Consequences of Space and Species Aggregation in Welfare Estimates of Invasive Species

Stephanie Brockmann

January 5th 2018

University of Wyoming

Purpose and Research Question

Great Lakes Fisheries

- Economically and ecologically valuable industries
- Heavily invaded and threatened by non-indigenous aquatic species
- Currently under threat from bighead carp, introduces new food web, biomass, and recreation impacts

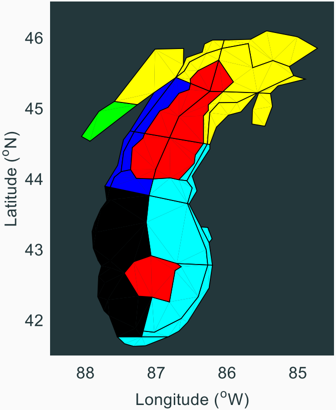
When invasions are spatially-explicit and species-specific, what biases exist in welfare estimates when one or both is ignored?

Approach for Adding Space and Species

Computable General Equilibrium (CGE) Model

Component I:
Incorporate Atlantis Model
(Fulton et al., 2011)

Component II:
Use household production function approach to find zone-level recreation demand
(Bockstael and McConnell, 1981)



Contributions

I. Include Recreation and Non-Market Values within the CGE

- Estimate impacts outside of the CGE, use those estimates to shock it
  (Seung et al., 1999, 2000; Watts et al., 2001; Lew and Seung, 2010; Hussain et al., 2012)

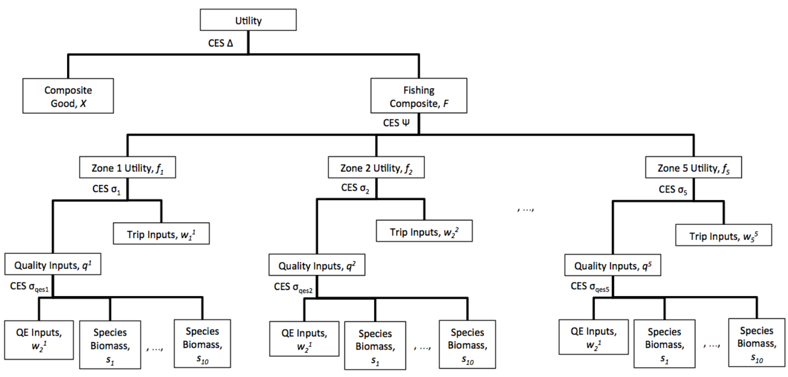
- Treat recreation demand as a constant proportion of spending on wildlife
  (Zhang and Lee, 2007)

II. Address Welfare Biases by Adding Space and Species

- Use a household production approach at a global scale to determine land preservation scenarios
  (Blandine et al., 2008)

- Allow for flexible demand equations, consider non-separability of use and non-use values in utility
  (Carbone and Smith, 2013)

Model: Utility Nesting Structure



Model

- **Step 1**: The representative consumer from household h maximizes utility by choosing consumption of the fishing composite, F, and the composite good, X, subject to his budget constraint:

$$\max_{X_h, F_h} U_h = U_h(F_h, X_h) \qquad \text{s.t.} \quad Y_h = p_X X_h + p_F F_h.$$

Model

- **Step 1**: The representative consumer from household h maximizes utility by choosing consumption of the fishing composite, F, and the composite good, X, subject to his budget constraint:

$$\max_{X_h, F_h} U_h = U_h(F_h, X_h) \qquad \text{s.t.} \quad Y_h = p_X X_h + p_F F_h.$$

- **Step 2a**: He maximizes X by choosing his consumption of each individual non-fishing good, x_j:

$$\max_{x_j} X = X(x_1, x_2, ..., x_9) \qquad \text{s.t.} \quad Y - p_F F = \sum_j x_j PA_j \qquad j = 1, 2, ..., 9.$$

Model

- **Step 1**: The representative consumer from household h maximizes utility by choosing consumption of the fishing composite, F, and the composite good, X, subject to his budget constraint:

$$\max_{X_h, F_h} U_h = U_h(F_h, X_h) \qquad \text{s.t.} \quad Y_h = p_X X_h + p_F F_h.$$

- **Step 2b.1**: He maximizes F by choosing his desired utility from fishing in each of the zones, f_z:

$$\max_{f_z} F = F(f_1, f_2, ..., f_5) \qquad \text{s.t.} \quad Y - p_x X = \sum_z p_{f_z} f_z \qquad z = 1, 2, ..., 5.$$

Model

- **Step 1**: The representative consumer from household h maximizes utility by choosing consumption of the fishing composite, F, and the composite good, X, subject to his budget constraint:

$$\max_{X_h, F_h} U_h = U_h(F_h, X_h) \qquad \text{s.t.} \quad Y_h = p_X X_h + p_F F_h.$$

- **Step 2b.1**: He maximizes F by choosing his desired utility from fishing in each of the zones, f_z:

$$\max_{f_z} F = F(f_1, f_2, ..., f_5) \qquad \text{s.t.} \quad Y - p_x X = \sum_z p_{f_z} f_z \qquad z = 1, 2, ..., 5.$$

- **Step 2b.2**: The consumer produces zone-level subutility using trip and quality inputs. He minimizes production costs for each zone:

$$\min_{{w_1}^z, q^z} \quad {p_1}^z {w_1}^z + {p_q}^z q^z \qquad \text{s.t.} \quad f_z = f_z({w_1}^z, q^z) \qquad \forall z.$$

Model

- **Step 1**: The representative consumer from household h maximizes utility by choosing consumption of the fishing composite, F, and the composite good, X, subject to his budget constraint:

$$\max_{X_h, F_h} U_h = U_h(F_h, X_h) \qquad \text{s.t.} \quad Y_h = p_X X_h + p_F F_h.$$

- **Step 2b.1**: He maximizes F by choosing his desired utility from fishing in each of the zones, f_z:

$$\max_{f_z} F = F(f_1, f_2, ..., f_5) \qquad \text{s.t.} \quad Y - p_x X = \sum_z p_{f_z} f_z \qquad z = 1, 2, ..., 5.$$

- **Step 2b.2**: The consumer produces zone-level subutility using trip and quality inputs. He minimizes production costs for each zone:

$$\min_{{w_1}^z, q^z} \quad {p_1}^z {w_1}^z + {p_q}^z q^z \qquad \text{s.t.} \quad f_z = f_z({w_1}^z, q^z) \qquad \forall z.$$

- **Step 2b.3**: The final step is to minimize total cost of producing quality, q^z.

$$\min_{{w_2}^z, s_b} \quad {p_2}^z {w_2}^z + \sum_b p^z_{s_b} s_b \qquad \text{s.t.} \quad q^z = q^z({w_2}^z, s_b) \qquad \forall z, \;\; \forall b = 1, ..., 10$$

Model

Step 1: The representative consumer from household h maximizes utility by choosing consumption of the fishing composite, F, and the composite good, X, subject to his budget constraint:

$$\max_{X_h, F_h} U_h = U_h(F_h, X_h) \qquad \text{s.t.} \quad Y_h = p_X X_h + p_F F_h.$$

Step 2b.1: He maximizes F by choosing his desired utility from fishing in each of the zones, f_z:

$$\max_{f_z} F = F(f_1, f_2, ..., f_5) \qquad \text{s.t.} \quad Y - p_x X = \sum_z p_{f_z} f_z \qquad z = 1, 2, ..., 5.$$

Step 2b.2: The consumer produces zone-level subutility using trip and quality inputs. He minimizes production costs for each zone:

$$\min_{{w_1}^z, q^z} \quad {p_1}^z {w_1}^z + {p_q}^z q^z \qquad \text{s.t.} \quad f_z = f_z({w_1}^z, q^z) \qquad \forall z.$$

Step 2b.3: The final step is to minimize total cost of producing quality, q^z.

$$\min_{{w_2}^z, s_b} \quad {p_2}^z {w_2}^z + \sum_b p^z_{s_b} s_b \qquad \text{s.t.} \quad q^z = q^z({w_2}^z, s_b) \qquad \forall z, \quad \forall b = 1, ..., 10$$

Comparative Analysis Approach

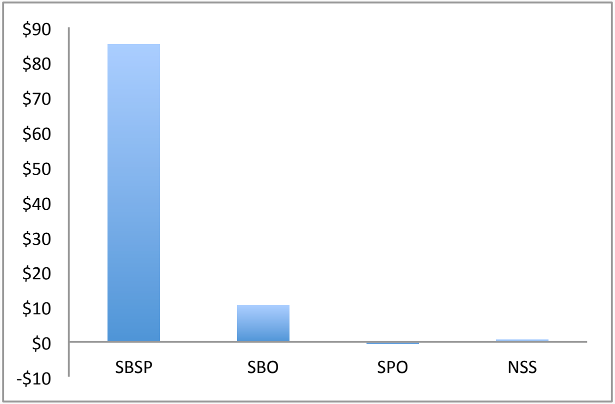
Compare Space and Species (SBSP) Model to:

- Species-Specifics Only (SBO)
- Space Only (SPO)
- No Space, Nor Species (NSS)

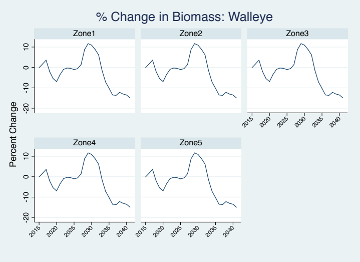
Initial approach: Aggregation is a summation over zones, species, or both

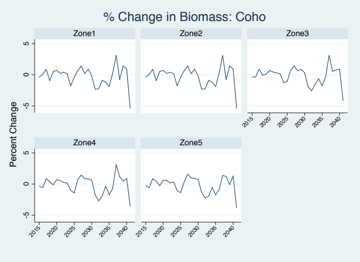
Preliminary Welfare Results: All Models

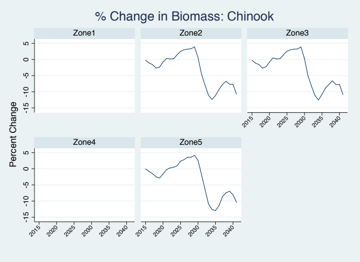
Discounted CV Measure for All Models

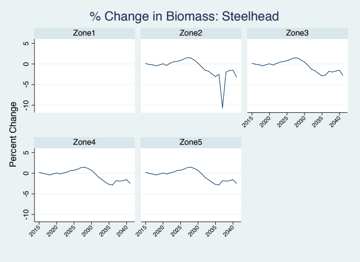


The SBSP Story: Zone-Level Biomass Impacts









The SBSP Story: Average Changes

Zone-Level Changes for Household Division 2

		Zone 3	Zone 4
SBSP	Demand Quality Enhancing Inputs	-	+
	Price of Quality Enhancing Inputs	-	-
	Demand Quality Inputs	-	+
	Price of Quality	+	-
	Demand for Trip Inputs	-	-
	Price of Trip Inputs	-	-
	Value of Zone Subutility	-	+
	Unit Price of Subutility	+	-

Zone-Level Changes for Household Division 6

		Zone 3	Zone 4
SBSP	Demand Quality Enhancing Inputs	+	+
	Price of Quality Enhancing Inputs	-	-
	Demand Quality Inputs	+	+
	Price of Quality	-	-
	Demand for Trip Inputs	+	+
	Price of Trip Inputs	-	-
	Value of Zone Subutility	+	+
	Unit Price of Subutility	-	-

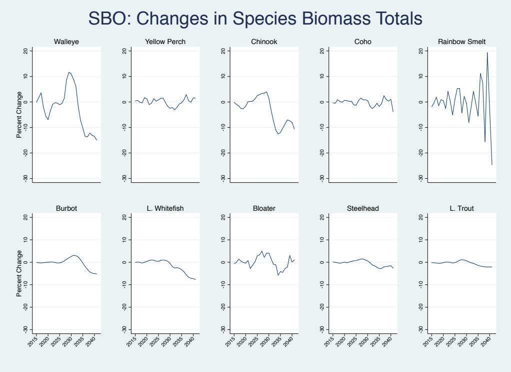
Household Level Changes for Household Division 2

SBSP	Fishing Composite Consumption	-
	Price of the Fishing Composite	+
	AOG Composite Consumption	-
	Price of the AOG Composite	+
	Household Income After Taxes and Savings	-

Household Level Changes for Household Division 6

SBSP	Fishing Composite Consumption	+
	Price of the Fishing Composite	-
	AOG Composite Consumption	-
	Price of the AOG Composite	+
	Household Income After Taxes and Savings	-

The SBO Story: Biomass Impacts and Average Changes



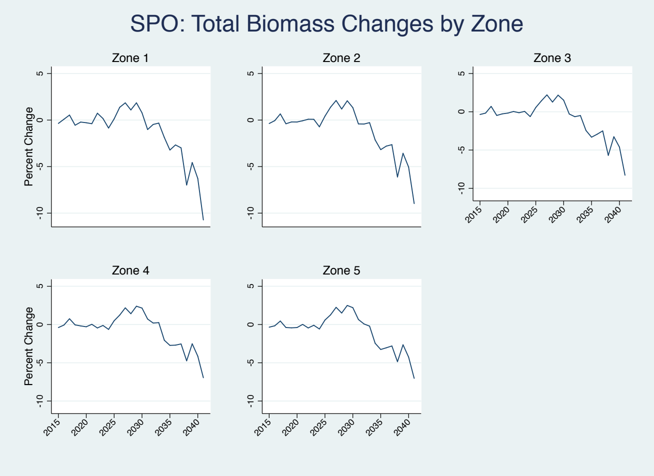
Changes for Household Division 2

	Demand Quality Enhancing Inputs	-
	Price of Quality Enhancing Inputs	-
	Demand Quality Inputs	-
	Price of Quality	+
	Demand for Trip Inputs	-
SBO	Price of Trip Inputs	-
	Fishing Composite Consumption	-
	Price of the Fishing Composite	+
	AOG Composite Consumption	-
	Price of the AOG Composite	-
	Household Income After Taxes and Savings	-

Changes for Household Division 6

	Demand Quality Enhancing Inputs	+
	Price of Quality Enhancing Inputs	-
	Demand Quality Inputs	+
	Price of Quality	-
	Demand for Trip Inputs	+
SBO	Price of Trip Inputs	-
	Fishing Composite Consumption	+
	Price of the Fishing Composite	-
	AOG Composite Consumption	+
	Price of the AOG Composite	-
	Household Income After Taxes and Savings	-

The SPO Story: Biomass Impacts



The SPO Story: Average Changes

Zone Level Changes for Household Division 2

		Zone 3	Zone 4
SPO	Demand Quality Enhancing Inputs	+	-
	Price of Quality Enhancing Inputs	+	+
	Demand Quality Inputs	+	-
	Price of Quality	-	+
	Demand for Trip Inputs	+	+
	Price of Trip Inputs	+	+
	Value of Zone Subutility	+	-
	Unit Price of Subutility	-	+

Zone Level Changes for Household Division 6

		Zone 3	Zone 4
SPO	Demand Quality Enhancing Inputs	-	+
	Price of Quality Enhancing Inputs	+	+
	Demand Quality Inputs	-	+
	Price of Quality	+	-
	Demand for Trip Inputs	+	+
	Price of Trip Inputs	+	+
	Value of Zone Subutility	-	+
	Unit Price of Subutility	+	-

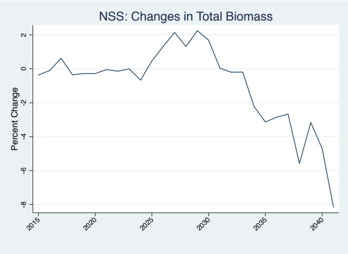
Household Level Changes for Household Division 2

SPO	Fishing Composite Consumption	+
	Price of the Fishing Composite	-
	AOG Composite Consumption	+
	Price of the AOG Composite	-
	Household Income After Taxes and Savings	+

Household Level Changes for Household Division 6

SPO	Fishing Composite Consumption	+
	Price of the Fishing Composite	-
	AOG Composite Consumption	-
	Price of the AOG Composite	+
	Household Income After Taxes and Savings	+

The NSS Story: Biomass Impacts and Average Changes



Changes for Household Division 2

NSS	Demand Quality Enhancing Inputs	-
	Price of Quality Enhancing Inputs	-
	Demand Quality Inputs	-
	Price of Quality	+
	Demand for Trip Inputs	+
	Price of Trip Inputs	-
	Fishing Composite Consumption	-
	Price of the Fishing Composite	+
	AOG Composite Consumption	-
	Price of the AOG Composite	-
	Household Income After Taxes and Savings	-

Changes for Household Division 6

NSS	Demand Quality Enhancing Inputs	+
	Price of Quality Enhancing Inputs	-
	Demand Quality Inputs	+
	Price of Quality	-
	Demand for Trip Inputs	+
	Price of Trip Inputs	-
	Fishing Composite Consumption	+
	Price of the Fishing Composite	-
	AOG Composite Consumption	-
	Price of the AOG Composite	+
	Household Income After Taxes and Savings	-

Results Summary

Main Stories From Each Model

- SBSP: Most desired species impacted in all zones, leads to higher quality demands, redistributions of resources
- SBO: Totaled species biomass values, deflates invasion impacts, reduces welfare implications compared to SBSP
- SPO: No species-specifics, invasion appears a net positive, substitutions for cost-effective fishing improves welfare slightly
- NSS: Aggregations over both, removes substitutions and flexibility, underestimates welfare as compared to SBSP and SBO

Results Summary

Main Stories From Each Model

- SBSP: Most desired species impacted in all zones, leads to higher quality demands, redistributions of resources
- SBO: Totaled species biomass values, deflates invasion impacts, reduces welfare implications compared to SBSP
- SPO: No species-specifics, invasion appears a net positive, substitutions for cost-effective fishing improves welfare slightly
- NSS: Aggregations over both, removes substitutions and flexibility, underestimates welfare as compared to SBSP and SBO

Takeaway: **Both space and species-specifics matter; aggregating out one or both may bias welfare estimates**

Appendices

Figure 1: Firm Nest

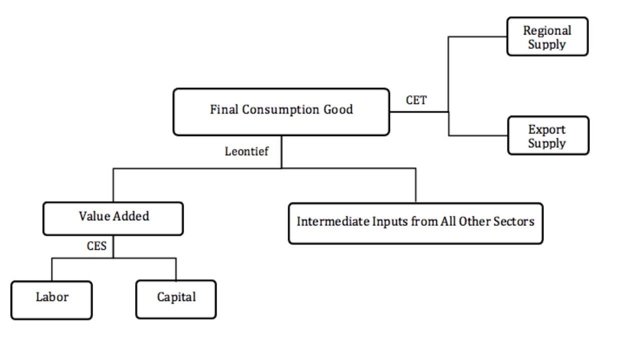


Figure 2: Utility Nest

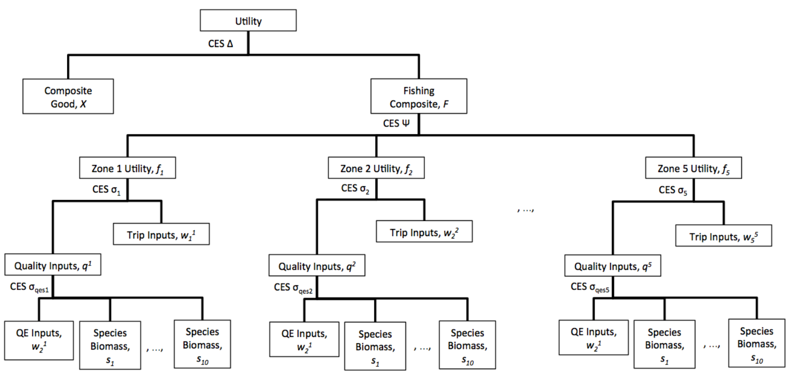
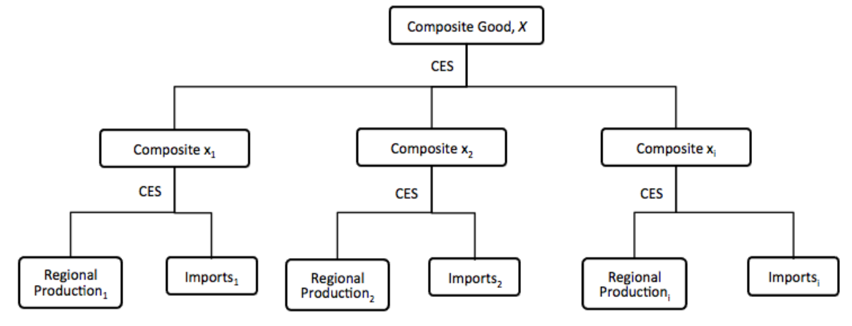


Figure 3: Composite Good Nest



Step 1: Maximize Utility

Explicit form for the first level of optimization:

$$\max_{X,F} U = \left(\theta F^{\delta} + (1-\theta)X^{\delta}\right)^{\frac{1}{\delta}}$$
$$\text{s.t.} \quad Y = p_X X + p_F F.$$

- Share of fishing in utility is θ; share of composite good is $(1-\theta)$
- Elasticity of substitution is Δ, transformed to $\delta = \frac{\Delta - 1}{\Delta}$
- Composite good price is p_X; fishing comp. price is p_F; disposable income is Y

Demand equations for F and X:

$$F = \left(\frac{\theta}{p_F}\right)^{\Delta}\left(\frac{Y}{\theta^{\Delta} p_F^{1-\Delta} + (1-\theta)^{\Delta} p_X^{1-\Delta}}\right)$$

$$X = \left(\frac{1-\theta}{p_X}\right)^{\Delta}\left(\frac{Y}{\theta^{\Delta} p_F^{1-\Delta} + (1-\theta)^{\Delta} p_X^{1-\Delta}}\right)$$

Back

Step 2a: Maximize X

The composite good X is a CES function of the $j = 1, 2, ..., 9$ other non-fishing goods.

Explicit form for the optimization:

$$\max_{x_j} X = \left(\sum_j \kappa_j {x_j}^{\rho_X} \right)^{\frac{1}{\rho_X}}$$

$$\text{s.t.} \quad Y - p_F F = \sum_j x_j PA_j$$

Demand equations for each good:

$$x_j = \left(\frac{\kappa_j}{PA_j} \right)^{\sigma_X} \left(\frac{Y - p_F F}{\sum_j {\kappa_j}^{\sigma_X} {PA_j}^{1-\sigma_X}} \right) \quad \forall j$$

Deriving the expenditure function from the indirect utility function and using the budget constraint, gives the price index for X:

$$p_X = \left(\sum_j {\kappa_j}^{\sigma_X} {PA_j}^{1-\sigma_X} \right)^{\frac{1}{1-\sigma_X}} \quad .$$

This price index is the connection between the top and second level in the nest.

Step 2b.1: Maximize F

The fishing composite, F, is a CES function of the subutility from fishing in each zone, f_z, for $z = 1, 2, ..., 5$.

Fishing composite optimization:

$$\max_{f_z} F = \left(\sum_z \beta_z {f_z}^{\omega} \right)^{\frac{1}{\omega}}$$

$$\text{s.t.} \quad Y - p_x X = \sum_z p_{f_z} f_z$$

Demands for zone-level subutility:

$$f_z = \left(\frac{\beta_z}{p_{f_z}} \right)^{\Psi} \left(\frac{Y - p_x X}{\sum_z {\beta_z}^{\Psi} {p_{f_z}}^{1-\Psi}} \right) \quad \forall z$$

Composite price index for F:

$$p_F = \left(\sum_z {\beta_z}^{\Psi} {p_{f_z}}^{1-\Psi} \right)^{\frac{1}{1-\Psi}}$$

This connects the second level of utility to the top level, on the fishing side.

Step 2b.2: Minimize costs of producing f_z

The consumer produces subutility from fishing in different zones, using travel/trip (or quantity) inputs and quality inputs.

Cost minimization problem for all zones:

$$\min_{{w_1}^z, q^z} \quad {p_1}^z {w_1}^z + {p_q}^z q^z$$

$$\text{s.t.} \quad f_z = \varphi_z(\alpha_z {w_1}^{z\,\rho_z} + (1-\alpha_z) q^{z\,\rho_z})^{\frac{1}{\rho_z}}$$

Input demand equations for all zones:

$${w_1}^z = \left(\frac{f_z}{\varphi_z}\right)\left(\frac{\alpha_z \varphi_z c_z}{{p_1}^z}\right)^{\sigma_z}$$

$$q^z = \left(\frac{f_z}{\varphi_z}\right)\left(\frac{(1-\alpha_z)\varphi_z c_z}{{p_q}^z}\right)^{\sigma_z}$$

Unit cost function for all zones :

$$c_z = \frac{1}{\varphi_z}\left(\alpha_z^{\sigma_z} {p_1}^{z\,1-\sigma_z} + (1-\alpha_z)^{\sigma_z} {p_q}^{z\,1-\sigma_z}\right)^{\frac{1}{1-\sigma_z}}$$

This unit cost function for each f_z is equal to p_{f_z} and acts as the connection between this step and the one above it.

Back Utility

Step 2b.3: Minimize the total cost of producing q^z

The final step is to minimize the cost of producing q^z by choosing species biomass demand s_b and quality-enhancing inputs w_2:

$$\min_{{w_2}^z, s_b} \quad {p_2}^z {w_2}^z + \sum_b p^z_{s_b} s_b$$
$$\text{s.t.} \quad q^z = \psi_z (\phi_{qe} {w_2}^{z\,\epsilon_{qes}} + \sum_b \phi_b {s_b}^{z\,\epsilon_{qes}})^{\frac{1}{\epsilon_{qes}}}.$$

Optimization yields the following input demand equations,

$${w_2}^z = \left(\frac{q^z}{\psi_z}\right)\left(\frac{\phi_{qe}\psi_z c_q^z}{{p_2}^z}\right)^{\sigma_{qes}},$$

$${s_b}^z = \left(\frac{q^z}{\psi_z}\right)\left(\frac{\phi_b \psi_z c_q^z}{{p_{s_b}}^z}\right)^{\sigma_{qes}} \quad \forall b,$$

and a unit cost equation

$${c_q}^z = \frac{1}{\psi_z}\left(\phi_{qe}^{\sigma_{qes}} {p_2}^{z\,1-\sigma_{qes}} + \sum_b {\phi_b}^{\sigma_{qes}} {p_{s_b}}^{z\,1-\sigma_{qes}}\right)^{\frac{1}{1-\sigma_{qes}}}.$$

Since ${c_q}^z$ is equivalent to ${p_q}^z$, this last piece connects this lowest level to the one above it.

Equations in Calibrated Share Form: Step 1

Fishing Composite Demand:

$$F = \bar{F}\left(\frac{ex}{\bar{ex}}\right)^{\Delta-1}\left(\frac{p_F}{\bar{p_F}}\right)^{-\Delta}\left(\frac{Y}{\bar{Y}}\right)$$

Composite Good Demand:

$$X = \bar{X}\left(\frac{ex}{\bar{ex}}\right)^{\Delta-1}\left(\frac{p_X}{\bar{p_X}}\right)^{-\Delta}\left(\frac{Y}{\bar{Y}}\right)$$

Unit expenditure for overall consumption:

$$ex = \bar{ex}\left(\theta\left(\frac{p_F}{\bar{p_F}}\right)^{1-\Delta} + (1-\theta)\left(\frac{p_X}{\bar{p_X}}\right)^{1-\Delta}\right)^{\frac{1}{1-\Delta}}$$

Cost share of fishing composite in benchmark:

$$\theta = \frac{\bar{p_F}\bar{F}}{\bar{p_F}\bar{F} + \bar{p_X}\bar{X}}$$

Connections to the next nest:

$p_F = ex_f$ unit price of fishing composite = unit expenditure on fishing

$p_X = ex_x$ unit price of composite good = unit expenditure on comp. good

Equations in Calibrated Share Form: Step 2a

Demand for All Other Goods (AOG):

$$x_j = \bar{x}_j \left(\frac{ex_x}{\bar{ex}_x} \right)^{\sigma_x - 1} \left(\frac{PA_j}{\bar{PA}_j} \right)^{-\sigma_x} \left(\frac{p_X X}{\bar{Y} - \bar{p_F} \bar{F}} \right)$$

Baseline total expenditures on all other goods must satisfy:

$$\bar{Y} - \bar{p_F} \bar{F} = \bar{p_X} \bar{X}$$

Unit expenditure on the composite good:

$$ex_x = \bar{ex}_x \left(\sum_j \kappa_j \left(\frac{PA_j}{\bar{PA}_j} \right)^{1-\sigma_x} \right)^{\frac{1}{1-\sigma_x}}$$

Cost share of each good in the composite, in benchmark:

$$\kappa_j = \frac{\bar{PA}_j \bar{x}_j}{\sum_j \bar{PA}_j \bar{x}_j}$$

Connection to system:

PA_j - is determined in the full set of equations from the equilibrium conditions for supply and demand and the Armington price equation

Back

Equations in Calibrated Share Form: Step 2b1

Demand for fishing subutility

$$f_z = \bar{f}_z \left(\frac{ex_f}{\bar{ex}_f} \right)^{\sigma_f - 1} \left(\frac{p_{f_z}}{\bar{p}_{f_z}} \right)^{-\sigma_f} \left(\frac{p_F F}{\bar{Y} - \bar{p}_X \bar{X}} \right)$$

Baseline total expenditures on fishing must satisfy:

$$\bar{Y} - \bar{p}_X \bar{X} = \bar{p}_F \bar{F}$$

Unit expenditure on the fishing composite:

$$ex_f = \bar{ex}_f \left(\sum_z \beta_z \left(\frac{p_{f_z}}{\bar{p}_{f_z}} \right)^{1-\sigma_f} \right)^{\frac{1}{1-\sigma_f}}$$

Cost share of each zone subutility in benchmark:

$$\beta_z = \frac{\bar{p}_{f_z} \bar{f}_z}{\sum_z \bar{p}_{f_z} \bar{f}_z}$$

Connection to the next nest:

$p_{f_z} = c_{f_z}$ unit price (value) of subutility in each zone = unit cost of producing subutility

Equations in Calibrated Share Form: Step 2b2

Trip Input Demand for all z:

$$w_1 = \bar{w_1} \left(\frac{c_{f_z} \bar{p_{w_1}}}{\bar{c_{f_z}} p_{w_1}} \right)^{\sigma_z} \left(\frac{f_z}{\bar{f_z}} \right)$$

Quality Input Demand for all z:

$$q_z = \bar{q_z} \left(\frac{c_{f_z} \bar{p_{q_z}}}{\bar{c_{f_z}} p_{q_z}} \right)^{\sigma_z} \left(\frac{f_z}{\bar{f_z}} \right)$$

Unit cost function for zone subutility:

$$c_{f_z} = \bar{c_{f_z}} \left(\alpha_z \left(\frac{p_{w_1}}{\bar{p_{w_1}}} \right)^{1-\sigma_z} + (1-\alpha_z) \left(\frac{p_{q_z}}{\bar{p_{q_z}}} \right)^{1-\sigma_z} \right)^{\frac{1}{1-\sigma_z}}$$

Benchmark share of trip costs in the production of zone subutility:

$$\alpha_z = \frac{\bar{p_{w_1}} \bar{w_1}}{\bar{p_{w_1}} \bar{w_1} + \bar{p_{q_z}} \bar{q_z}}$$

Connections to the system and the next nest:

p_{w_1}	determined in the full system
$p_{q_z} = ex_x$	unit price of quality = unit cost of producing quality

Equations in Calibrated Share Form: Step 2b3

Quality Enhancing Input Demand for all z:

$$w_2 = \bar{w}_2 \left(\frac{c_{q^z}\, \bar{p_{w_2^z}}}{\bar{c_{q^z}}\, p_{w_2^z}} \right)^{\sigma_{qeb}} \left(\frac{q^z}{\bar{q^z}} \right)$$

Species Biomass Demand for all z and b:

$${s_b}^z = \bar{s_b}^z \left(\frac{c_{q^z}\, \bar{p_{s_b^z}}}{\bar{c_{q^z}}\, p_{s_b^z}} \right)^{\sigma_{qeb}} \left(\frac{q^z}{\bar{q^z}} \right)$$

Unit cost function for zone quality production:

$$c_{q_z} = \bar{c_{q_z}} \left(\alpha_{qz} \left(\frac{p_{w_2^z}}{\bar{p_{w_2^z}}} \right)^{1-\sigma_{qeb}} + \sum_b \alpha_b \left(\frac{p_{s_b^z}}{\bar{p_{s_b^z}}} \right)^{1-\sigma_{qeb}} \right)^{\frac{1}{1-\sigma_{qeb}}}$$

Benchmark share of species biomass demand and QE inputs:

$$\alpha_b = \frac{\overline{p^z_{s_b}}\ \overline{{s_b}^z}}{\sum_b \overline{p^z_{s_b}}\ \overline{{s_b}^z} + \overline{p_{w_2^z}}\ \overline{{w_2}^z}} \qquad \alpha_{qz} = \frac{\overline{p_{w_2^z}}\ \overline{{w_2}^z}}{\sum_b \overline{p^z_{s_b}}\ \overline{{s_b}^z} + \overline{p_{w_2^z}}\ \overline{{w_2}^z}} \quad \forall b, z$$

Connections: p_{w_2} determined in the full system and $c_{q_z} = p_{q_z}$

Figure 4: SAM Part I

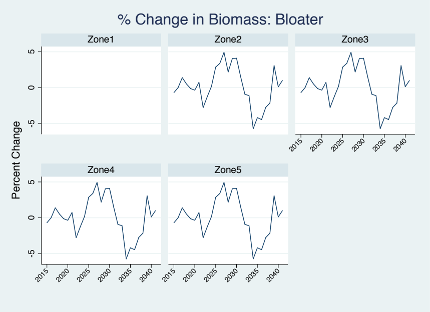
	AGR	FISH	POW	FUEL	MISC	AIRT	RAILT	WTRT	TRKT	Z1TRIP	Z2TRIP	Z3TRIP	Z4TRIP	Z5TRIP	Z1QUAL	Z2QUAL	Z3QUAL	Z4QUAL	Z5QUAL	LAB	CAP
AGR	625.076			0.787	5763.261																
FISH					235.192																
POW	29.179		6720.325	24.293	6704.667	5.685	0.302	5.313	14.669												
FUEL	0.353	0.002	1.677	0.491	558.509	0.009	0.066	0.702	8.261	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001	0.001		
MISC	3030.616	14.434	7708.433	689.247	441515.544	2889.321	595.678	437.201	5324.417	7.997	7.997	7.997	7.997	7.997	8.306	8.306	8.306	8.306	8.306		
AIRT	3.952	0.006	22.676	1.399	2041.558	0.214	0.406	1.185	62.164	0.003	0.003	0.003	0.003	0.003	0.004	0.004	0.004	0.004	0.004		
RAILT	22.305	0.017	129.843	0.183	1791.196	2.145	2.609	0.210	94.682	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010	0.010		
WTRT	14.548	0.015	4.371	0.048	358.470	1.580	0.333	0.160	2.773	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008	0.008		
TRKT	64.604	0.033	12.485	17.073	6443.092	13.152	6.213	2.973	144.738	0.018	0.018	0.018	0.018	0.018	0.019	0.019	0.019	0.019	0.019		
Z1TRIP					16.640					0.169											
Z2TRIP					16.640						0.169										
Z3TRIP					16.640							0.169									
Z4TRIP					16.640								0.169								
Z5TRIP					16.640									0.169							
Z1QUAL					17.284										0.176						
Z2QUAL					17.284											0.176					
Z3QUAL					17.284												0.176				
Z4QUAL					17.284													0.176			
Z5QUAL					17.284														0.176		
LAB	969.980	4.627	2742.449	607.760	247863.258	1368.357	360.050	63.243	2772.712	10.837	10.837	10.837	10.837	10.837	11.256	11.256	11.256	11.256	11.256		
CAP	4105.840	23.225	3556.615	213.761	154191.693	698.614	152.377	55.961	1385.161	17.407	17.407	17.407	17.407	17.407	18.081	18.081	18.081	18.081	18.081		
INDT	-93.655	11.554	1869.163	336.688	30497.709	383.410	-1.991	12.760	82.876	4.421	4.421	4.421	4.421	4.421	4.592	4.592	4.592	4.592	4.592		
HHD1																				796.440	236.319
HHD2																				856.857	173.813
HHD3																				5001.821	1022.862
HHD4																				8694.814	1621.636
HHD5																				18521.416	3300.508
HHD6																				39541.132	6572.286
HHD7																				37219.299	6631.997
HHD8																				51761.324	10588.901
HHD9																				62289.371	25129.764
FGOV	87.941				3.712															31399.523	2233.572
SGOV	6.016	9.651			14257.639					5.347	5.347	5.347	5.347	5.347	5.554	5.554	5.554	5.554	5.554	553.210	391.848
INV	119.934	0.093			3315.463					0.052	0.052	0.052	0.052	0.052	0.054	0.054	0.054	0.054	0.054		106035.873
FT	1062.486	368.230	169.048		92864.999	1146.020	15.567		144.851												-232.370
DT	2876.996	4.122	1804.312	286.756	275569.172	899.123	1422.062	557.575	843.175	2.284	2.284	2.284	2.284	2.284	2.372	2.372	2.372	2.372	2.372	227.690	853.678

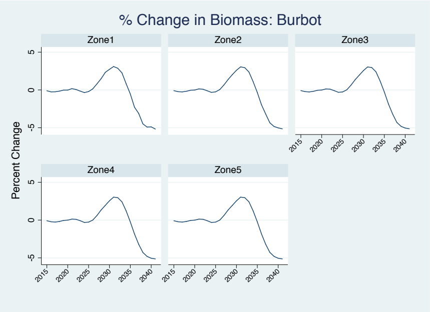
Back

Figure 5: SAM Part II

	HHD1	HHD2	HHD3	HHD4	HHD5	HHD6	HHD7	HHD8	HHD9	FGOV	SGOV	INV	FT	DT
AGR	77.760	52.629	141.774	152.527	229.175	363.108	287.147	338.647	269.050	0.032	70.283	273.566	1058.681	3222.666
FISH	5.871	4.025	10.330	10.753	16.249	25.104	19.536	22.093	15.994		10.252		60.034	0.576
POW	273.507	212.481	523.661	543.605	768.111	1046.365	733.535	780.195	547.422	14.719	262.556		58.727	5472.081
FUEL	59.566	31.769	124.085	136.413	168.131	252.583	199.912	282.560	258.129	0.036	0.904	77.558		16.763
MISC	12889.329	8431.928	25488.591	28387.800	40672.167	64598.680	51352.045	64203.305	56161.559	15873.119	62796.792	73635.366	70199.763	247167.900
AIRT	104.207	47.986	162.262	185.762	266.498	468.906	389.837	582.352	683.021	122.976	96.232	56.927	1191.229	915.842
RAILT	6.814	2.887	8.767	10.369	16.557	31.694	26.978	41.121	52.318	11.756	84.537	46.473	151.951	18.162
WTRT	15.700	7.050	23.327	26.889	39.519	71.043	59.428	89.411	107.533	5.665	29.566	4.764	255.477	19.530
TRKT	69.747	34.222	158.096	185.662	263.143	444.511	374.800	493.280	474.652	55.108	143.270	498.265	977.997	3.177
Z1TRIP	1.425	1.425	2.245	2.518	4.156	5.248	4.429	3.610	2.245					4.445
Z2TRIP	1.425	1.425	2.245	2.518	4.156	5.248	4.429	3.610	2.245					4.445
Z3TRIP	1.425	1.425	2.245	2.518	4.156	5.248	4.429	3.610	2.245					4.445
Z4TRIP	1.425	1.425	2.245	2.518	4.156	5.248	4.429	3.610	2.245					4.445
Z5TRIP	1.425	1.425	2.245	2.518	4.156	5.248	4.429	3.610	2.245					4.445
Z1QUAL	1.480	1.480	2.331	2.615	4.317	5.451	4.600	3.749	2.331					4.617
Z2QUAL	1.480	1.480	2.331	2.615	4.317	5.451	4.600	3.749	2.331					4.617
Z3QUAL	1.480	1.480	2.331	2.615	4.317	5.451	4.600	3.749	2.331					4.617
Z4QUAL	1.480	1.480	2.331	2.615	4.317	5.451	4.600	3.749	2.331					4.617
Z5QUAL	1.480	1.480	2.331	2.615	4.317	5.451	4.600	3.749	2.331					4.617
LAB														
CAP														
INDT														
HHD1										1983.467	460.946	9777.812		
HHD2										3486.511	786.640	3359.516		
HHD3										8964.193	2040.603	8897.077		
HHD4										8518.062	1946.768	8508.436		
HHD5										10668.412	2437.109	8441.793		
HHD6										13137.242	2990.325	10070.801		
HHD7										8811.628	2018.103	5392.863		
HHD8										8857.370	2080.696	3967.199		
HHD9										8575.224	2257.382	8245.741		
FGOV	-380.486	-215.961	-966.624	-705.658	111.002	3272.277	4795.064	7745.262	22688.125	8406.306		31586.803		
SGOV	118.442	39.792	229.408	329.931	776.324	1684.020	1790.463	2585.543	4309.143	16788.020	28996.966	7664.413		
INV								54.926	20907.657	0.000		13038.919	51553.283	
FT	568.202	429.486	1325.671	1508.172	2275.737	3863.804	3124.202	3802.502	3282.845	1452.000	1447.388	6888.303		
DT	-568.202	-429.486	-1325.671	-1508.172	-2275.737	-3863.804	-3124.202	-3802.502	-3282.845	-1452.000	-1447.388	-5405.921		

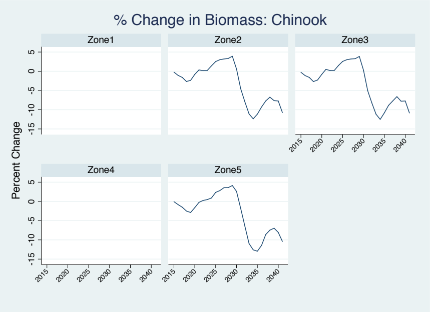
Biomass Charts: Individual Species

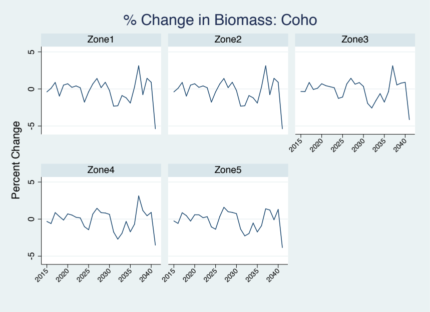




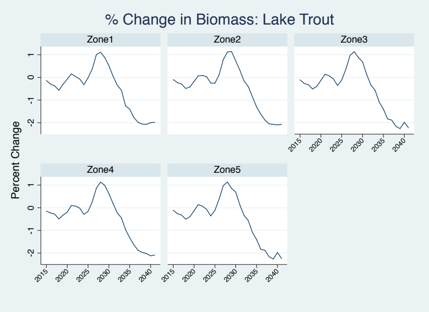
SSB NOSSB

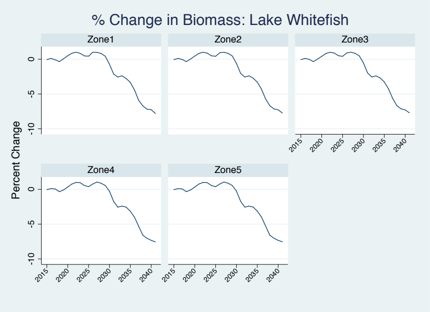
Biomass Charts: Individual Species



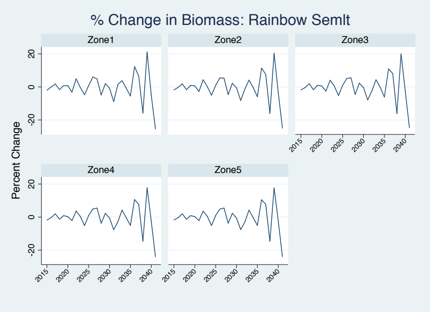


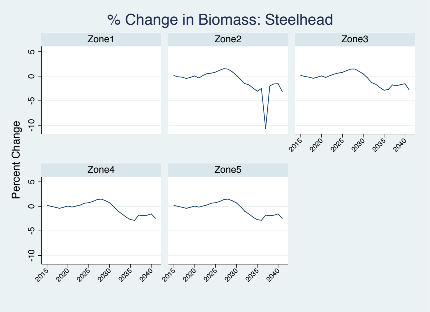
Biomass Charts: Individual Species



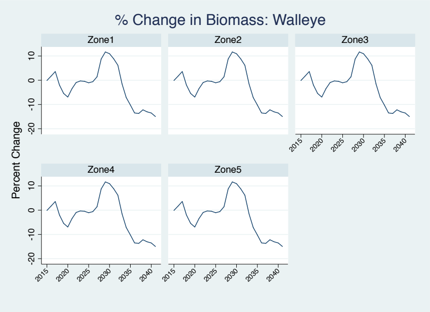


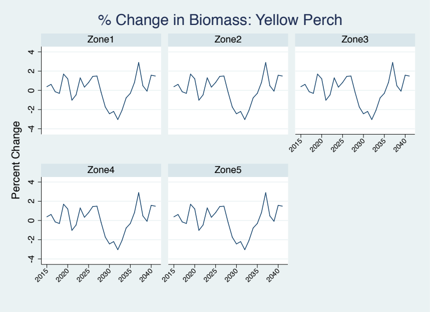
Biomass Charts: Individual Species



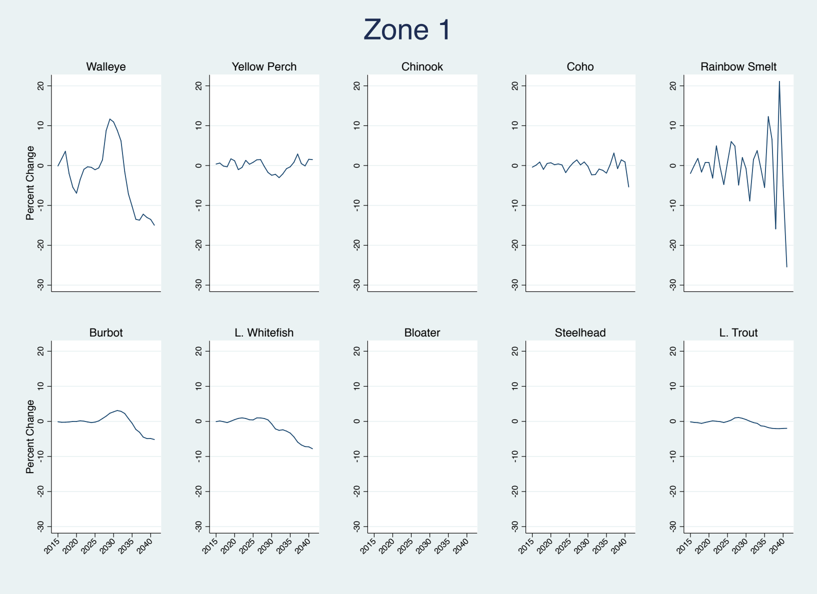


Biomass Charts: Individual Species



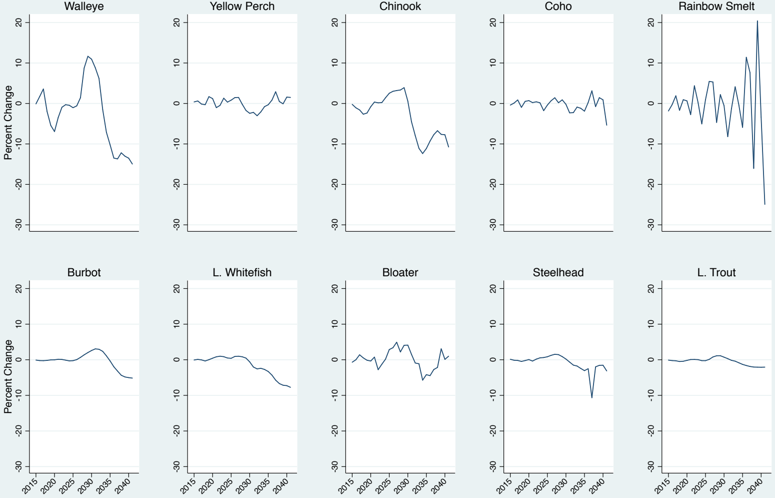


Biomass Changes By Zone

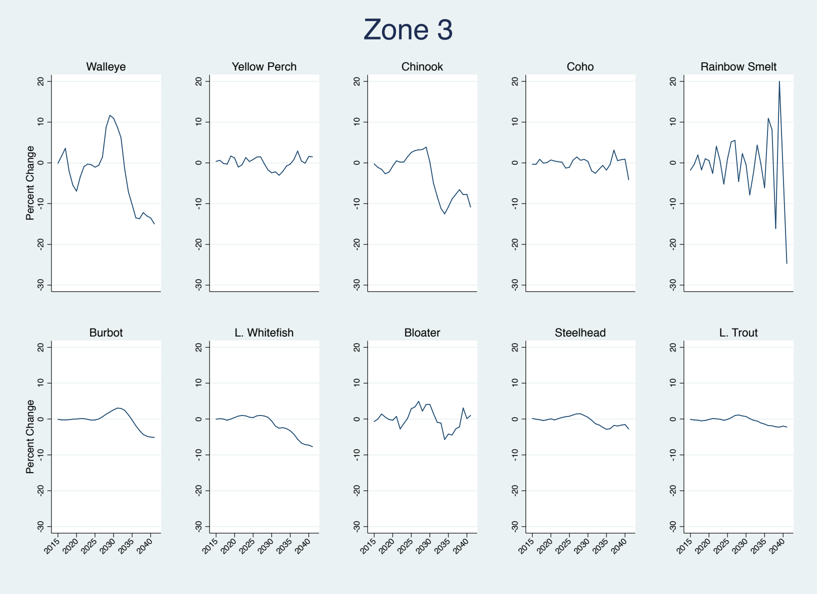


Biomass Changes By Zone

Zone 2



Biomass Changes By Zone



Biomass Changes By Zone

Biomass Changes By Zone

Ecological Web