Network3D Simulation Engine

CSC 631/831

Science Discovery Game for Ecological Research

Introduction

- www.foodwebs.org
- https://www.youtube.com/watch?v=us6UQqrGXMg

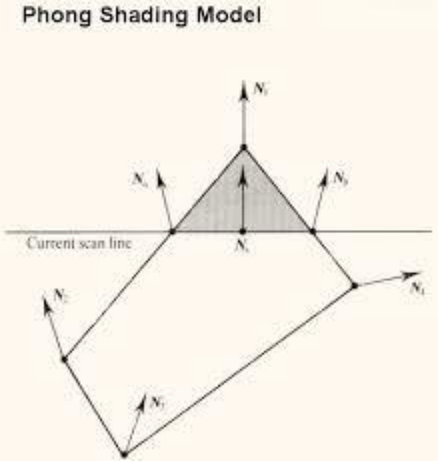
Scientists have long strived to simplify and abstract nature into fundamental categories and statements that could yield understanding of, and predictive insight into, the phenomena they study. Only a few of such abstractions survive the test of time and continue to yield both broad and deep scientific insights.

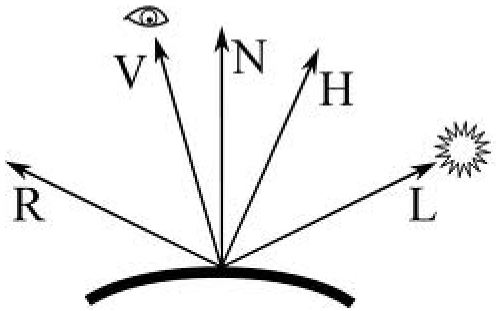
Mission of Ecology Computation Model

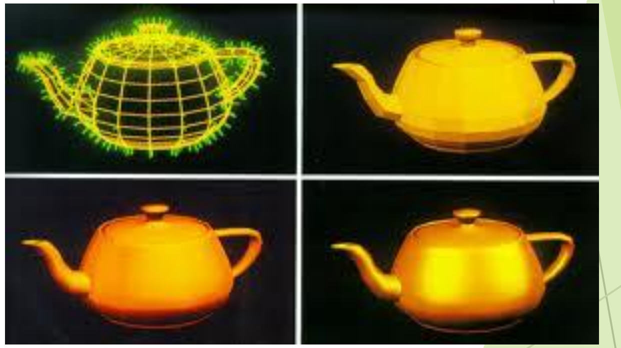
- Maximum correspondence with nature and empirical tractability combined with minimal complexity.
- **Abstractions based on the fewest but most useful and easily measured parameters** in order to minimize the costs of complexity while trying to model it.

Phong shading (1973) Simplified Simulation of physical illumination

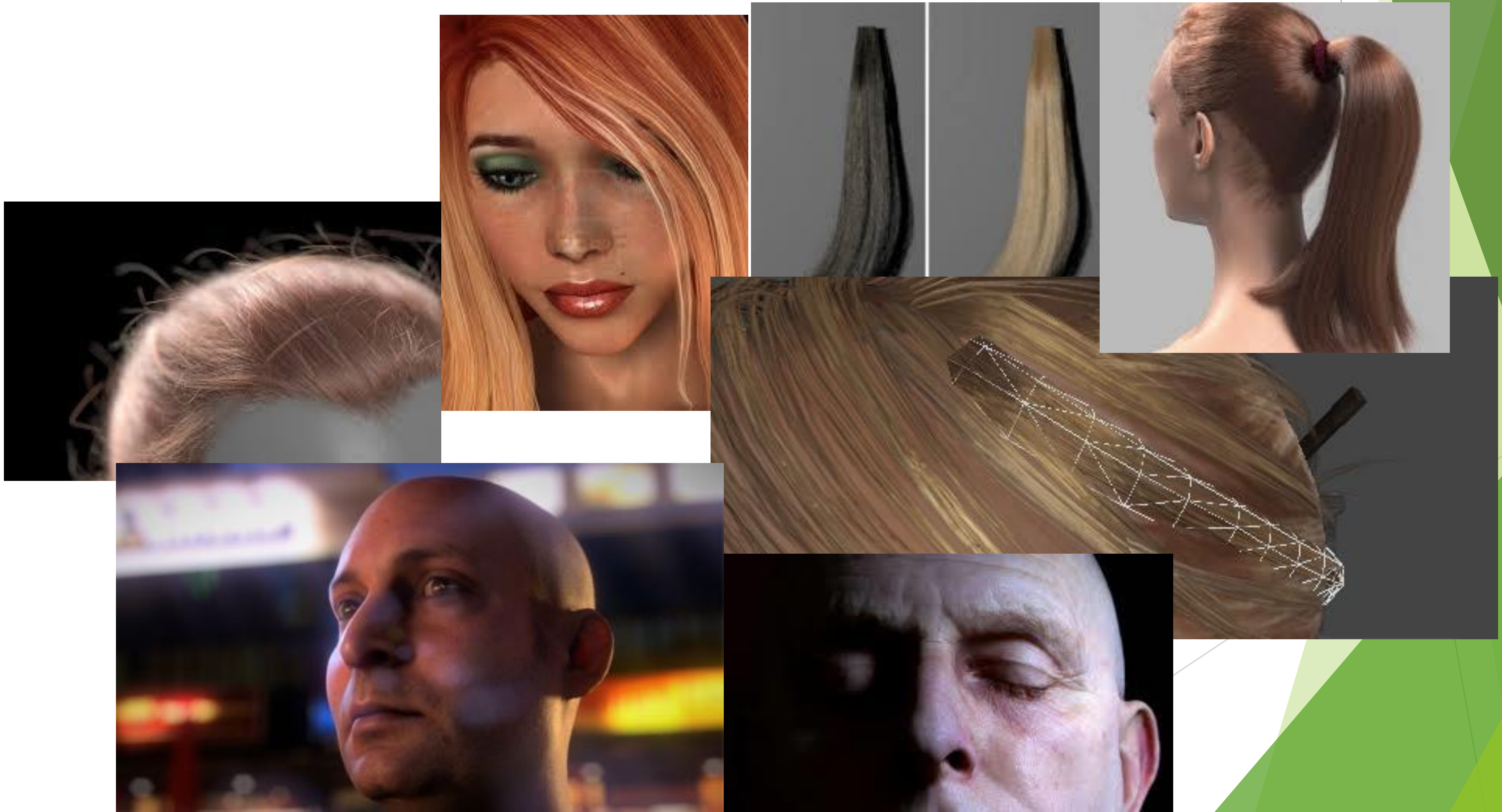
$$I_p = k_a i_a + \sum_{\text{lights}} (k_d (L \cdot N) i_d + k_s (R \cdot V)^{\alpha} i_s).$$





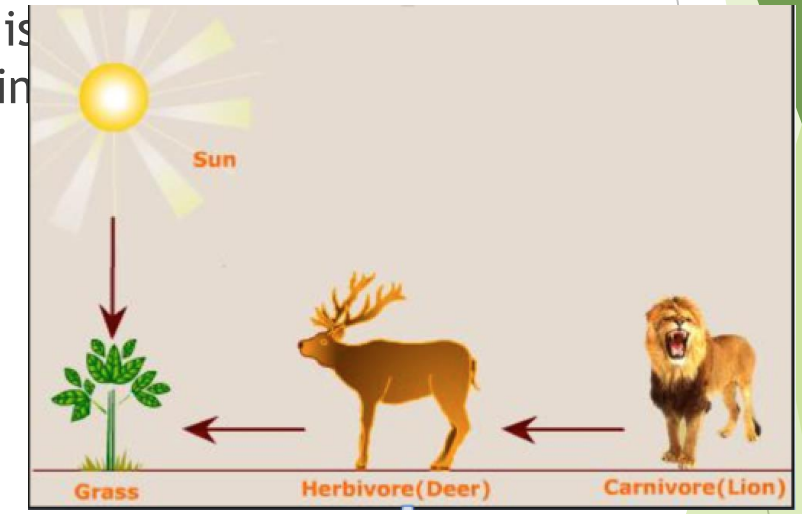


Illumination has been advanced….



Food Chain

- Food web is the interconnection of food chains
- Trophic level (feeding) of the organism is the position it occupies in the food chain
- Energy flow between prey - predator



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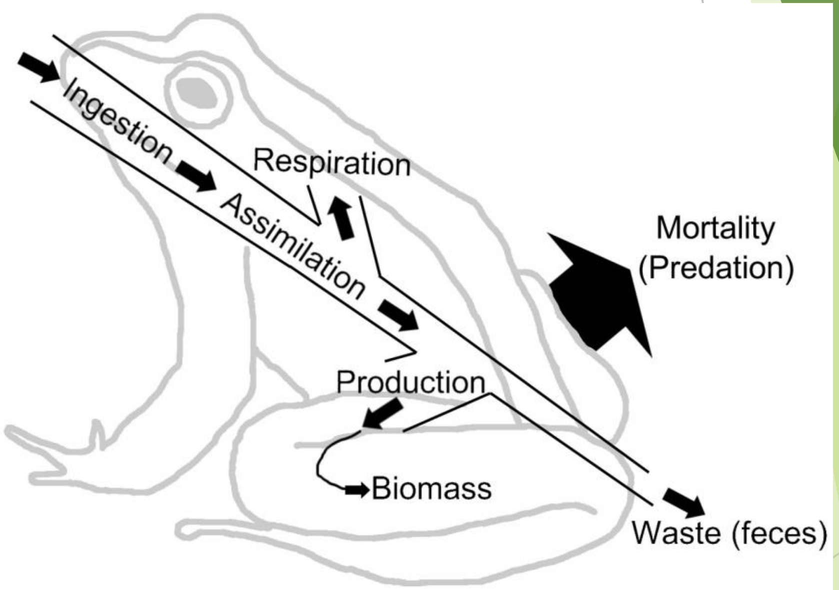
Energy flow in food web

- Energy ingested is utilized for metabolic process and transformed into **biomass**
- Frog is ingested by predators and energy flow continues
- Energy is lost duringmetabolic process



Source: https://upload.wikimedia.org/wikipedia/commons/5/52/EnergyFlowFrog.jpg Last accessed Nov 15

Equations for population dynamics model

For primary producers i

$$\frac{\mathrm{d}B_i}{\mathrm{d}t'} = \underbrace{r_i B_i \hat{G}_i(B)}_{\text{term 1}} - \underbrace{\sum_{j=\text{predators}} x_j y_{ji} B_j \hat{F}_{ji}(B)/f_{eji} e_{ji}}_{\text{term 2}}$$

- term 1: The first term is gain in biomass due to growth.
- term 2: The second term is the loss in biomass due to predation. The denominator in the predation term, fractional value eji, and controls how much loss there is in addition to the biomass gained by the predator(s).

Equations for population dynamics model (Contd)

For consumers it is given

$$\frac{dB_i}{dt'} = \underbrace{-x_iB_i}_{\text{term 1}} + x_iB_i \underbrace{\sum_{j=\text{prey}} y_{ij}\hat{F}_{ij}(B)}_{\text{term 2}} - \sum_{j=\text{predators}} \underbrace{x_jy_{ji}B_j\hat{F}_{ji}(B)/f_{eji}e_{ji}}_{\text{term 3}}$$

- term 1: The first term is loss in biomass due to metabolism.
- term 2: The second term is the gain in biomass due to consumption.
- term 3: The third term is loss in biomass due to predation by other species. The denominator in the predation term, fractional value eji, and controls how much loss there is in addition to the biomass gained by the predators(s).

2009 *PNAS* 106:187-191

Application: Species loss

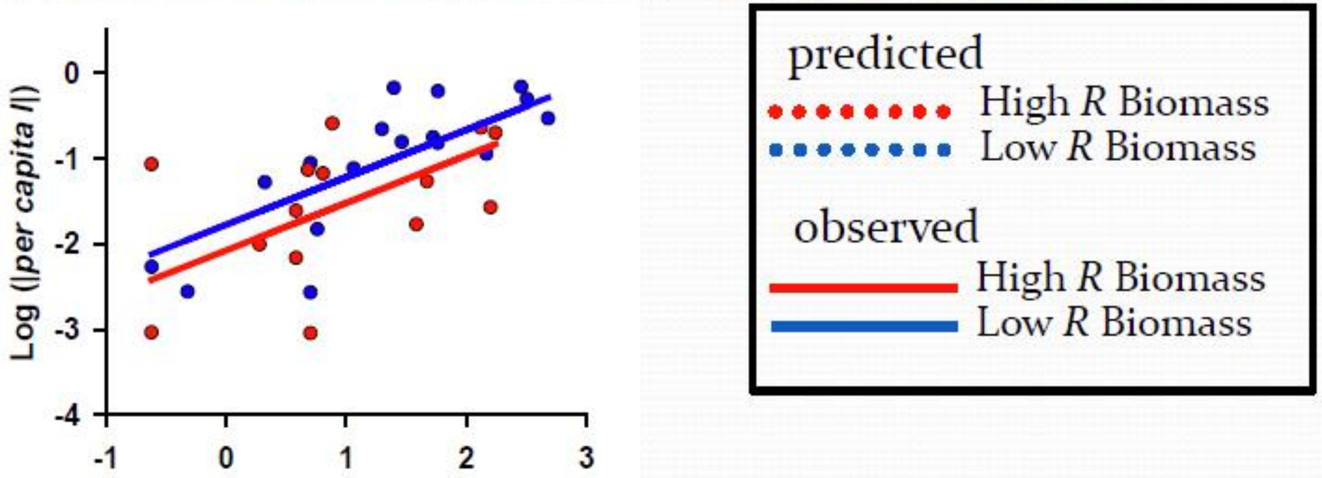
PNAS

Simple prediction of interaction strengths in complex food webs

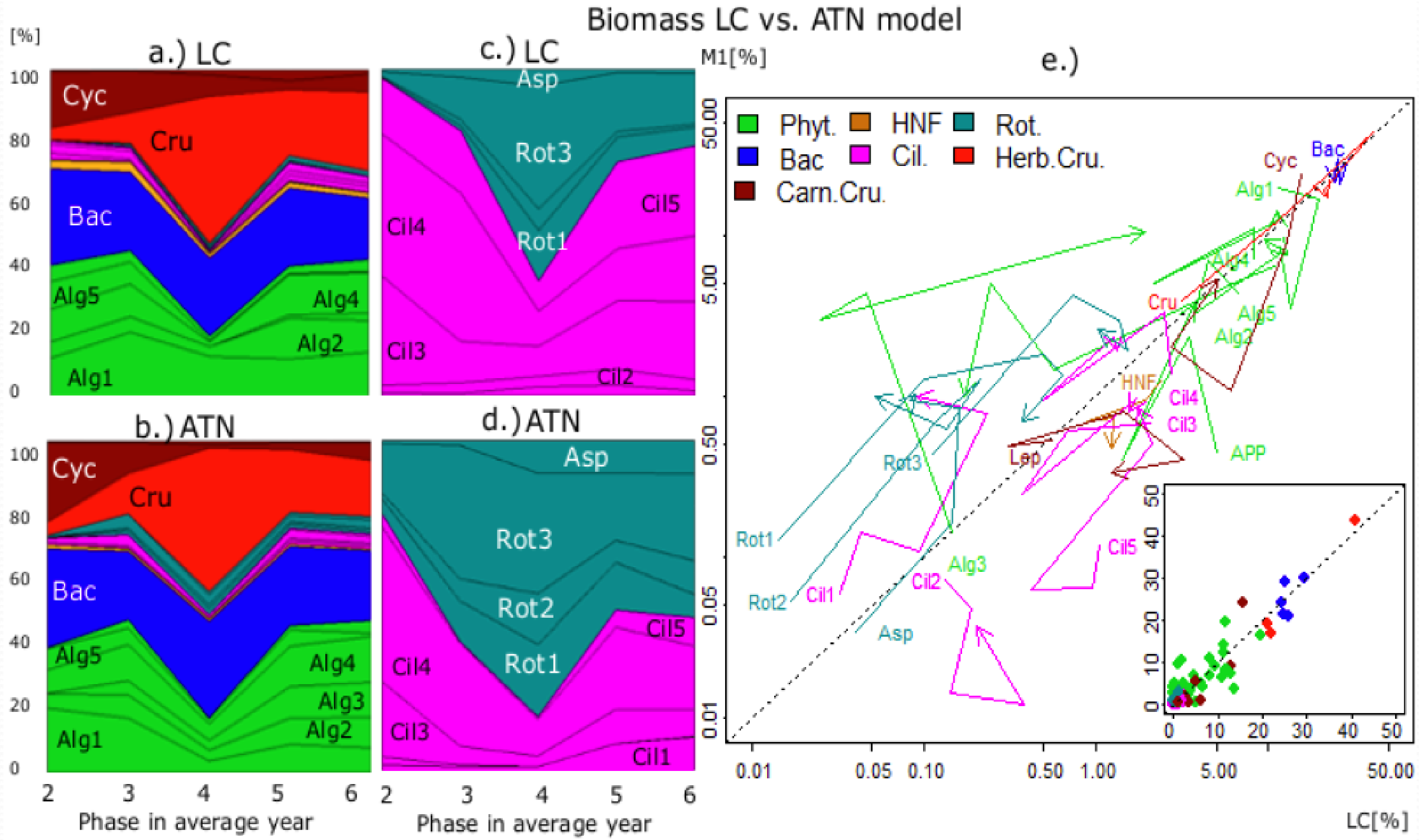
Eric L. Berlow[a,b,c,1,2], Jennifer A. Dunne[c,d], Neo D. Martinez[c], Philip B. Stark[e], Richard J. Williams[c,f], and Ulrich Brose[b,c,2]

[a]University of California, Merced, Sierra Nevada Research Institute, Wawona Station, Yosemite National Park, CA 95389; [b]Darmstadt University of Technology, Department of Biology, Schnittspahnstrasse 10, 64287 Darmstadt, Germany; [c]Pacific Ecoinformatics and Computational Ecology Lab, 1604 McGee Ave., Berkeley, CA 94703; [d]Santa Fe Institute, 1399 Hyde Park Road, Santa Fe, NM 87501; [e]University of California Berkeley, Department of Statistics, Berkeley, CA 94720-3860; and [f]Microsoft Research Ltd, 7 J. J. Thomson Avenue, Cambridge CB30FB United Kingdom

Edited by Simon A. Levin, Princeton University, Princeton, NJ, and approved November 10, 2008 (received for review July 15, 2008)



Lake Constance Biomass: Model-Data Similarity = 0.82

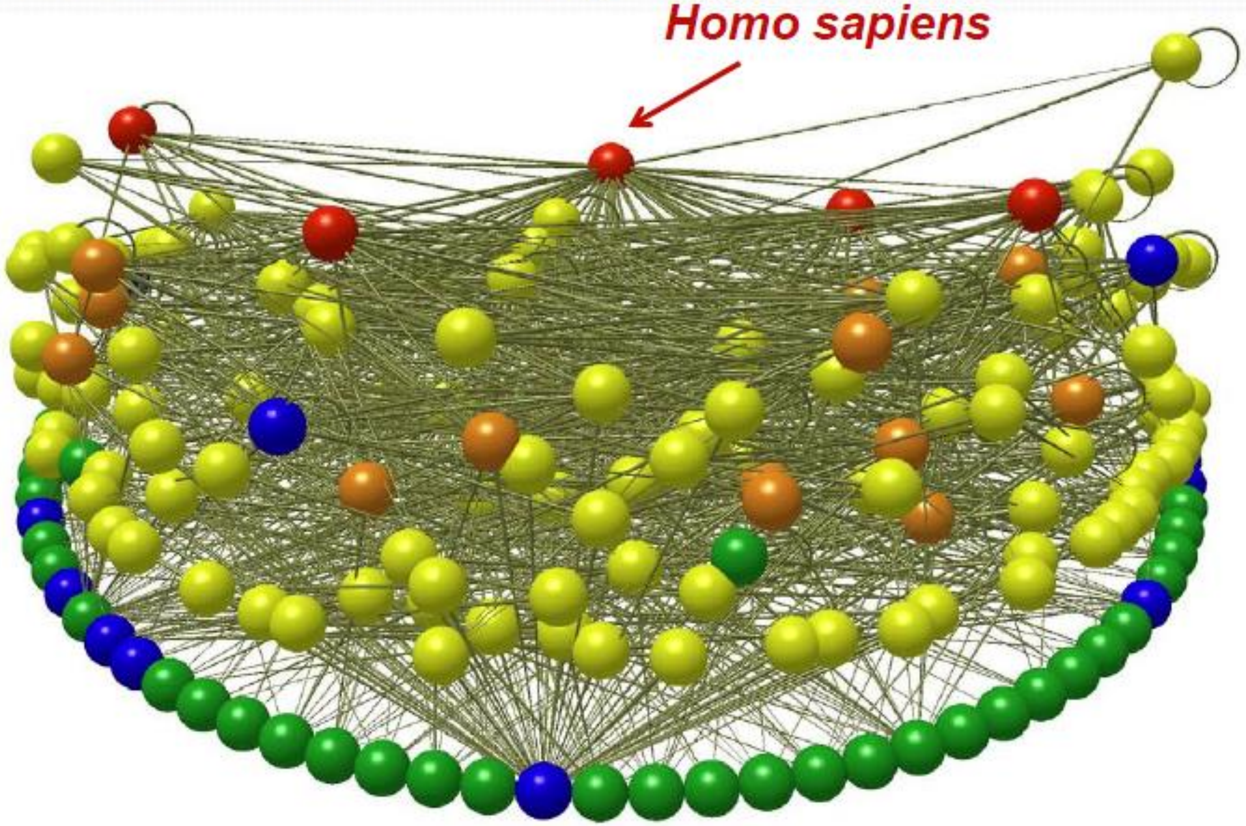


Allometric Trophic Network (ATN) model

- ATN models
  - feeding (trophic) interactions
  - population dynamics
  - Allometric scaling
  - Functional Response
- The predator/prey relationships in a food web, initial biomass of each species and system parameters are provided as input
- Prediction results (biomass) over a period of time
- Uses a set of differential equations developed by Yodzis and Innes 1992, extended by Williams & Martinez 2004; Williams et al. 2007; Boit et al. 2012

Forecasting Example: Humans

- Coupled Human-Natural Networks
- Aleuts on the Sanak Archipeligo



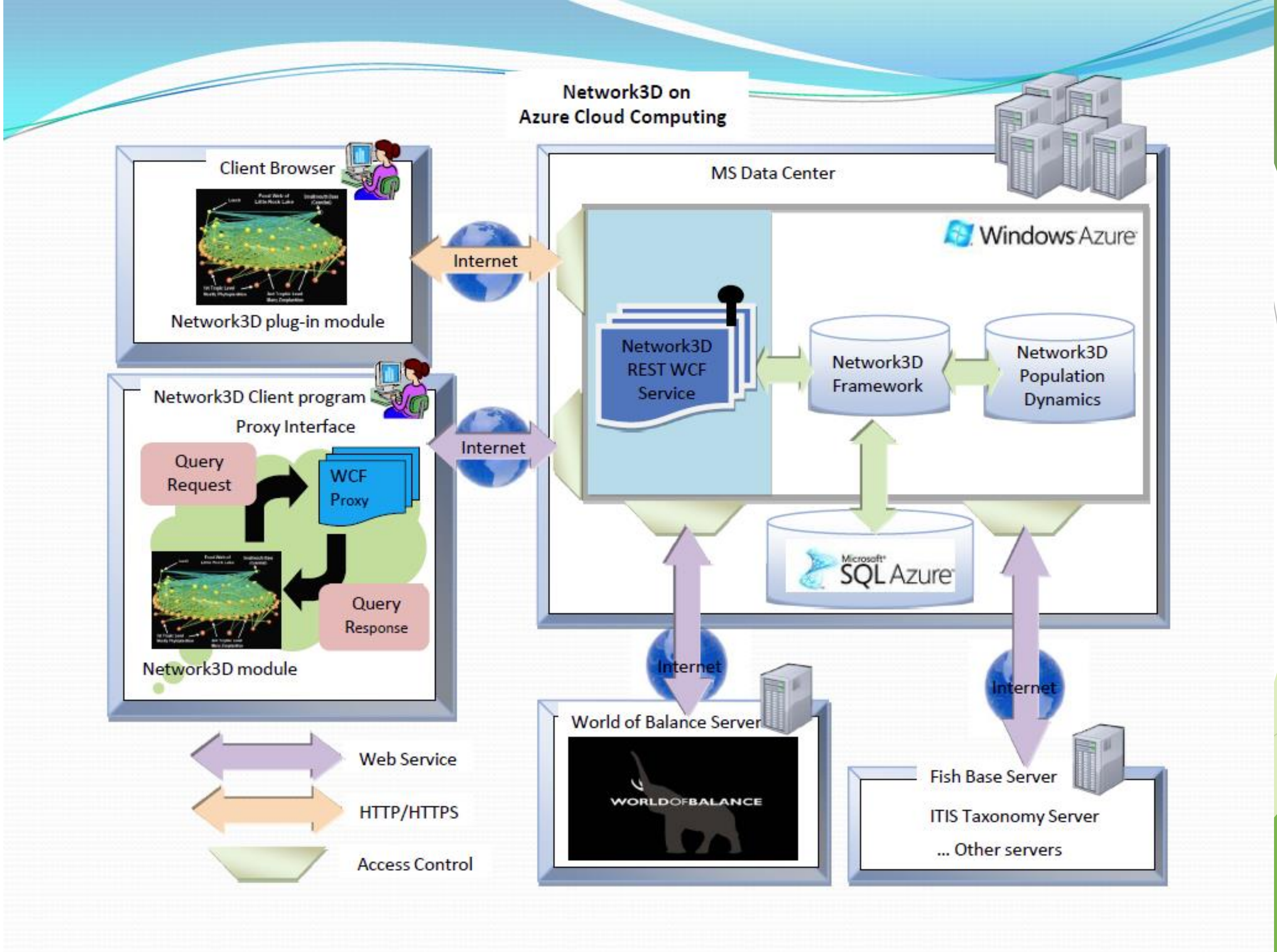
Martinez, Tonin, Bauer, Rael, Singh, Yoon, Yoon & Dunne *AAAI2012*

Forecasting Example: Fisheries

- $\dot{E} = \mu \ (pqB_i - c_o) \ E$
  - E is fishing effort for species I
  - p is the price per unit catch
  - q is the "catchability coefficient",
  - B_i is the biomass density of exploited species i,
  - c_o is the cost per unit effort,
  - μ is market openness

  - E increases with profit
  - E decreases with loss

Martinez, Tonin, Bauer, Rael, Singh, Yoon, Yoon & Dunne *AAAI2012*



Network3D on
Azure Cloud Computing
Client Browser
Network3D plug-in module
Internet
MS Data Center
Windows Azure
Network3D
REST WCF
Service
Network3D
Framework
Network3D
Population
Dynamics
Network3D Client program
Proxy Interface
Query
Request
WCF
Proxy
Query
Response
Network3D module
Internet
SQL Azure
Internet
Internet
World of Balance Server
WORLDOFBALANCE
Fish Base Server
ITIS Taxonomy Server
... Other servers
Web Service
HTTP/HTTPS
Access Control

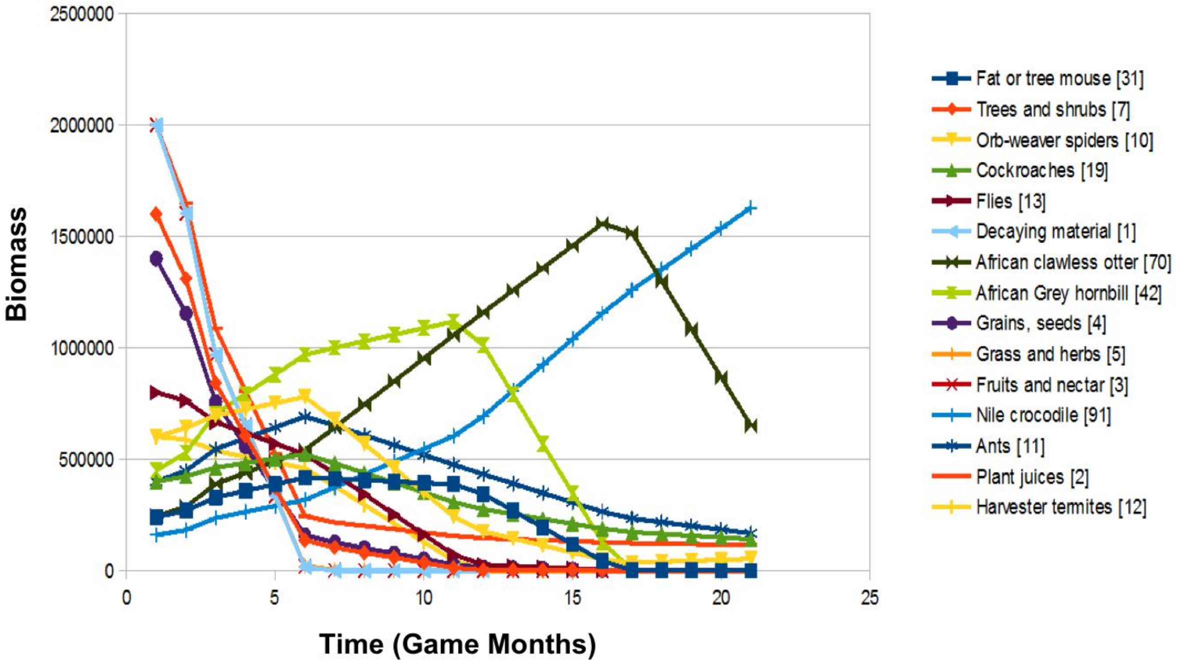
WoB: World of Balance

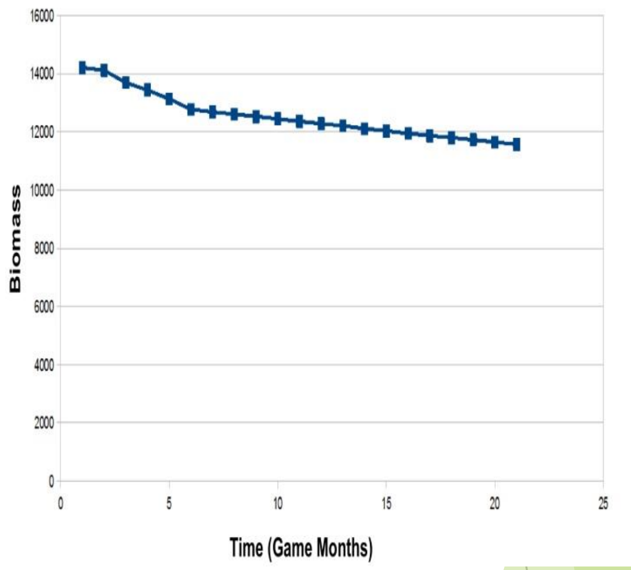
http://smurf.sfsu.edu/~debugger/wb/guide_user_interface.php

World of Balance
Menu
1 Players Online
Year 1
October
Environment Score
11,089
Top Scores
High Score
wbuser14 - 29989
wbuser9 - 29696
wbuser2 - 26344
Total Score
wbuser8 - 442828
wbuser2 - 417492
wbuser14 - 409442
Current Score
wbuser17 - 19816
wbuser10 - 17561
wbuser16 - 17224
Zone Species Count
902 Big Tree 5
902 Cape Teal 5
902 Dwarf Puddle Frog 1
902 Flies 1
902 Maasai Giraffe 3
902 Oribi 3
902 Tree Mouse 1
YY:MM Species Activity Count
Cape Teal Purchase 5
African Elephant Purchase 5
Oribi Purchase 3
Maasai Giraffe Purchase 3
1:9
Big Tree Birth 50
1:8
Tree Mouse Eaten 1
Big Tree Birth 1
1:7
Level 10
1,400 / 7,450
5,494 G

World of Balance
Menu
1 Players Online
Year 1
June
Environment Score
5,641
Your Scores
High Score
11034
Total Score
41991
Current Score
5641
Charts
# of Organisms
Flies
Tree Mouse...
Dwarf Pudd...
Fruits and...
Trees and ...
Grains and...
Plant Juic...
Hide All
Month
Jan '01
Feb '01
Mar '01
Apr '01
May '01
Jun '01
Stats
Charts
Params
Acacia
Big Tree
Boabab
Grass an...
Level 10
XP
1,861 / 7,450
4,594 G
Send

Selection of Initial Species and biomass allocation
Environment Score Changes over time

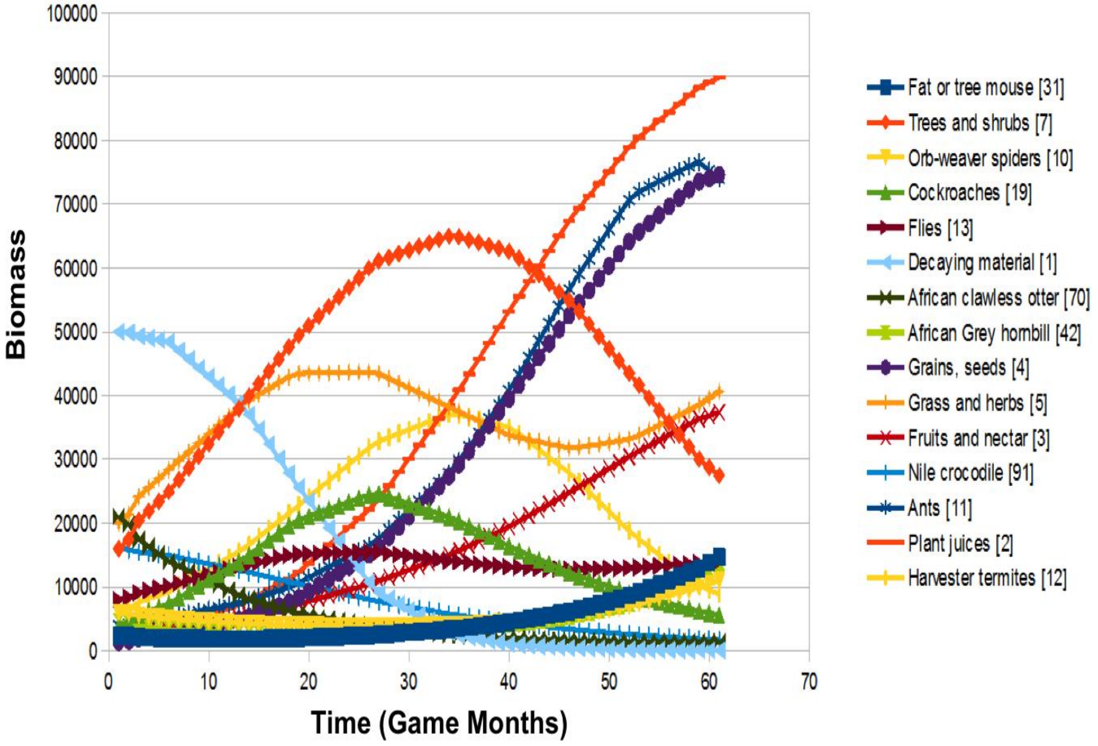




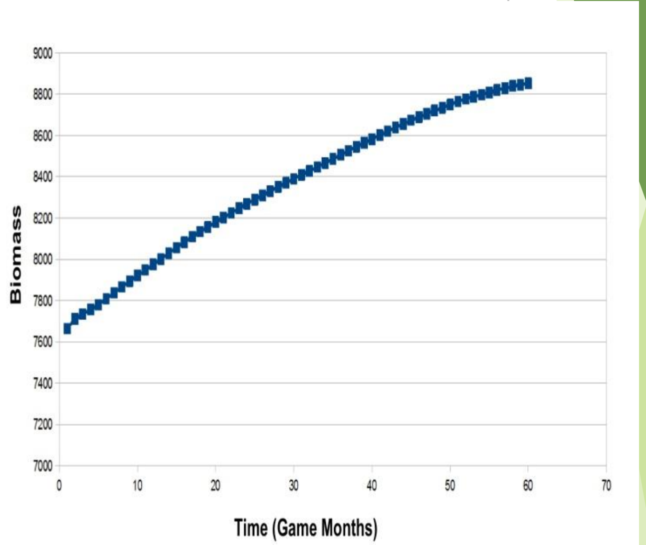
Ecosystem with same 15 species, but different starting biomass and parameters. Not a good gameplay as species are quickly dying out.

Corresponding Environment Score chart for an ecosystem with 15 species, not so good case.

Selection of Initial Species and biomass allocation
Environment Score Changes over time

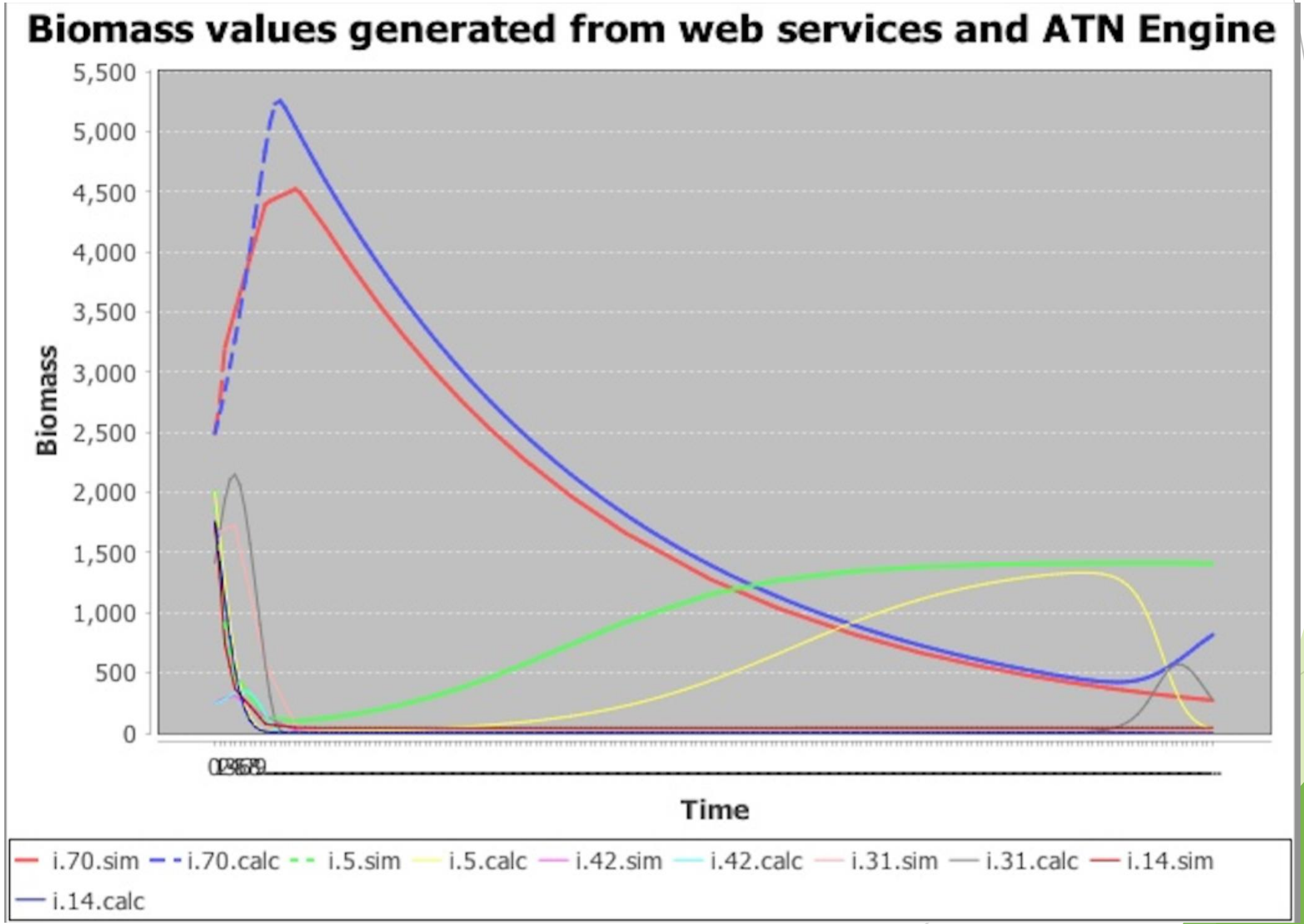


Ecosystem with 15 species without user intervention

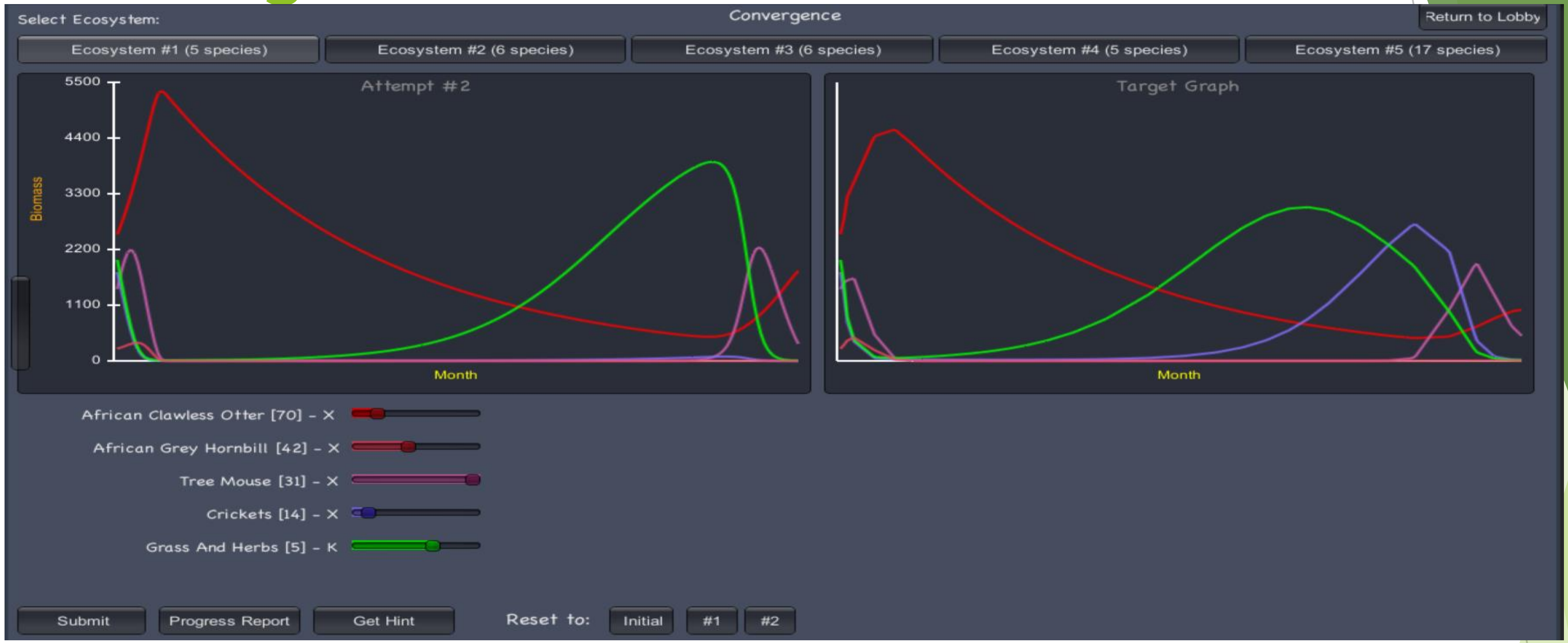


Corresponding Environment Score chart for an ecosystem with 15 species

Integration of Jfree Chart Charting Library



Convergence Game



- “Default” ecosystem with known parameter values
- “Target” ecosystem with unknown parameter values
- Visually compare the target ecosystem’s species biomass generated over time against the default ecosystem’s biomass data over time
- Changes to the parameter values for each species
- Parameters are submitted of an ecosystem to the ATN Engine
- ATN Engine performs the simulations for the configurations
- Results are sent back to the client to display the target ecosystem

Game Terminology

- World - A World represents a type of ecosystem. In our game the world represents the Serengeti ecosystem.
- Zone - A Zone is an area of land in a World. A World is divided into multiple Zones.
- Ecosystem - The Ecosystem class is used to store information about a specific section of an Environment such as species residing in this zone.
- Lobby - Lobbies are menu screens where players can inspect the upcoming game session, examine the results of the last, change their settings, and talk to each other.

Basic Functions of ATN Model

- 1) Species invasion (Add New species)
- 2) Species proliferation (Increase Biomass of existing species)
- 3) Species exploitation (Delete species)
- 4) Species removal/reduction (Decrease Biomass of existing species)
- 5) Updating the system parameters (Both the node and link parameters – Note: A provision is provided for link parameter though it has not been tested)

Simulation Engine, IN3DService

- For our game, we have Serengetti Food web
  - http://smurf.sfsu.edu/~wob/guide/species.php
  - Note: There are species that are eaten by lots of species
  - There are species that eat lots of species
- For each sub game, we create sub Food web
- Simulation vs/ Manipulation
  - One simulation attempt is called manipulation

Simulation Engine Wrappers.

createATNServices	The method in the EcosystemController class used to create the unique ATN manipulation Id.
createEcosystem	The method in the EcosystemController class used to create the ecosystem if it wasn’t already created
startEcosystem	The method in the EcosystemController class used to start the ecosystem by loading data from database
initializeSpecies	The method in the GameEngine class is used to create a SpeciesZoneType of object and add it to the ZoneNodes class of the ecosystem.

Simulation Engine Wrappers.

runSimulation	The method in the GameEngine class that is used run the simulation for the species in the ecosystem
updatePrediction	The method in the GameEngine class that is used to analyze the data from pre and post simulation.
createPurchaseBySpecies	The method in GameEngine class that is called when biomass is varied or a species is purchased or added.
removeSpeciesFromZone	The method in GameEngine class that is called when a species node is to be removed from ecosystem.
run	The method in the ATNPredictionRunnable class that is used to getPrediction results and updatePrediction results.

Simulation Engine Wrappers.

getPrediction	The method in the ATNEngine class to run simulations for the specified timesteps.
constructNodeConfig	The method in the ATNEngine class to assemble the node configuration to submit to the ATN Engine.
setSystemParameters	The method in the ATNEngine class to append the system parameters.
setSystemParametersNode	The method in the ATNEngine class to create an individual node parameter type.
setSystemParametersLink	The method in the ATNEngine class to create an individual link parameter type.
updateBiomass	The method in the ATNEngine class to persist the latest biomass to the database.

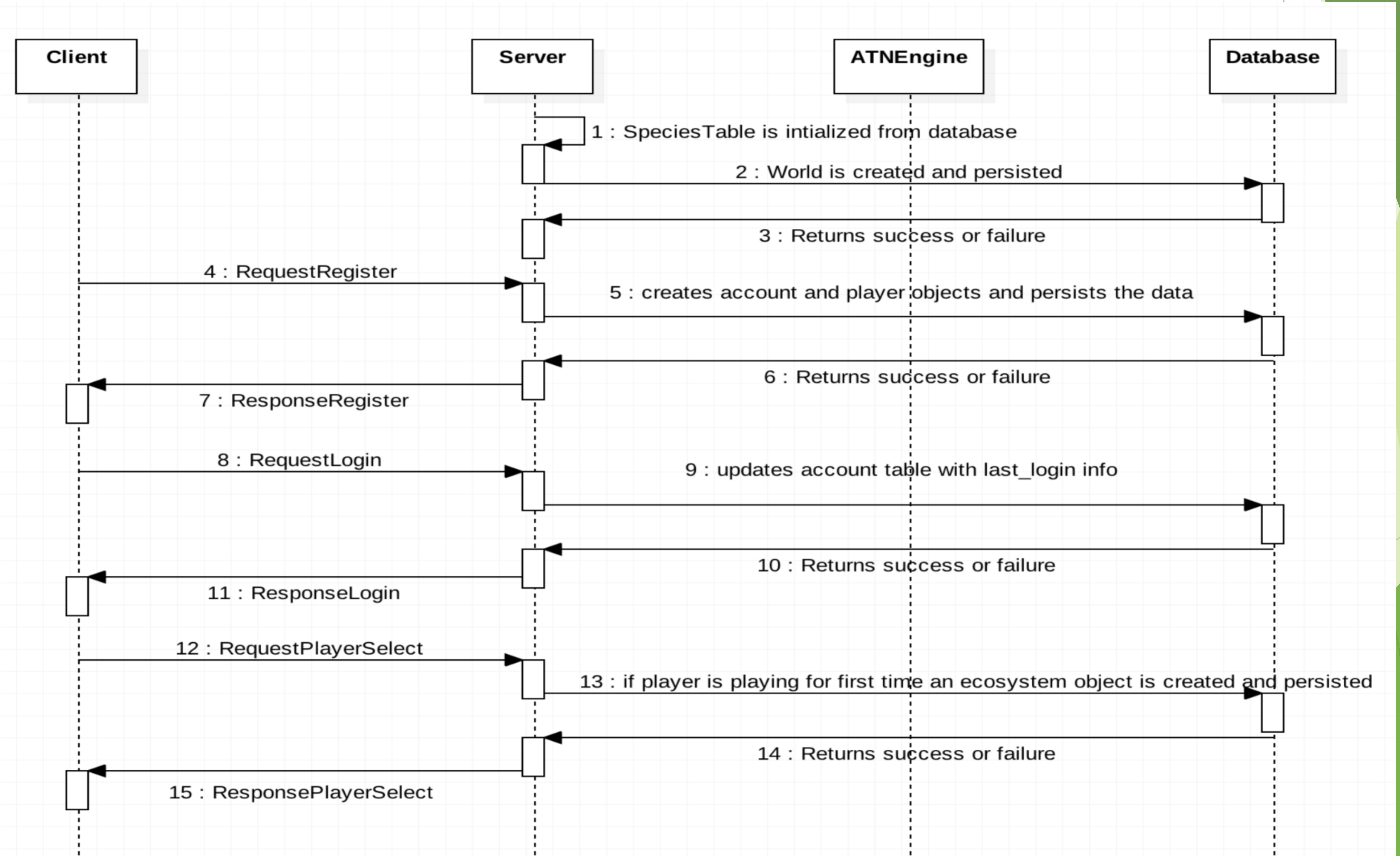
createATNServices method in EcosystemController class

```
private static void createATNServices(Ecosystem ecosystem, Map<Integer, Integer> nodeBiomassList) {
                Log.println("Creating ATN Engine ...");
                ATNEngine atnEngine = new ATNEngine();
                if(ecosystem.getATNManipulationID() == null){
                        String atnManipId = UUID.randomUUID().toString();
                        ecosystem.setATNManipulationID(atnManipId);
                }

    // Update Zone Database
    EcosystemDAO.updateATNManipulationID(ecosystem.getID(), ecosystem.getATNManipulationID());
    // Initialize Biomass and Additional Parameters
    List<SpeciesZoneType> mSpecies = new ArrayList<SpeciesZoneType>();
    for (Entry<Integer, Integer> entry : nodeBiomassList.entrySet()) {
        int node_id = entry.getKey(), biomass = entry.getValue();
        mSpecies.add(atnEngine.createSpeciesZoneType(node_id, biomass));
    }

    // First Month Logic
    for (SpeciesZoneType szt : mSpecies) {
        int species_id = ServerResources.getSpeciesTable().getSpeciesTypeByNodeID(szt.getNodeIndex()).getID();
        //Will write the values into 'eco_species' table
        EcoSpeciesDAO.createSpecies(ecosystem.getID(), species_id, (int) szt.getCurrentBiomass());
    }
}
```

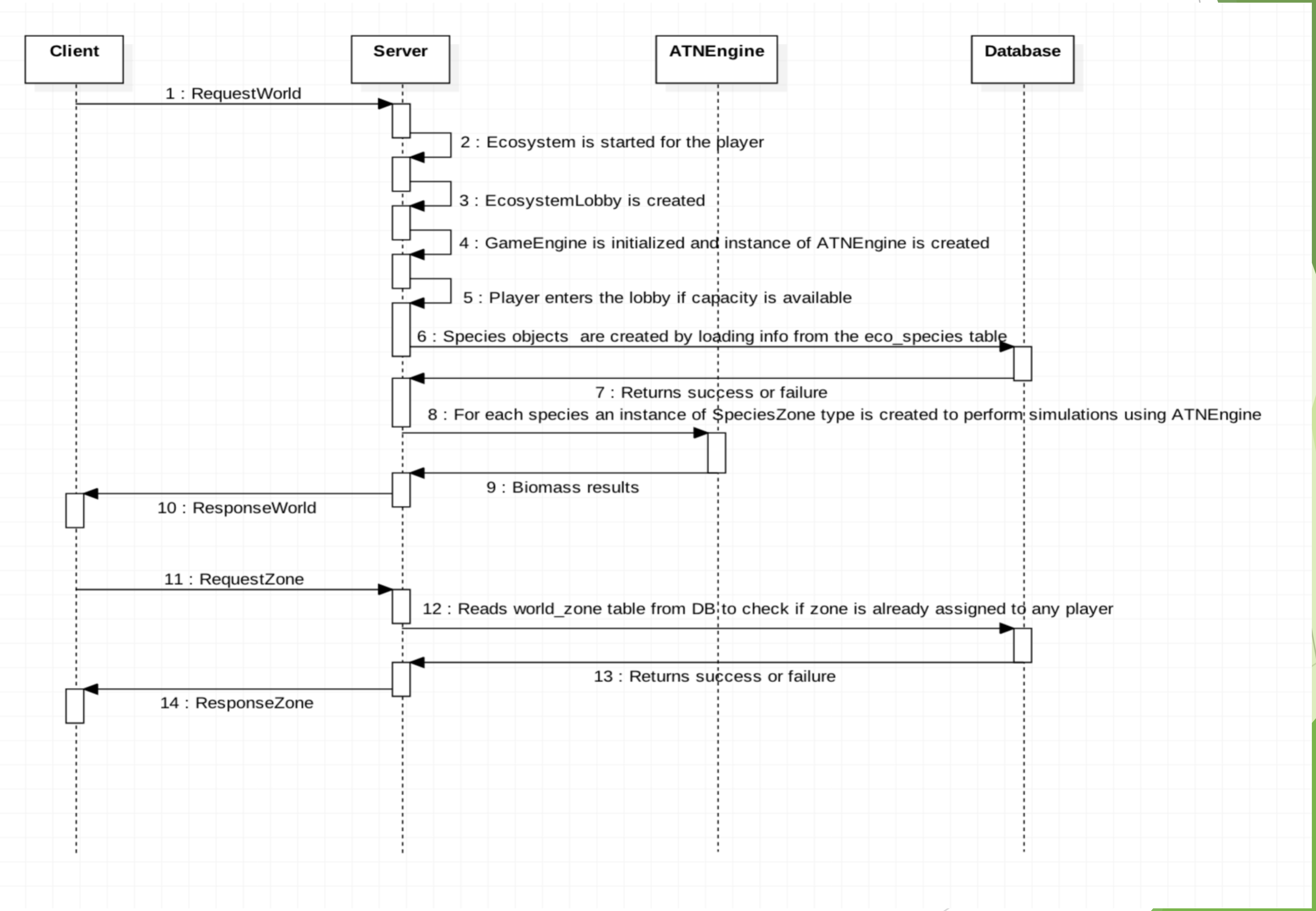
‘createEcosystem’ method of EcosystemController class

```
public static void createEcosystem(Ecosystem ecosystem, Map<Integer, Integer> speciesList) {
    // Map Species IDs to Node IDs
    Map<Integer, Integer> nodeBiomassList = GameFunctions.convertSpeciesToNodes(speciesList);
    if(Constants.useAtnEngine){
        createATNServices(ecosystem, nodeBiomassList);
    }
        if(Constants.useSimEngine){
                // Perform Web Services
                createWebServices(ecosystem, nodeBiomassList);
        }
    // Update Environment Score
    double biomass = 0;

    for (Map.Entry<Integer, Integer> entry : speciesList.entrySet()) {
        SpeciesType speciesType = ServerResources.getSpeciesTable().getSpecies(entry.getKey());
        biomass += speciesType.getBiomass() * Math.pow(entry.getValue() / speciesType.getBiomass(), speciesType.getTrophicLevel());
    }

    if (biomass > 0) {
        biomass = Math.round(Math.log(biomass) / Math.log(2)) * 5;
    }

    int env_score = (int) Math.round(Math.pow(biomass, 2) + Math.pow(speciesList.size(), 2));
    ScoreDAO.updateEnvironmentScore(ecosystem.getID(), env_score, env_score);
    // Generate CSVs from Web Services
    if(Constants.useSimEngine){
        createCSVs(ecosystem);
    }
    // Logging Purposes Only
    {
        String tempList = "";
        for (Entry<Integer, Integer> entry : speciesList.entrySet()) {
            tempList += entry.getKey() + ":" + entry.getValue() + ",";
        }
        LogDAO.createInitialSpecies(ecosystem.getPlayerID(), ecosystem.getID(), tempList);
    }

}
```

Game Server Initialization Events



Events during RequestWorld



Can game players reproduce the similar or better results?

- Game players will test this hypothesis through two types of quests that will be developed in Farmville (Quest 1.1) and Jenga style (Quest 1.2) formats.
  - In Berlow's simulation, 600 networks were used ranging from 10-30 species with varied species, link and network attributes and were created with criteria of body size relationships and other parameters. <Quest 1>
  - Once networks are ready, then let players play Jenga style <Quest 2>
    - Removing species that affect the network least
    - Removing species that affect the network most

nature COMMUNICATIONS

ARTICLE

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DOI: 10.1038/ncomms1163

Rescuing ecosystems from extinction cascades through compensatory perturbations

Sagar Sahasrabudhe[1] & Adilson E. Motter[1,2]

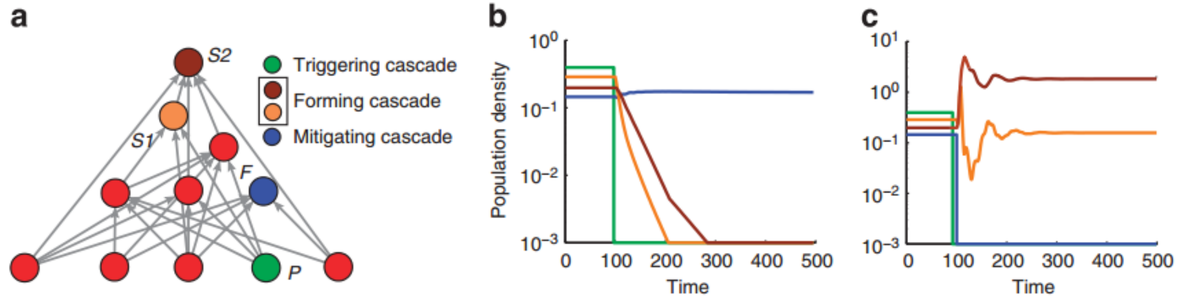


Figure 1 | Example of the impact of species removal. (**a**) The removal of a basal species, *P*, triggers a cascade that leads to the subsequent extinction of two high-trophic species, *S1* and *S2*, in this initially persistent 11-species food web. The removal of an intermediate-trophic species, *F*, shortly after the removal of *P* prevents the propagation of the cascade, and causes no additional extinctions. (**b**,**c**) The time evolution of the populations following the removal of *P* (**b**) and following the combined removal of *P* and *F* (**c**) shows that the otherwise vanishing populations of *S1* and *S2* can reach stationary levels comparable to or higher than the unperturbed ones in a time-scale of the order of the time-scale of the cascade (colour code defined in (**a**)). The long-range character of the underlying interactions is emphasized by the fact that species *F* is not directly connected to either the species triggering the cascade or the ones rescued. This food web was simulated using the consumer-resource model (Supplementary Methods).

The bioenergetic approach of Yodzis and Innes (1992)

- Two fundamental aspects of organisms as central to the modeling of their feeding interactions and population dynamics: *body size and metabolic type*.
- The relevance of **body size** to "metabolism" or the energetic maintenance cost of staying alive has recently become a spectacularly successful and currently highly active research program (Whitfield 2004). Much earlier, Yodzis and Innes (1992) realized that the combination between the biological importance and empirical ease of measuring body size made it an ideal variable to incorporate into population dynamics.
- **Metabolic type**, recognizes that all bodies are not the same and that, in particular, fundamental distinctions among plants, invertebrates and endotherm, and ecotherm vertebrates needed to be made in order for body size to reasonably predict both the metabolic and maximum assimilation rates of organisms.

In the previous equations

- Bi is the biomass of population i,
- Gi is the mass-specific net growth rate of primary producer population i and is potentially a function of the biomasses of any or even all of the populations in the system,
- Ti is the mass specific respiration rate,
- Fij is the rate of consumption of population j by population i (i.e., the rate population j loses biomass due to consumption activities of i such as herbivory, predation, infection),
- eij is an assimilation efficiency equal to the fraction of the biomass of species j lost due to consumption by species i that is actually metabolized,
- feij is ingestion efficiency equal to the fraction of biomass lost from resource j that is actually ingested by consumer i (e.g., some carnivores do not consume the whole of a kill nor do parasitoids consume all of a host).
- Assimilation efficiency is separated from ingestion efficiency because the former can theoretically be allometrically scaled while the latter is less systematic and contingent on natural history of consumption such as that between a nematode that causes a disease that kills a host and a different nematode that parasitizes a host without killing it. The former nematode has a much lower feij than the latter.

Each parameters can be further developed in terms of mass (body size)

- The mass-specific respiration rate, Ti, is given by

$$T_i = a_{Ti} M_i^{-0.25}$$

- The mass-specific maximum assimilation rate, eijJij , is given by

$$e_{ij} J_{ij} = f_{Jij} a_{Ji} M_i^{-0.25}$$

- The mass-specific maximum growth rate of a producer species is given by

$$r_i = f_{ri} a_{ri} M_i^{-0.25}$$

Population Dynamics Engines in WoB

- Network3D Web services (Pacific Ecoinformatics and Computational Ecology Lab)

+

Simulation Engine – set of wrappers for the Web Services

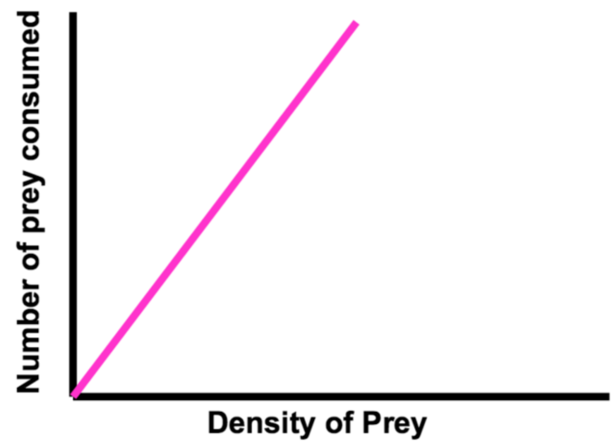
- ATN Model (Proceedings of the National Academy of Sciences, 106(1): 187-191, 2009) (Implementation by Justina Cotter)

+

ATN Engine – set of wrappers for the ATN Model

Type I functional response

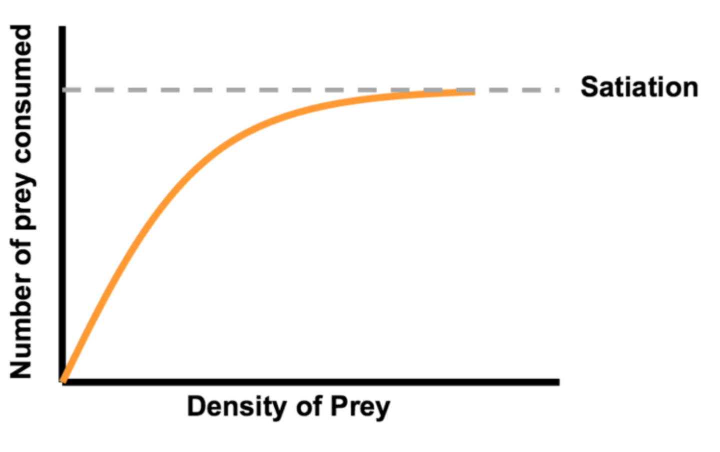
- Also known as the “Lotka-Voterra” functional response
- Assumes that the per capita consumption does not saturate at high prey densities, which causes an infinite linear increase of consumption with prey density
- Ecologically unrealistic because it did not account for predator satiation



Source: Digital image. N.p., n.d. Web. 31 Oct. 2015. <http://www.cfr.washington.edu/classes.esrm.450/Lecture8/Lecture8.pdf>.

Type II Functional Response

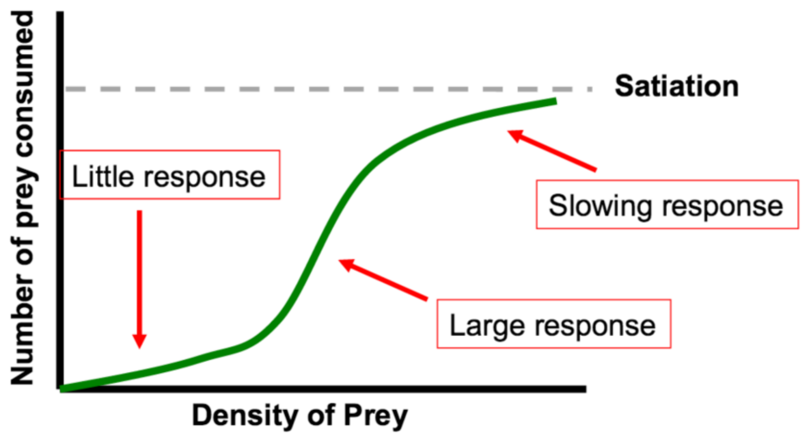
- Predator satiation (less commonly called predator saturation) in which prey occur at high population densities, reducing the probability of an individual organism being eaten.
- When predators are flooded with potential prey, they can consume only a certain amount, so by occurring at high densities prey benefit from a safety in numbers effect.
- As available food increases, a predator has more chances of survival, growth, and reproduction. However, as food supply begins to overwhelm the predator's ability to consume and process it, consumption levels off.



Source: Digital image. N.p., n.d. Web. 31 Oct. 2015. <http://www.cfr.washington.edu/classes.esrm.450/Lecture8/Lecture8.pdf>.

Type III Functional Response

- At high levels of prey density, saturation occurs, but at low prey density levels, the graphical relationship of number of prey consumed and the density of the prey population is a more than linearly increasing function of prey consumed by predators.



Source: Digital image. N.p., n.d. Web. 31 Oct. 2015. <http://www.cfr.washington.edu/classes.esrm.450/Lecture8/Lecture8.pdf>.

Type III functional response (Contd)

3 processes that cause this type of functional response

- Firstly, when preys are rare, predator has little opportunity to learn, where to find their prey and how to catch and kill them.
- A lack of learned search behavior has been observed with low prey encounter rate. Secondly, switching by predator to alternative food sources when prey density is low.
- And lastly, there may be a limited number of safe places, in which prey are not vulnerable to predation. As prey become common, some must use unprotected areas