Animal Pee in the Sea: Consumer-Mediated Nutrient Dynamics in the World’s Changing Oceans

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Promotion Seminar
September 2016
I. Consumer Mediated Nutrient Supply in the World’s Oceans

II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

IV. Other Research and Academic Opportunities
Coastal Ecosystems in a Human-Dominated World
Coastal Ecosystems in a Human-Dominated World

Nutrient Loading  Over-exploitation
Top-down (consumption)

We Use Ecological Constructs and Theory to Explore these Stressors

Bottom-up (resource supply)
Consumers supply nutrients – but this is often not considered in marine systems.
Consumer Nutrient Supply Well-Studied in Terrestrial Systems

Yellowstone National Park

African Savannah

Frank et al., 1994, *Biochemistry*

McNaughton et al., 1988, *Bioscience*
Fish are a Primary Source of Limiting Nutrients in Freshwater Systems

- Nitrogen
- Phosphorus
Consumers Create “Hot Spots” of Nutrient Supply Through Excretion/Egestion

Form of spatial heterogeneity represented by a patch of intensified biogeochemical reaction rates

Fish biomass (g/m²)
- 4–15
- 15–23
- 23–37
- 37–54
- 54–78
- 78–242

N excretion (μmol N·m⁻²·h⁻¹)
- 11–37
- 37–55
- 55–86
- 86–120
- 120–160
- 160–538

McIntyre et al., 2008, Ecology
Coral Growth
Increased 70% by Fish Aggregations
(Meyer et al. 1985)
A Notable Example in Marine Systems

Coral Growth
Increased 70% by Fish Aggregations (Meyer et al. 1985)

Yet a 20 year gap following this initial research....
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The Bahamas
Turtle grass (*Thalassia testudinum*) communities <4m deep
First Step: Nutrient Diffusing Substrates to Assess Nutrient Limitation

Control  Nitrogen  Phosphorus  Both

Experimental units containing a nutrient enriched agar

Treatment that elicits the greatest response, in terms of algal biomass, is the most limiting nutrient(s)

Allgeier, Rosemond, and Layman, 2010, *Limnology and Oceanography*
Allgeier, Rosemond, and Layman, 2011, *JEMBE*
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

- Control
- Nitrogen Only
- Phosphorus Only
- Nitrogen and Phosphorus

\[ p < 0.001 \]

[chl a/μg cm⁻²]

- Control
- Nitrogen Only
- Phosphorus Only
- Nitrogen and Phosphorus

Strong and Consistent N and P Co-Limitation
Systems Where Consumers May be Crucial Sources of Nutrient Supply to Primary Producers
First Reefs Constructed March 2009

Intended to simulate natural patch reefs

Original Experiments:
40 Blocks (High grass density)
40 Blocks (Low grass density)
10 Blocks
0 Blocks
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Fish Aggregate Around Reefs During the Day and Forage at Night

Zapata et al., 2014, Caribbean Naturalist
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Distinct Spatial Patterns Provide the Template for Our Design and Analysis

Decreasing Nutrient Supply

Layman et al., 2013, Ecology
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Quantifying Fish Nutrient Supply

Jake Allgeier, Mr. Fish Pee, UCSB Post-doc

Measuring Nutrients Before and After Fish

Largest Existing Marine Database
29 families - 46 genera - 76 species
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Quantifying Fish Nutrient Supply

Combining empirical excretion rate measurements with visual surveys of fishes to estimate community-level nutrient supply

Allgeier et al., 2013, Ecology
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Fish are **THE Primary Source of Nutrient Supply to Producers**
Spatial Patterns of Seagrass Structure and Function

II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Spatial Non-linearities in Ecosystem Responses

Layman et al., 2013, Ecology
Create Habitat Structure

Increased Secondary Productivity

Biogeochemical Hot Spot?

Increased Seagrass Productivity/Complexity

Concentrated Nutrient Supply

Fish Aggregate
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Higher Seagrass Productivity/Complexity is Linked to Enhanced Invertebrate Production

Yeager, Acevedo, and Layman, 2013, MEPS
Create Habitat Structure

Concentrated Nutrient Supply

Fish Aggregate

Increased Secondary Productivity

Biogeochemical Hot Spot?

Increased Seagrass Productivity/Complexity

Concentrated Nutrient Supply
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Spatial Patterns of Seagrass Structure and Function

Spatial Non-linearities in Ecosystem Responses

Layman et al., 2013, Ecology
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

Positive Feedbacks Drive Temporal Variation

Size of “hot spots” increase over time

2-4m distance after two years

7-9m distance after four years

Yeager et al., 2014, Ecological Applications
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

The Mechanism: Relative Allocation to Above- and Belowground Structures

Layman et al., 2016, Ecological Engineering
II. Does Consumer Nutrient Supply Influence Seagrass Traits at the Patch Scale?

The Mechanism: Relative Allocation to Above- and Belowground Structures

Layman et al., 2016, Ecological Engineering
Consistent with Theories of Resource Allocation

A

B

Ecological Threshold Crossed?

C

Layman et al., 2016, Ecological Engineering
Create Habitat Structure

Concentrated Nutrient Supply

Increased Fish Aggregate

Increased Seagrass Productivity/Complexity

Biogeochemical Hot Spot?

Increased Secondary Productivity

Concentrated Nutrient Supply
Implications for Artificial Reef Design and Implementation

Ecological Thresholds Can Inform Reef Design
Artificial reefs viewed from the “bottom-up”: An ecosystem ecology perspective

Layman and Allgeier, To be submitted to *Frontiers in Ecology and the Environment*
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Ecosystem Scale Approaches – Coral Ecosystems
- Excretion and Nutrient Ratios
- Patterns Across Regional Fishing Gradients

Different Environmental Conditions – Seagrass Ecosystems
- Experimental Manipulations
- Alternative Environmental Contexts
An Apparent Paradox

Coral Growth Increased 70% by Fish Aggregations (Meyer et al. 1985)
THREATS TO CORAL REEFS

LAND-BASED SOURCES OF POLLUTION

- Coastal development & impervious surface
- Stormwater runoff
  - sedimentation, toxins, nutrients, and pathogens
- Deforestation
  - sedimentation
- Oil and chemical spills
  - toxins
- Road construction
  - sedimentation
- Agriculture
  - nutrients and sedimentation
- Failed septic systems
  - nutrients and pathogens

POLLUTION
sedimentation
- toxins
- pathogens
- increased nutrients

causes
disease and mortality
- disrupts ecological functions
- changes dynamics and feeding behaviors
prevents
coral growth and reproduction

pollution = sedimentation • toxins • pathogens • increased nutrients

As human population & development expands in coastal areas, the landscape is altered, increasing land-based sources of pollution & threatening coral reef health.

HOW YOU CAN HELP

- Apply fertilizers and pesticides sparingly.
- Pick up after your pets.
- Wash your car on your lawn.
- Dispose of lawn clippings in a compost pile.
- Harvest rooftop rain water through rain barrels or rain gardens.
- DO NOT dump paint, oil, antifreeze, debris, or other household chemicals into street gutters or storm drains.
- Clean up spilled brake fluid, oil, grease, and antifreeze.
- Maintain proper septic system function with inspections and pumpouts every 3-5 years.
Do Nutrients Increase or Decrease Coral Fitness?

Published Accounts of Nutrient Additions and Coral Fitness

Positive Effects

Increasing N:P

Negative Effects

Allgeier, Layman, et al., 2014, Global Change Biology
Allgeier, Layman, et al., 2015, Ecological Monographs
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

Scaling Up from Individuals to Community Nutrient Supply

**Gray snapper**

- Relating nutrients to wet mass for different consumer species:
  - **$\mu g$ NH$_4$ nutrient·h$^{-1}$**
    - $y = 0.345x + 1.72$
    - $R^2 = 0.89$
  - **$\mu g$ TDP nutrient·h$^{-1}$**
    - $y = 0.287x + 0.495$
    - $R^2 = 0.35$

Now we are moving up to an ecosystem scale – entire coral reef tracts.
Coupling Extensive Fish Survey Data Sets with Empirical Excretion Estimates

III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

Fish

- 172 communities
  - 71,729 fish
  - 158 species
- 79 species, 48 genera, 26 families
  + bioenergetics models
  - 28 families
= 144 species
- 99.4% of biomass

Processes

- N and P supply
- N, P and C storage
- Multifunctionality

Habitats

- Mangrove
- Gorgonian plain
- Acropora reef
- Seagrass
- Patch reef
- Montastrae reef
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

**Consumer Nutrient Supply Ratios**

![Graph showing nutrient supply ratios for different fish communities. The x-axis represents fish communities, and the y-axis represents N:P ratios. The graph includes data points for various nutrient ratios (17:1, 18:1, 20:1, 22:1) across different fish community types (Acropora, Gorgonian, Montastrae, Patch, Mangrove, Seagrass).]
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

Do Nutrients Increase or Decrease Coral Fitness?

Positive Effects

Consumer Supply on 4 Reef Types

Increasing N:P

Negative Effects

1:1  10:1  20:1  30:1  150:1  750:1

Allgeier, Layman et al., 2014, Global Change Biology
Allgeier, Layman, et al., 2015, Ecological Monographs
Do Nutrients Increase or Decrease Coral Fitness?

Have zooxanthellae evolved to utilize nutrients in the proportions being supplied by consumers on reefs?
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

**Ecosystem Scale Approaches – Coral Ecosystems**
- Excretion and Nutrient Ratios
- Patterns Across Regional Fishing Gradients

**Different Environmental Conditions – Seagrass Ecosystems**
- Experimental Manipulations
- Alternative Environmental Contexts
How Does Fishing Affect Consumer-mediated Nutrient Dynamics at a Regional Level?

III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?
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Fishing Alters the Nature of Nutrient Supply from the Fish Community

![Graph showing the nature of nutrient supply from the fish community under fishing (F) and no-fishing (NF) conditions. The graph includes a bar chart and a line graph representing percent reduction in nutrient supply.]

Allgeier et al., 2016, Nature Communications
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

Fishing Affects Functional Groups – and Thus Nutrient Supply – Differently

![Graph showing percent reduction in various nutrient supplies for different functional groups under fished and not-fished conditions.]

Legend:
- Gray = Whole Community
- Blue = Microinvertebrate
- Brown = Omnivore
- Green = Herbivore
- Red = Macroinvertebrate
- Orange = Piscivore
- Purple = Planktivore
- Yellow = Piscivore-Invertivore

Allgeier et al., 2016, Nature Communications
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

Fish excrete different ratios of N and P.
Fishing Affects Biomass, Trophic Structure and Size Structure – *Not Species Richness*
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

Ecosystem Scale Approaches –
Coral Ecosystems
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Coastal Ecosystems in a Human-Dominated World

Nutrient Loading  Over-exploitation
Can nutrient pollution supplant loss of nutrients from fishing?

Experimental manipulation of nutrients and fish densities (2x2 factorial design)

*Nutrient loading at lower N:P ratios than supply by fishes*

Longest running seagrass nutrient enrichment experiment
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

Do Nutrients Increase or Decrease Coral Fitness?

Consumer Supply on 4 Reef Types

Positive Effects

Negative Effects

Increasing N:P

Allgeier, Layman et al., 2014, Global Change Biology
Allgeier, Layman, et al., 2015, Ecological Monographs
Can nutrient pollution supplant loss of nutrients from fishing?

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Nutrient supply rate, but not ratio, drives productivity of the dominant seagrass.

Artificial nutrients shift community composition.

An opportunity to test coral ratio supply hypothesis.

Preliminary Results

To be submitted to *PNAS*
III. Does Consumer Nutrient Supply Matter at the Ecosystem Scale Under Different Environmental Contexts?

Ecosystem Scale Approaches – Coral Ecosystems
- Overfishing and Nutrient Supply
- Ratios of Nutrient Supply

Different Environmental Conditions – Seagrass Ecosystems
- Experimental Manipulations
- Alternative Environmental Contexts
Extreme Fishing Pressure in Haiti

Decreased Importance of Consumers for Nutrient Supply to Primary Producers
The Bahamas
A World Without Fishing....
At the local patch scale, fish aggregations drive biogeochemical hotspots in oligotrophic seagrass ecosystems.

Nutrient supply ratios, not just total quantity, can affect primary productivity patterns.

The next extension of our research is exploring the relative importance of this supply dynamic under different environmental conditions.

Consumer nutrient cycling is a critical component of our understanding of coastal marine ecosystems.
Animal Pee in the Sea: Consumer-Mediated Nutrient Dynamics in the World’s Changing Oceans

Consumption = Maintenance + Growth + Ex + Eg

Allgeier, Burkepile and Layman, In press, Global Change Biology
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Rapid Evolution in Altered Coastal Habitats

Giery and Layman, *In revision, Proc B*
Giery and Layman, 2015, *American Naturalist*
Giery et al., 2015, *Evolutionary Applications*
Araújo et al., 2014, *Ecology and Evolution*
Mechanisms Driving Mangrove Die-Off
Stoichiometry of Urban Streams
Academic Program Development and Outreach

Active Group of Graduate Students

Undergraduate Mentoring (~3,000 hours in 2015)

Applied Ecology (AEC 400) and Introduction to Biological Research (AEC 592)

Active Community Outreach Program in The Bahamas (Abaco Scientist Website)

Fishery Education and Management in Haiti
Animal pee in the sea: consumer-mediated nutrient dynamics in the world’s changing oceans