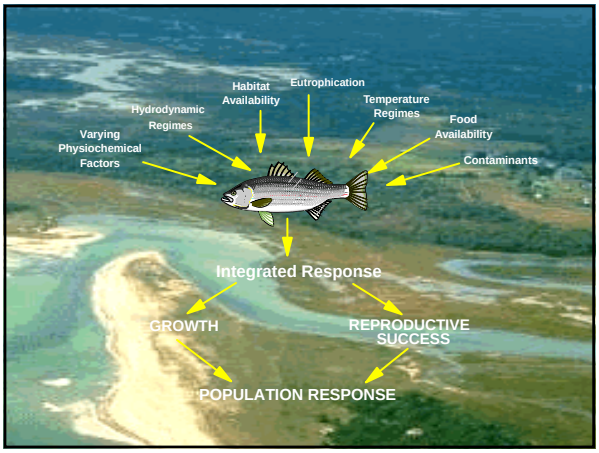
Definitions of Environmental Stress and Stressor

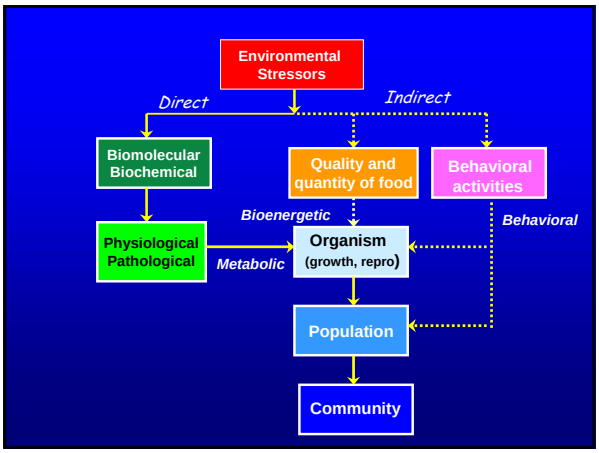
Stressor - Any environmental condition, situation, or factor that causes a biological system to mobilize its resources and increase its energy expenditure

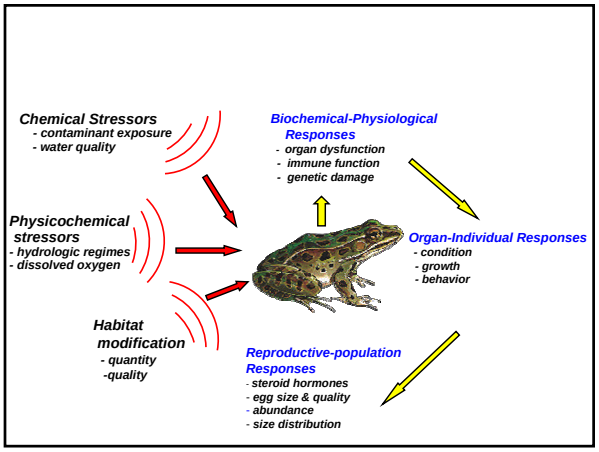
Stress - A state produced by an environmental stressor which extends the adaptive responses of an organism beyond its normal range, or which disturbs normal functioning to such an extent that the chances of survival are significantly reduced

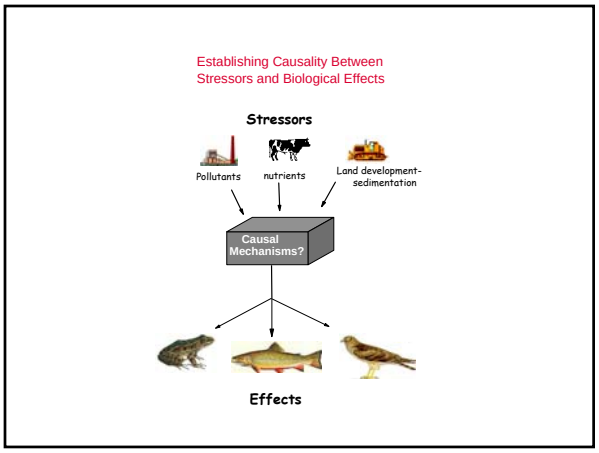

Healthy
Stressed
Damaged
but Curable
Irrepairable
Incurable
Increasing stress
Physiological Condition
Physiological Tolerance Limit
Disease, Reproductive Impairment, Death

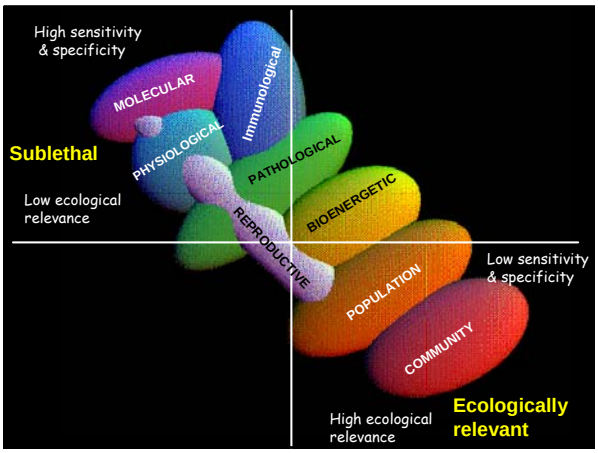

Death
Disease
Healthy
DISABILITY
Severely Damaged
Zone 3
Moderately
Damaged
Zone 2
Repair
Stressed
Zone 1
OK
Homeostasis
Compensation
Non-Compensation
IMPAIRMENT

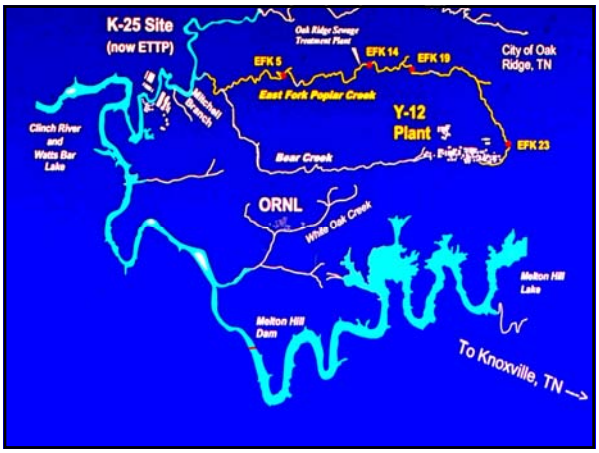

Habitat
Availability
Eutrophication
Hydrodynamic
Regimes
Temperature
Regimes
Food
Availability
Varying
Physiochemical
Factors
Contaminants
Integrated Response
GROWTH
REPRODUCTIVE
SUCCESS
POPULATION RESPONSE

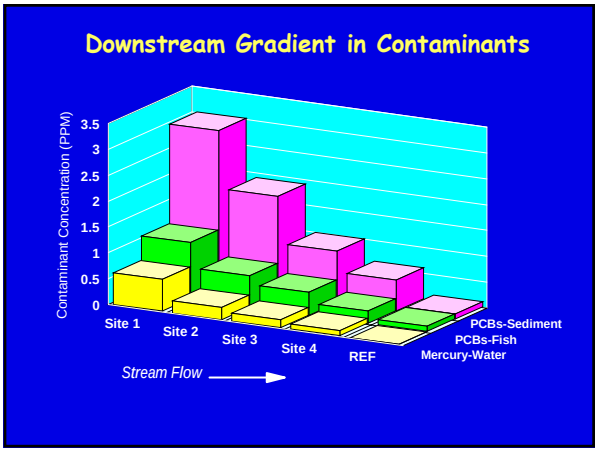

Environmental Stressors
Direct
Indirect
Biomolecular Biochemical
Quality and quantity of food
Behavioral activities
Bioenergetic
Behavioral
Physiological Pathological
Metabolic
Organism (growth, repro)
Population
Community


Chemical Stressors
- contaminant exposure
- water quality
Biochemical-Physiological Responses
- organ dysfunction
- immune function
- genetic damage
Physicochemical stressors
- hydrologic regimes
- dissolved oxygen
Organ-Individual Responses
- condition
- growth
- behavior
Habitat modification
- quantity
-quality
Reproductive-population Responses
- steroid hormones
- egg size & quality
- abundance
- size distribution

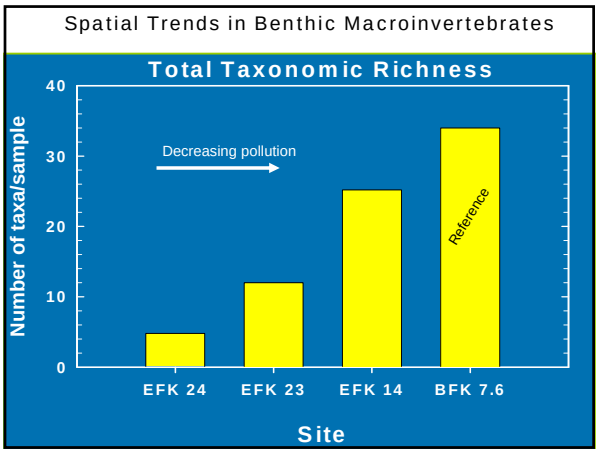

Establishing Causality Between Stressors and Biological Effects
Stressors
Pollutants
nutrients
Land development-sedimentation
Causal Mechanisms?
Effects


High sensitivity
& specificity
MOLECULAR
Immunological
PHYSIOLOGICAL
PATHOLOGICAL
Sublethal
Low ecological
relevance
BIOENERGETIC
REPRODUCTIVE
Low sensitivity
& specificity
POPULATION
COMMUNITY
High ecological
relevance
Ecologically
relevant

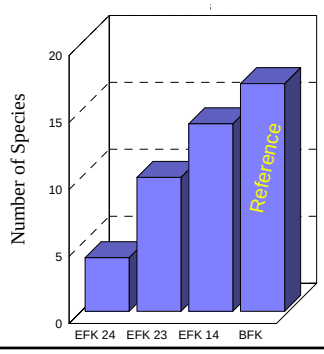

K-25 Site
(now ETTP)
Oak Ridge Sewage Treatment Plant
EFK 5
EFK 14
EFK 19
City of Oak Ridge, TN
East Fork Poplar Creek
Y-12 Plant
EFK 23
Clinch River and Watts Bar Lake
Bear Creek
ORNL
White Oak Creek
Melton Hill Lake
Melton Hill Dam
To Knoxville, TN

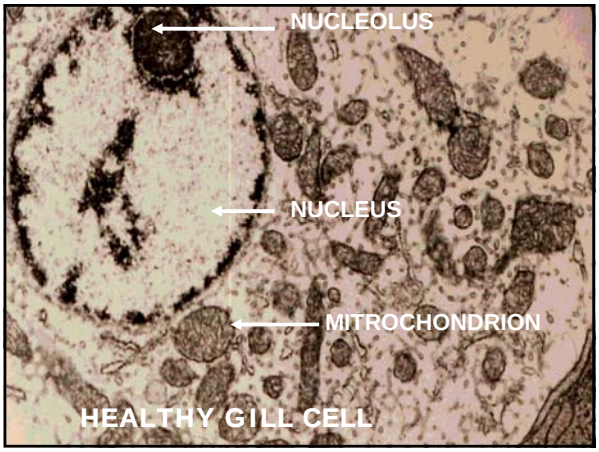

Downstream Gradient in Contaminants
Contaminant Concentration (PPM)
3.5
3
2.5
2
1.5
1
0.5
0
Site 1
Site 2
Site 3
Site 4
REF
PCBs-Sediment
PCBs-Fish
Mercury-Water
Stream Flow

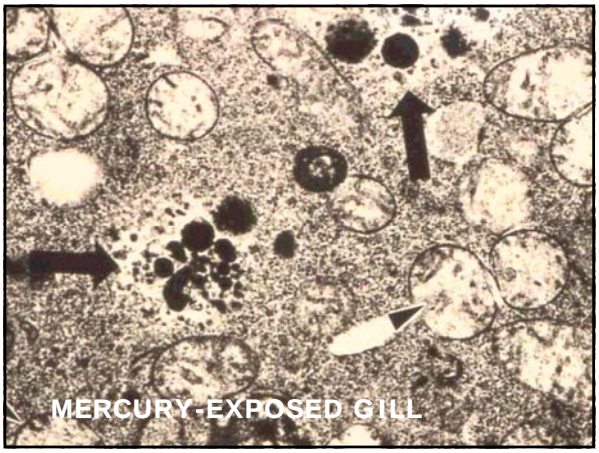
Spatial Trends in Benthic Macroinvertebrates

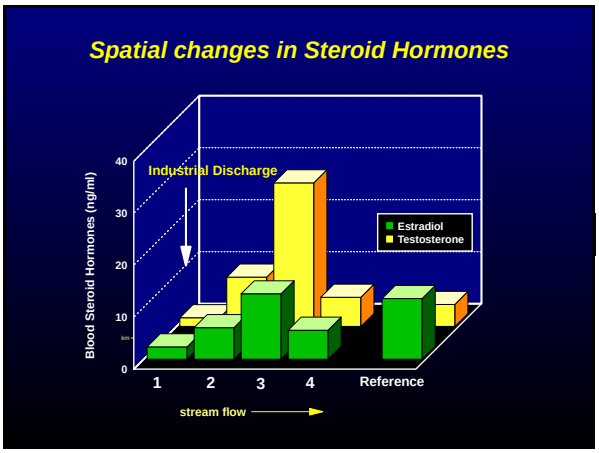


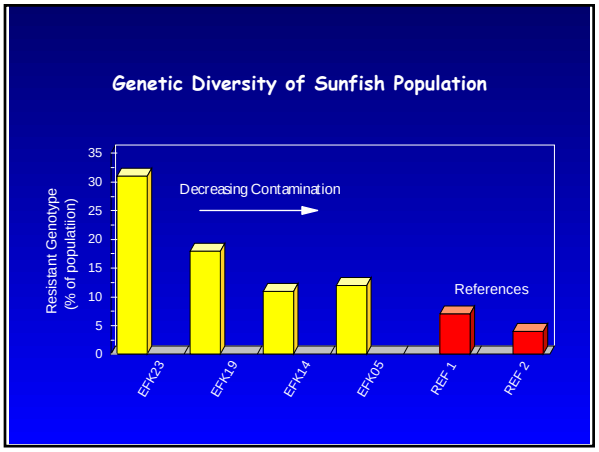
Spatial Pattern in Fish Divsrsity

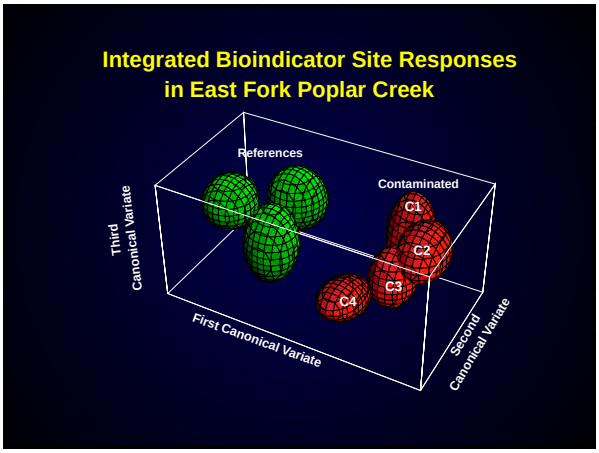


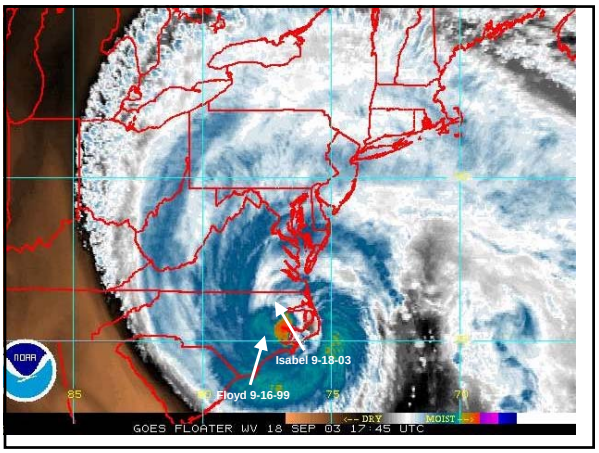

NUCLEOLUS
NUCLEUS
MITROCHONDRION
HEALTHY GILL CELL

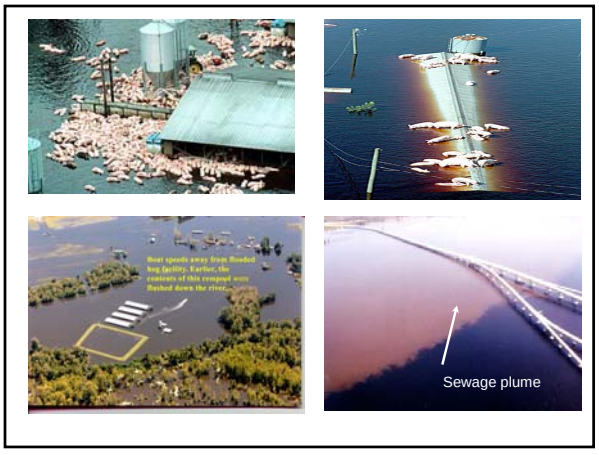

MERCURY-EXPOSED GILL


Spatial changes in Steroid Hormones
Blood Steroid Hormones (ng/ml)
40
30
20
10
0
Industrial Discharge
Estradiol
Testosterone
1
2
3
4
Reference
stream flow

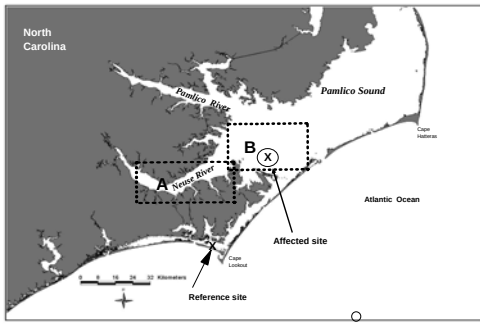

Genetic Diversity of Sunfish Population
Resistant Genotype
(% of population)
35
30
25
20
15
10
5
0
Decreasing Contamination
References
EFK23
EFK19
EFK14
EFK05
REF 1
REF 2

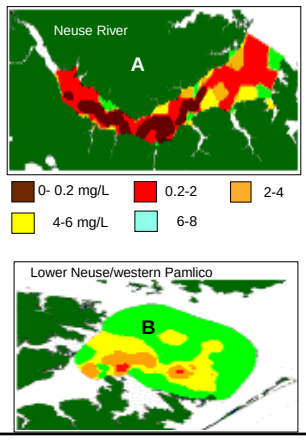

Integrated Bioindicator Site Responses
in East Fork Poplar Creek
References
Contaminated
C1
C2
C3
C4
Third
Canonical Variate
First Canonical Variate
Second
Canonical Variate

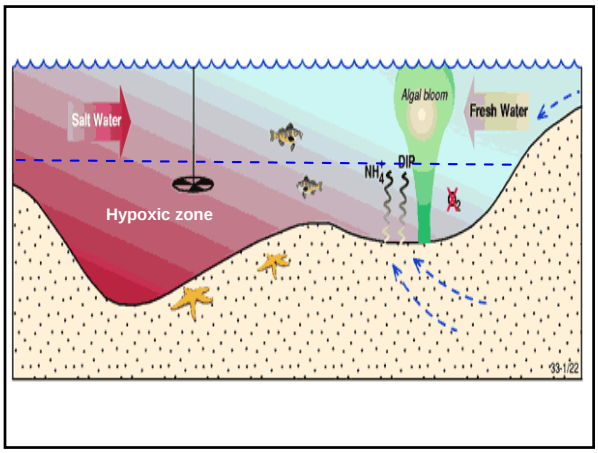

Isabel 9-18-03
Floyd 9-16-99
GOES FLOATER WV 18 SEP 03 17:45 UTC


Sewage plume


Nutrients-pollutants


North
Carolina
Pamlico River
Pamlico Sound
B
A
Neuse River
Atlantic Ocean
Affected site
Reference site

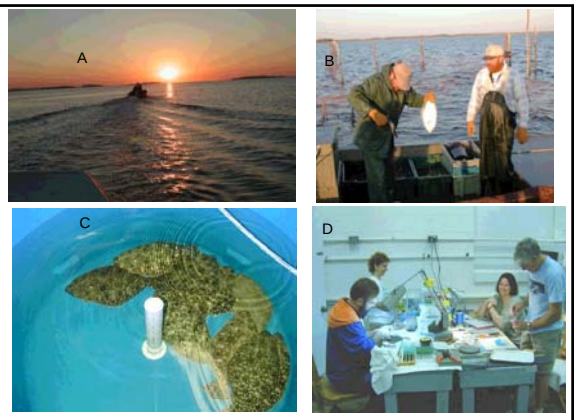

Neuse River
A
0- 0.2 mg/L
0.2-2
2-4
4-6 mg/L
6-8
Lower Neuse/western Pamlico
B

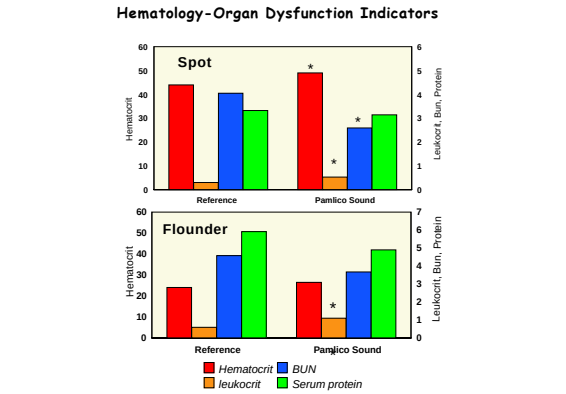


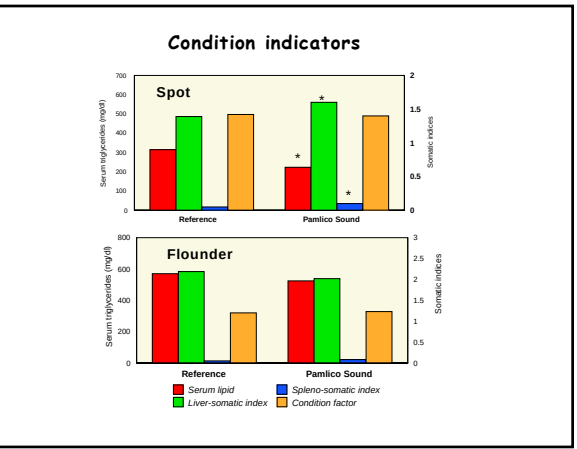
Hypothesis: Fish sampled from areas in Pamlico Sound with low dissolved oxygen are sublethally stressed compared to fish from non-affected reference areas

Southern Flounder (ambush predator, carnivore)

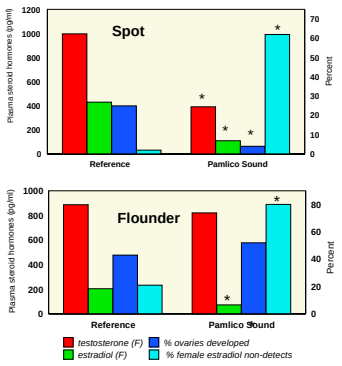
Spot (omnivore, benthic forager)


A
B
C
D


Hematology-Organ Dysfunction Indicators
Spot
Hematocrit
Leukocrit, Bun, Protein
Reference
Pamlico Sound
Flounder
Hematocrit
Leukocrit, Bun, Protein
Reference
Pamlico Sound
Hematocrit
BUN
leukocrit
Serum protein


Condition indicators
Spot
Serum triglycerides (mg/dl)
Somatic indices
Reference
Pamlico Sound
Flounder
Serum triglycerides (mg/dl)
Somatic indices
Reference
Pamlico Sound
Serum lipid
Spleno-somatic index
Liver-somatic index
Condition factor

Reproductive Indicators



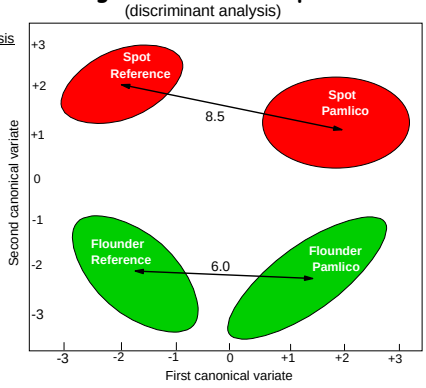
Integrated Health Responses

(discriminant analysis)

Indicators used in analysis

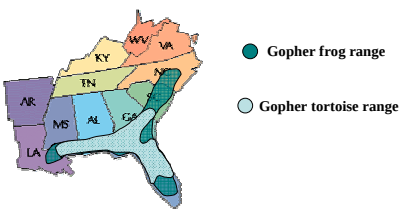
- Immunological - 7
- Hematology - 2
- Physiological - 4
- Reproductive - 6
- Condition - 5

Total= 24

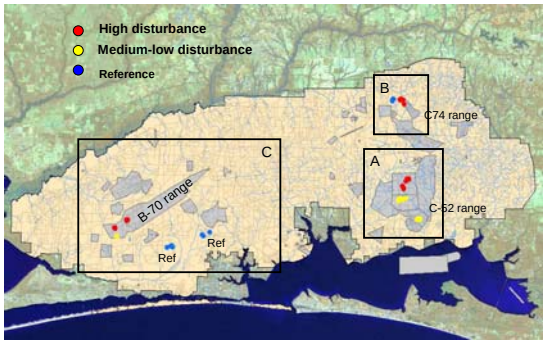


Gopher frog

Gopher tortoise



Sampling design & site selection gopher frogs-Eglin AFB



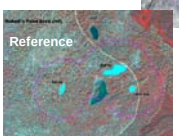
Assessment of Military Impact

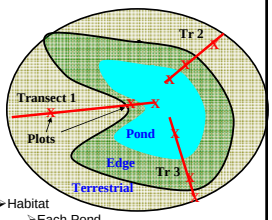
Sample site	Explosive residuals	Ordinance/ unit area	Cratering/ unit area	Soil disturb.	Burning/ scorching	Composite score	Miitary impact
C52N-1	3	3	3	3	2	14	High
C52N-2	3	3	3	3	1	13	High
C52N-3	3	3	3	2	2	12	High
C52C-1	1	1	2	2	1	7	Moderate
C52C-2	1	2	2	2	1	8	Moderate
C52C-3	1	1	2	2	2	8	Moderate
Reference-1	0	0	0	1	2	3	Low
Reference-2	0	0	0	1	1	2	Low
Reference-3	0	0	0	0	2	2	Low

Criteria for assessing military disturbance
3= moderate to high
2= low to moderate
1= none to low

Sampling design-Gopher frogs

- 9 "Treatment" areas
  - **3 High disturbance** (C52N, C74, C52CE)
  - **3 low disturbance** (C52C, C52A, B70)
  - **3 Reference**
- 2-6 Ponds per treatment



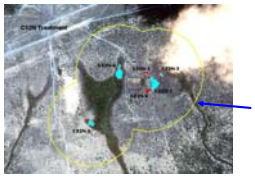


- Habitat
  - Each Pond
    - Morphology, water quality, general substrate, vegetation, and military disturbance
  - Edge/Terrestrial
    - 2-3 transects per pond
    - random plots within each community type
    - % cover plant layers; disturbance metrics, no of burrows, etc.
  - Remote sensing 300 m home range

Sampling devices deployed at Eglin

- Total sites with drift fences and traps - 40
- Total number of 30m drift fences with cages- 162
- Total feet of drift fencing- 5700
- Total number of traps at 40 sites- 940
- Number of traps at each site standardized based on pond surface area

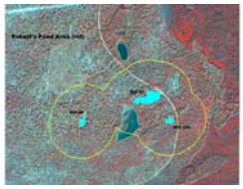
High disturbance site- C52 bombing range



300m home range radii from pond

Low disturbance site-C52A range

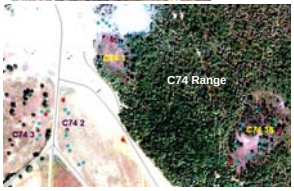
Undisturbed site-reference ponds



High activity sites-Eglin AFB

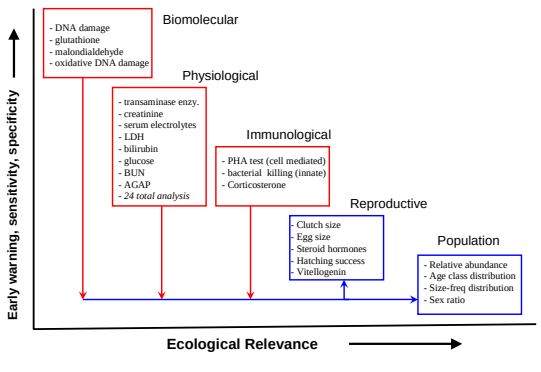
fences + traps

fences + traps



Low activity and reference sites-Eglin AFB

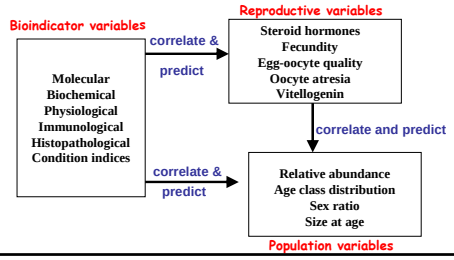
Construction and installation of sampling devices



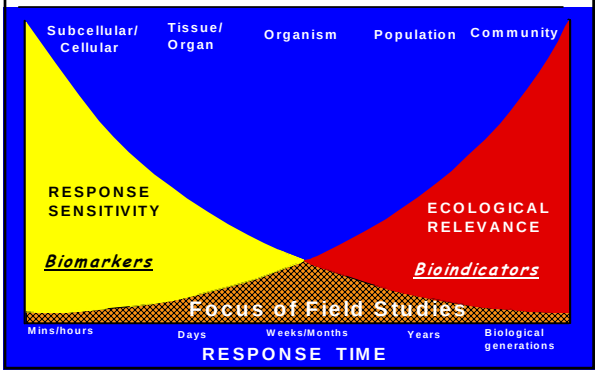
Linking indicators to health and fitness

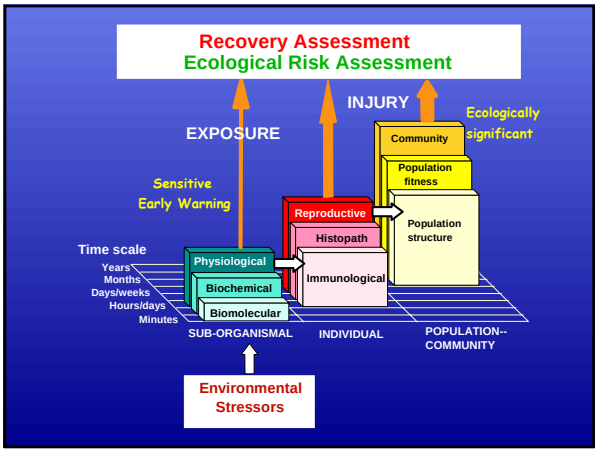
Hypothesis: Physiological indicators (bioindicators) can be used to assess or predict the health and fitness of TES populations at military sites

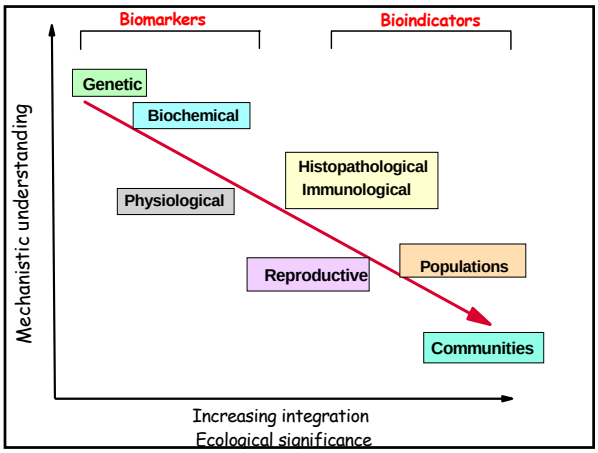
- Canonical correlation analysis in conjunction with canonical variate analysis used to predict and assess reproduction and population fitness based on sets of measured bioindicator variables

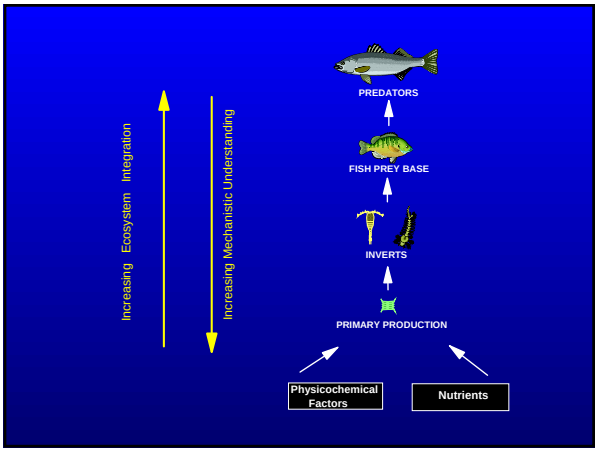


Organism-level responses provide a pivotal point through which mechanistic understanding and the ecological consequences of stress can be linked









Summary

Multiple indicators of stressare useful for:

- Early warning indicators of environmental problems
- Providing insights into causal mechanisms linking stressors and biological effects
- Assessing cumulative and/or synergistic effects of stress on organisms
- Identifying sources & causes of environmental damage related to specific stressors
- Evaluating the effectiveness of environmental cleanup (remedial) actions

Establishing Causality Between
Stressors and Biological Effects