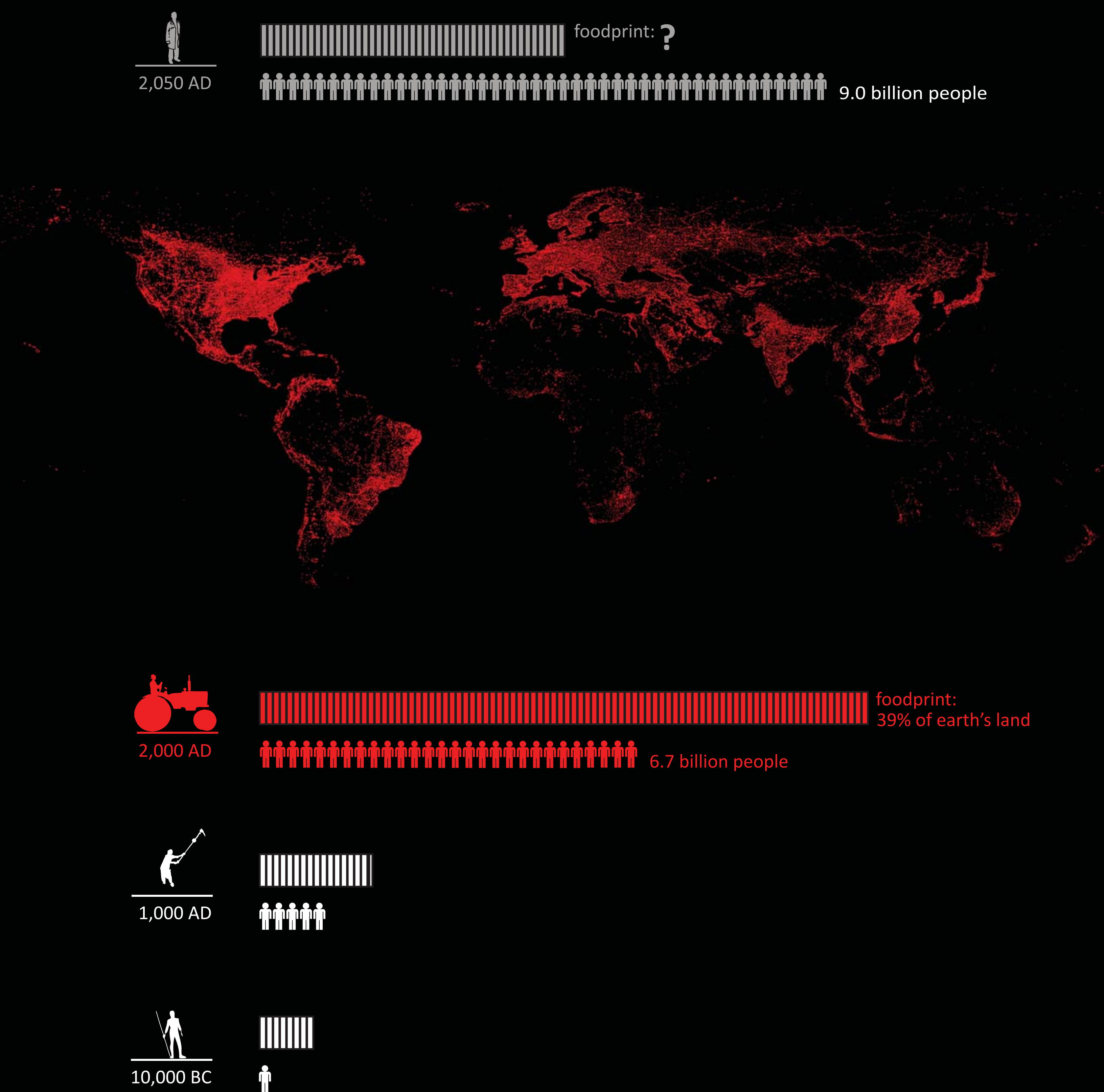
THIRD MILLENNIUM FARMING 3MF



source (FAO, 2009)

November, 2009
document v 1.0

There is an emerging wave of thinking where the axiom is to do more with less. The heros of this philosophy are often the tinniest of animals and micro-organisms. From the single cell process of photosynthesis, to algae's remarkable capability to reproduce quickly, even though what these organisms do is small, sometimes they do it with astounding efficiency.

The purpose of this living document is to add clarity and factual depth to a concept called micro-farming; where the remarkable ability of micro-organisms and insects to rapidly reproduce is harnessed for the production of food. Cross disciplinary information and collaboration for advancing this document is always welcome.

Jakub Dzamba
University of Toronto
k.dzamba@utoronto.ca

Advisor: Professor Adrian Blackwell
University of Toronto

1.0 SPECTRE:

Currently the World's population is about 6.4 billion people; out of that roughly 850 million people suffer from malnourishment and starvation (United Nations, 2009). The developed parts of the world produce more than enough food to sustain themselves; so how is it that so many people still go hungry (FAO, 2008)?

It's not that we can't produce enough food; we just can't do it reliably and get it to all the people that need it. The problem doesn't stop there. The world's population is supposed to peak at about 9 billion people in 2050; how will we feed all those new people when the time comes?

Some people say that we should expand our current food production system; the one that's based on the Green Revolution (see explanation inside). For many people this brings up a few concerns:

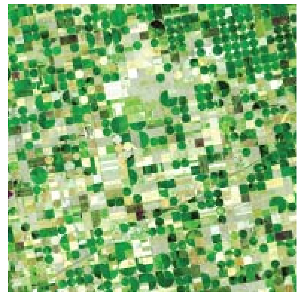
In many cases the pressure of the world's foodprint has a destructive effect on local and regional eco-systems; on a global scale this appears to be stressing the planet's bio-systems to their tipping points. The collapse of global fisheries, dissappearing rainforests, and city peripheries that constantly expand are examples of these stresses. To simply increase fish harvests or the amount of arable land to be farmed may have destructive consequences beyond what we can foresee or reliably estimate.

"This century is the last century of wild seafood"

- Steve Palumbi, a scientist at Stanford University, comments based on the findings of a major scientific study: *Impacts of Biodiversity Loss on Ocean Ecosystem Services*

(BBC News)

The large scale use of intensive fertilizers & pesticides, irrigation, and growth hormones & antibiotics in our crops and livestock leads to an accumulation of foreign chemicals in our foods and eco-systems. We are slowly becoming aware that the expansion of aquatic dead zones, like in the Gulf of Mexico (Bruckner, 2008), deterioration of croplands to drought and high salinity, and increased rates of various human illnesses are all related to these farming practices (FAO, 2009). In the long run, no one knows for certain what the health implications of these farming practices will be for us, our children and our planet.



circular crop fields

Kansas, United States

- crop irrigation accounts for 70% of the world's fresh water use
- all agricultural chemicals eventually find their way back into our fresh water systems

(Pimentel)

Many of us like to eat meat, but many people are also disgusted by the way it is produced. Increasingly cheaper and efficient means of raising and slaughtering livestock resemble industrial, mass production, operations. In an industry that is driven by lowest cost, there is increasingly less room concern for the quality of life, and death, of the animals we use for food. Many of us struggle with this ethical dilemma; some deal with it by giving up meat, and many of us turn a blind eye.

battery chickens

- lifespan: 1 to 2 years, less than 8.5 x 11" living space per hen
- living conditions and lifestyle cause violent pecking; as a result hens are de-beaked
- reoccurringly starved to spike egg production

(Canandian Colation for Farm Animals)

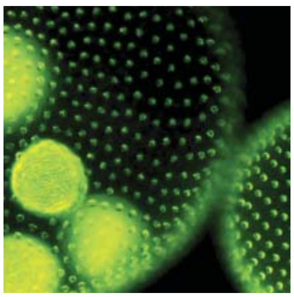
For these reasons expanding the world's current food production system may be more difficult than it seems and definitely more complicated than simply looking at the price of food may suggest.

But humans have faced food crisis many times before. At one point it drove us to take up agriculture and domesticate animals, creating the first man made food pyramid; the one we've been improving on ever since and still use today. But we know there are other, much more vast, food sources out there, and the potential for harnessing them in a new kind of food pyramid. Third Millennium Farming (3MF) is based on exactly this idea.

1.1 VISION:

3MF seeks to decrease the size of our foodprint, produce cheaper food, and do it sustainably. It also brings new components into the food pyramid. Eventually this will actually create a new food pyramid altogether. Though this may sound scary, it may be less alien that it first appears.

3MF is about using species of micro-organisms (algae and plankton) that are much better converters of sunlight into plant biomass than even our fastest growing crops, and similarly using species of micro-livestock (insects) that are much better converters of plant biomass into edible meat than even our fastest growing livestock. These organisms are not only vastly more efficient for farming food, but the actual processes that will be involved in this type of farming can play key roles in making the function of our cities more sustainable.



microalgae

- over 200,000 species
- growth temperatures: 0 to 70C
- requirements: nutrients (salts), sunlight, CO_2
- uses include biodiesel and feed for livestock

(Wageningen University)

3MF would change the tectonics of traditional farming, and move operations into cities. 3MF farming operations will require completely controlled environments in order to recreate the exact conditions necessary to enable the explosive growth rates that micro-organisms and micro-livestock are capable of; and the built environment of cities is all about creating controlled environments. The availability of infrastructure in cities, and the tectonics of our built environment provide precisely the type of conditions necessary for grafting on the photo-bio reactors (used to grow micro-algae and seaweed) and insect incubation chambers (requiring 24/7 access to heat, light and nutrients) that 3MF would utilize.

tubular photobioreactors

- optimal growth rate: 24hrs doubling time
- production: 60 tons/ha/year, more than 12x that of food crops
- constructed of arrays of tubes (max. 10cm radius)

(Wageningen University)

3MF operations would feed off the organic and semi-organic wastes produced in every city. The farming of micro-organisms would require large inputs of CO_2, of which we have no shortage of today, and nutrients like nitrogen and phosphor (District), the exact same stuff we try to filter out of our waste water before returning it to lakes and rivers. These micro-organisms produce plant biomass that is semi-edible for humans, but more importantly, which can be fed to insects that are edible to humans. Similarly termites and other decompiculture insects can play a key role in the digestion of biomass from agricultural, industrial and forestry wastes; digesting the wastes, sequestering the CO_2 content and producing food – and sometimes hydrogen – all at the same time.

entomophagy

- "entomophagy (eating insects) is what sushi was to North America 25 years ago"

In order to make the step from concept to reality 3MF requires much more factual depth and cross disciplinary innovation in fields ranging from biology to culinary arts to farming to architecture, etc. But what if we could reduce our foodprint? And what if we could bring farming into our cities? And what if we could make our cities more sustainable?

Maybe the antagonism between city and agriculture, core and periphery, would fade away, allowing for one to be grafted onto the other, while simultaneously allowing nature to creep back into our metropolises and daily lives. Farmers might return to the city transformed - a mix between engineer, biologist, botanist and scientist - managing high-tech farms integrated into our buildings' systems and city infrastructure.

2.0 FOODPRINTS and FARMING REVOLUTIONS

Since the beginning of agricultural practices, at about 10,000BC, the human population has endured a steady growth. Throughout the history of human settlement there has also been a parallel growth of lands used for food production, however it's actually the reduction of the average person's foodprint that has allowed for a continued, exponential, population growth. It's possible to define several revolutionary moments of advancement in human food production that are responsible for initiating and driving these reductions in our foodprint.

The following define the most prominent such moments of advancement:

Neolithic Revolution: Began about 10,000 BC in the tropical and subtropical areas of southwestern and southern Asia, northern and central Africa and Central America (Gupta). Agriculture allowed for creation of permanent settlements, unprecedented concentrations of people, and increased birth rates due to a stationary lifestyle (BBC). Large scale spread of agriculture practice began around 4000 BC, and resulted in a population explosion (BBC).

- World population: 7 to 162m people, from 4000 BC to 400 BC (Bureau).

Muslim Agricultural Revolution: Took place during the 8th and 13th centuries in the Islamic Medieval Empire, and was accompanied by the Islamic Golden Age (Hobson). During this time a diffusion of farming technology, and a globalization of crops occurred that led to significant improvements in the mechanization of agriculture, and a longer crop season as a result utilizing new species which could survive in the extreme summer heat – previously a fallow season (Watson). This allowed for larger urban densities in cities, and as the empire grew, utilization of new, and better suited/surviving crops allowed for a greater utilization of newly acquired, and previously unproductive, arable lands (Watson).

- Magnitude of population increase unknown.

British Revolution: This time period roughly coincides with the industrial revolution. At the beginning of this period the iron plough became available in large quantities and crop rotation was adjusted to return larger amounts of nitrogen to the soil (Overton). However, the sustainable nature of farming until this point became undermined with the development of industrially produced fertilizers, which dramatically increased the production of food, but did so through energy intensive inputs dependant on fossil fuel exploitation (Overton).

During this time there were significant increases in the production of food, while the agricultural workforce itself shrunk. As a result, large amounts of agrarian workforce were freed up to participate in the industrial revolution, and cities could reach new densities of population (Overton).

- World population nearly doubled from 1550 to 1850, while the British population, the epicenter of the industrial revolution, increased about seven fold from 2.8 to 22m during the same period (Rotberg and Rabb).

Green Revolution: Took place between about 1960 and 1990, and saw the world-wide spread of improved fertilizers, irrigation techniques, pesticides, and genetically engineered, higher-yielding, crops (FOA). As world population grew, and the price of food remained stable, the green revolution was initially deemed a great success (FOA). The green revolution fueled the fastest growing human expansion in history, standardized crops and farming in many places around the world, and became a major force of globalization.

However, some of the repercussions of the green revolution's surge of productivity are becoming apparent; biodiversity has decreased as farmers abandoned many local varieties of crops for the higher-yielding, genetically engineered ones, the widespread use of pesticides and agro-chemicals has caused severe environmental degradation and danger to public health in many regions, and unprecedented increases in irrigation have put a strain on the world's water resources (FOA). It is becoming clear that simply increasing the world's food supply is not enough; food production must be made sustainable to end world hunger and meet the world's future food demands (FOA).

- World population: 2.3 to 5.3b people, from 1960 to 1990 (Bureau).

Table 2.1: World Foodprint (ha/person)

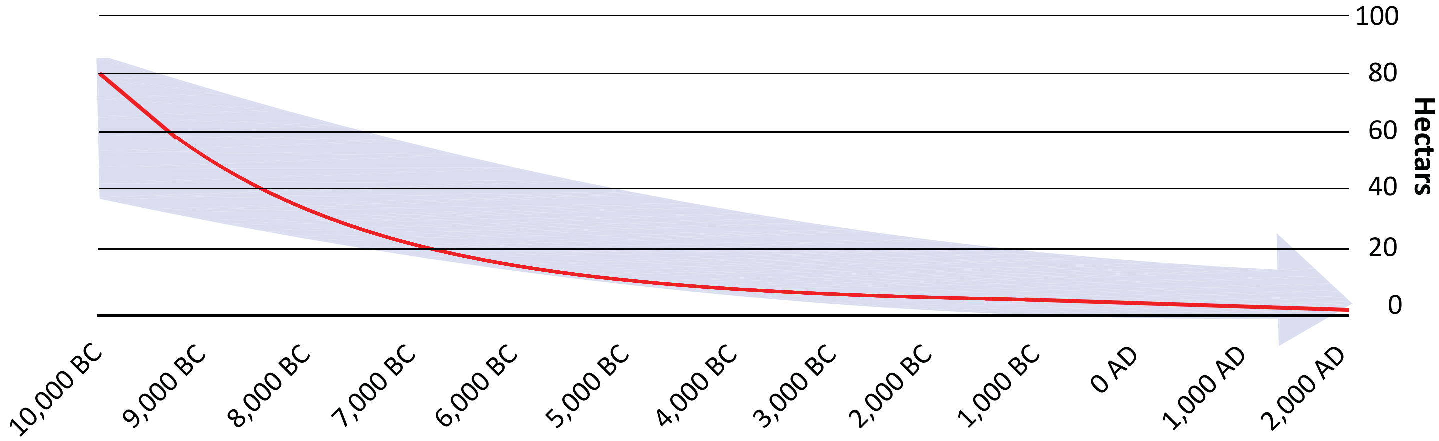


Table 2.2: World Population

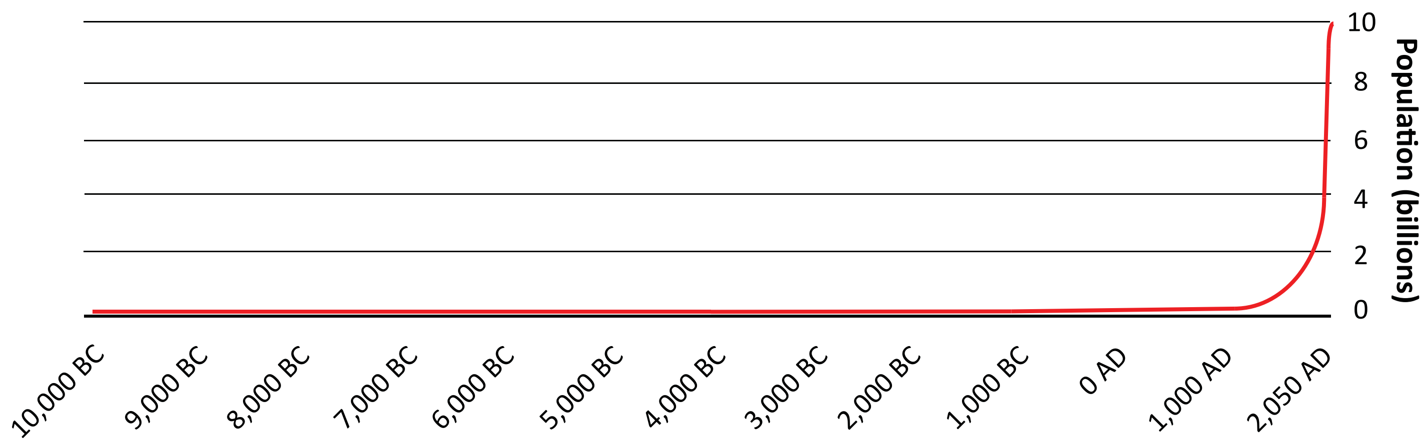
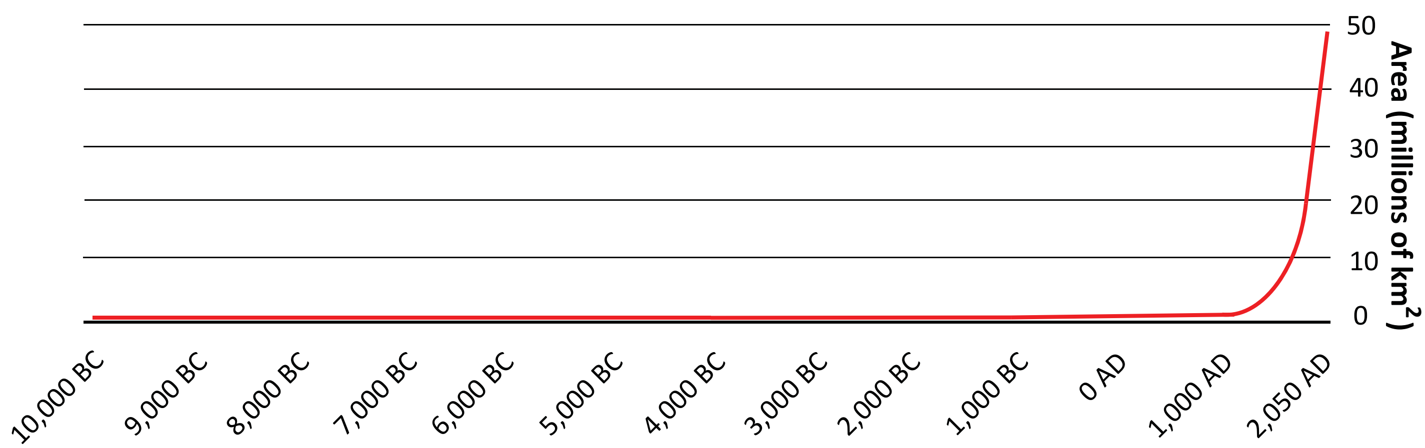


Table 2.3: World Agricultural Land



Above: *even as the average person's foodprint has decreased over time, it has been outpaced by rapid population growth; resulting in a steady expansion of humanity's foodprint.*

See section 6 for methods and sourcing.

Tracing a Finer Trend:

Taking a closer look at these farming revolutions reveals that there is a strong link between increases in food production and population growth. In the next 50 years the world population is expected to increase by 2.5 billion people. So how exactly are we going to feed all of these new people?

One option is that we could expand our current farming operations, those based on the green revolution; however, as mentioned before (see Specter) this may be more complicated and dangerous than we currently understand. Another thing we could try to do is to curb our future population growth; however, to date there have been no fully successful examples of this, and even limited success in this regard would still result in some added population. Furthermore, our current foodprint appears to be straining the world's ecosystems and biosphere to the point of near collapse – do we really want to keep this up, or do we try to find a better way?

In order for 3MF to be "better" it would have to do several things: it would have to significantly decrease our foodprint, enough to alleviate the current stress of our current foodprint, while at the same time producing more food (enough to feed an additional 2.5 billion people), it would have to be sustainable – this is partially achieved by a reduced foodprint, but it would also have to utilize renewable energy sources (unlike pesticides and fertilizers), and finally, in order to have a shot of making it in the real world, it would have to produce food cheaper than we can today.

In this report, the concept of 3MF focuses mainly on finding a more sustainable way of producing meat. The reason for this is that meat production is the most intensive type of farming, which is reflected by the fact that about 70% of our foodprint is dedicated to it (p272, Livestock's Long Shadow). The hope is that if 3MF is capable of producing meat sustainably, it will also be able to find sustainable ways of producing other types of food.

Lastly this report hinges on the assumption that, using micro-livestock, future chefs and culinary experts will demonstrate unlimited creativity and innovation in whipping out things from oozes to mousses, right down to a protein cookie which will feed a hungry child for a day.

Tracing a Larger Trend:

Since the domestication of livestock farmers have strove to increase yields of meat. Today we use a host of antibiotics, growth hormones, engineered feeds and other tools to boost livestock's yields of meat. It appears that utilization of livestock has come down to making them the most efficient converters of feed into meat, with little regard for their ethical treatment or slaughter. In essence 3MF would be about retiring livestock as an engine for converting feed into meat, and substituting it with micro-livestock, which should be a more efficient engine for doing this. However, its most likely 3MF will not be the final step in this trend. Any type of food production is essentially about converting the sun's energy into something we can consume. In the future it may become possible to completely substitute the organic converters of the sun's energy (crops and livestock) from our food chain, with some artificial means.

***Right:** see section 6 for methods and sourcing, and more insect ECI values.*

3.0 MICRO-LIVESTOCK

The term micro-livestock usually refers to the farming of relatively small animals, such as rodents and insects. The idea behind farming micro-livestock is to use the relatively better survival skills of these animals to farm in areas that would be inhospitable for traditional livestock. However, in this essay micro-livestock refers only to the farming of insects.

Insects display a significant advantage over any warm-blooded animals in their ability to convert food into body mass, or when speaking in terms of farming, feed into meat. There are two main reasons for this advantage; the first is that insects are cold blooded, allowing them to use more energy for growing - typically insects require only about 1/10 as much energy as warm blooded animals (Ramel). Secondly, when it comes to the functioning of animals, smaller scale generally translates into greater efficiency.

Generally the larger an animal is the longer it lives, and the more food and water goes to maintaining its existing body mass. Imagine how much energy a cow spends maintaining its body mass while putting on its final pound. Micro-livestock comes in significantly smaller packages, which translates into less energy spent on maintaining existing body mass.

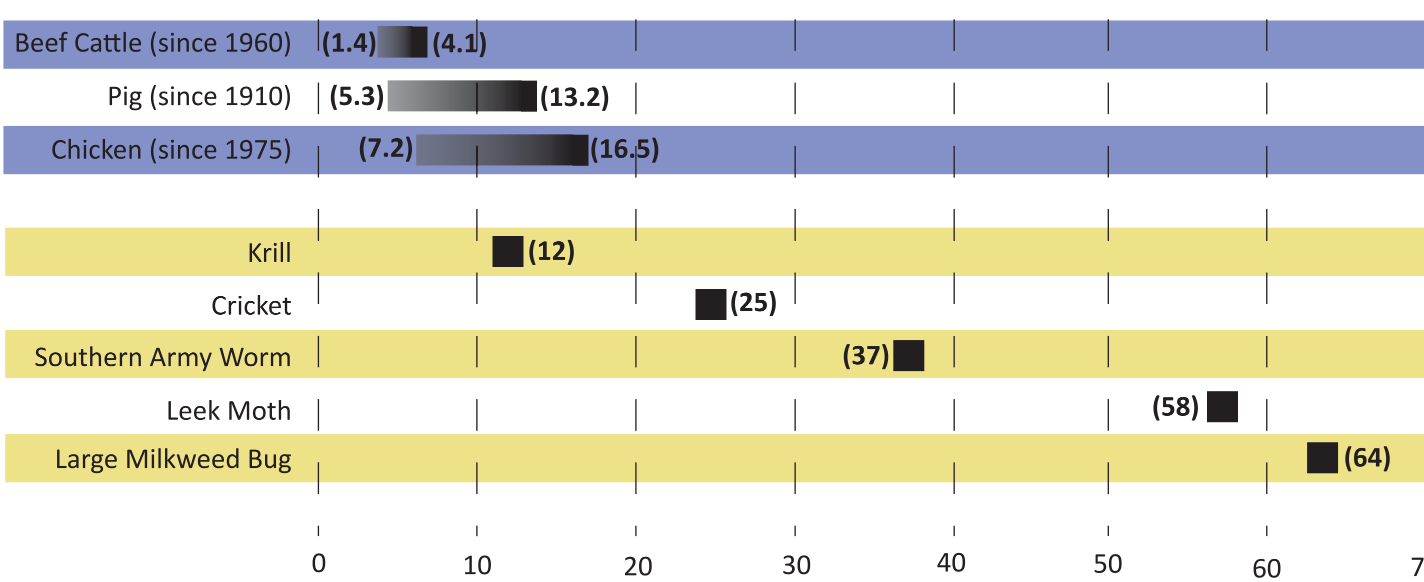
In the interest of bringing more clarity to exactly how micro-livestock can outperform livestock, the following section identifies and quantifies the advantages of micro-livestock. In order to allow for easy comparison beef, the least efficient animal, and poultry, the most efficient animal, have been selected to represent livestock, and the cricket has been selected to represent micro-livestock, not because it's most efficient, but because it's the world's most popular food insect.

Efficiency:

The efficiency of converting food into meat can be measured using a number of techniques; the most common being *food conversion efficiency (FCE)* for livestock, and *energy conversion index (ECI)* for insects.

As can be seen in Table 1 below, the efficiencies of insects are noticeably better than those of livestock. However, an additional factor needs to be considered. The domestication of livestock is a practice that has continuously been improved upon for several millennia. Today, rearing livestock is a mass-production industry that involves using specialized feeds, hormonal and bacterial treatments, and optimized (and often inhumane) living conditions, all designed to increase the FCE of the animals. On the other hand, insect rearing hasn't been developed on the same scale or to the same technical depth as livestock. However, the rearing of insects is dependent on similar criteria as that of livestock, such as appropriate feed, and environmental and physiological conditions; implying that if we focus on improving the farming of insects, as we focused on improving the farming of livestock, we should be able to achieve similar improvements.

Table 3.1: ECI Values for Livestock and Insects



Footprint (area/water):

Micro-livestock farming operations should be able to achieve a significantly smaller footprint than livestock farming operations. This is due to two main reasons.

The first is that micro-livestock reach their maturation age much quicker than even the fastest growing livestock, making it possible to create several micro-livestock harvests in the same time it would take to create just one livestock harvest. On a side note the relatively quick life spans of micro-livestock may make it easier to selectively breed them for desirable traits.

- Beef Cattle = 24 months (University)
- Broiler Chicken = 7 weeks (Australia)
- Cricket = 4.5 weeks (Ghann)

The second reason behind micro-livestock's smaller footprint is their small scale, which makes it much easier to miniaturize their farming operations. Many strategies, such as stacking, layering, etc., can easily be used to decrease the physical footprint of farming operations and change the tectonics of farming from two dimensions to something three dimensional.

- Beef Cattle = 1 steer/acre (545kg/acre) (Rayburn)
- Broiler Chicken = 20 birds (40kg)/sq m (Australia)
- Cricket = 64kg/cu m (Ghann)

All insects require water, in addition to simply drinking water many insects posses the ability to supplement or completely replace drinking water by extracting it, on a molecular level, from the food they eat, or absorbing it from humidity in the air (Chown and Nicolson). These last two methods are an ability that only insects posses, which translates into a lower water footprint for micro-livestock.

More scalable Engine:

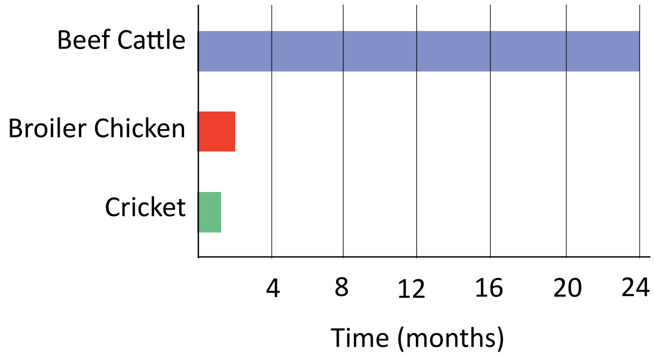
All stable livestock farming operations require that the number of slaughtered animals be replenished by an equal number of new animals. For this reason livestock farming operations spare a percentage of the herd or flock from slaughter and instead use them as a dedicated breeding base. The rate at which this replenishment of population occurs varies by the species of livestock being farmed. Out of traditionally farmed livestock, cows are one of the slowest to reproduce, and chickens are by far the fastest; but as can be seen below, crickets are in a league of their own.

- Beef Cattle = 0.2/year (see section 6 for methods and sourcing)
- Battery Chicken = 300 eggs/year (Animals)
- Cricket = 100 eggs/year (Haniffa and Jose)

A direct implication of micro-livestock's ability to reproduce at explosive rates is that farming operations will be able to sustain themselves with a relatively smaller breeding base than livestock farming operations. Given micro-livestock's explosive growth rates, it may also be possible to scale up micro-livestock populations at unprecedented rates – population increases by factors of 100x's with every batch of eggs. This could make it possible to utilize infrequent or irregular food sources and crops – something that traditional livestock could never achieve.

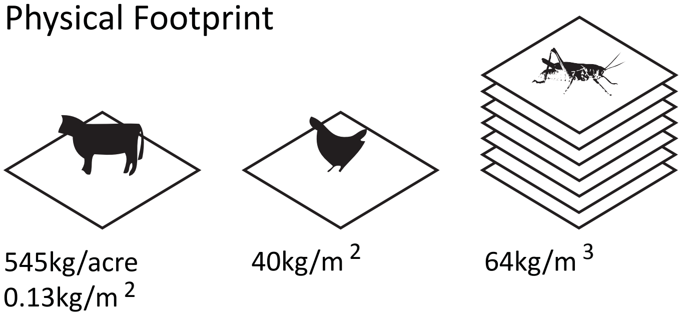
Diagram 3.2: Livestock Footprint

Maturation Age



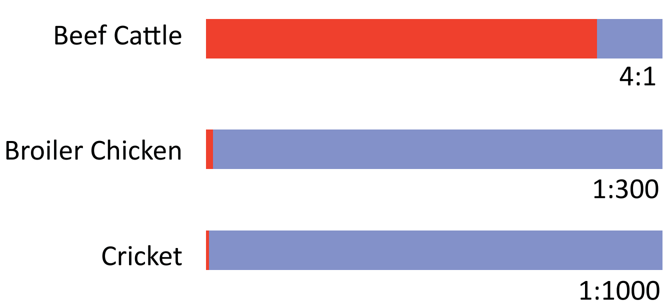
Beef Cattle: 13.7
Broiler Chicken: 1.0
Cricket: 0.65

Physical Footprint



Beef Cattle: 308
Broiler Chicken: 1.0
Cricket: 0.63

Breeding Base (ratio of breeders to population)



Beef Cattle: 5.0
Broiler Chicken: 1.0
Cricket: 1.0

Beef Cattle: 21,098
Broiler Chicken: 1.0
Cricket: 0.41

__Left:__ the relative footprint of livestock farming, with broiler chickens serving as a basis of comparison (footprint of 1.0).

All things being equal, the final results show that beef cattle takes 21,098 times more space than broiler chickens; and that crickets take 0.41 times as much space as broiler chickens.

4.0 CROPS

There are over 1400 known species of edible insects, and its estimated there are several times this amount of undiscovered edible insects. Many of these species can thrive under very different environmental and physiological conditions, but most importantly on a much more diverse range of food than traditional livestock. As a result several new strategies for farming feed for micro-livestock can now be considered. Micro-livestock's ability to utilize alternate feeds is equally central to the idea of 3MF as is the farming micro-livestock itself, but is even more powerful in decreasing the end foodprint of 3MF.

Micro-livestock can be fed traditional fodder crops, the same ones we use to feed livestock (usually cereals). They can also be fed some plant species which posses an ability for achieving rapid growth rates like algae, sugarcane and phytoplankton; or they can be fed using industrial/agricultural waste products that aren't ordinarily considered edible such as paper, wood pulp and non-usable lumber.

Cereals: Cereals are the main component in most engineered livestock feeds and significantly contributed to improving livestock's ECI values (Agriculture). Current research suggests that feeding cereals to micro-livestock creates a similar increase in ECI values (Hinks and Erlandson). This implies that traditional fodder crops can be used to feed micro-livestock farming operations and achieve significant decreases in our foodprint.

Rapid-Growth Plants: Some plant species exhibit explosive growth rates when exposed to ideal growing conditions.

Algae: Algae and its more complex forms of Seaweed are an aquatic plant species that posses an ability for rapid reproduction. One of the main reasons for this rapid-growth ability is that algae and seaweed are entirely immersed in water, which is the environment from which they draw their nutrients; unlike terrestrial plants which expend a great deal of energy growing elaborate root and leaf systems to acquire their nourishment. An additional advantage of farming algae is that it has no inedible parts, meaning 100% of its biomass can be used for micro-livestock feed.

Algae reproduce rapidly under their optimal growing conditions, and continue to do so until something inhibits this - such as a chemical imbalance produced by a over concentration of algae, or the depletion of the necessary conditions for optimal growth. The main inputs alga requires are fairly basic: water, carbon dioxide, light and nutrients (Classroom).

Sugar Cane: Sugar Cane is a terrestrial plant and is one of the most efficient photosynthesizers in the plant kingdom. Processing 100 tons of sugar cane would result in 74 tons of sugar cane juice and 26 tons of wet bagasse, the fibrous remains of the crushed stalks. Currently, bagasse is burned in sugarcane processing facilities to power their operations, however many insects (including termites) eat sugar cane – proof of this is that they are frequent pests of this crop.

Industrial/City Waste: The wood and paper industry ends up with various types of waste products that have no other use than being incinerated for energy. Examples of this are wood pulp, recycled paper, and even lumber destroyed by pests such as the B.C. Mountain Pine Beetle. These waste products are could be used as feed for some species of insects.

Considering the above mentioned plant species and city wastes could be used to feed micro-livestock farming operations it becomes easier to picture how 3MF could integrate with our cities. Imagine algae-culture operations that harness both: waste water treatment plants, as a source for nutrients, and fossil fuel power plants, as a source of concentrated CO_2. Or micro-livestock farms integrated into industrial operations, using the biomass waste as feed and converting it into a viable source of food and perhaps (using termites) hydrogen as well.

Right top: *see section 6 for methods and sourcing.*

Far right: *the relative footprint of producing feedstock, with broiler chickens serving as a basis of comparison (footprint of 1.0).*

All things being equal, the final results show that growing feedstock for beef cattle takes 4.5 times more space than for broiler chickens; and that growing feedstock for crickets take 0.035 times as much space as broiler chickens.

Near right: *a breakdown of all the types of food production lands in the world (FAO Crops, 2009). Notice 70% of the lands are used for livestock operations - either as pasture land or for growing feedstock.*

Table 4.1: Food Crops vs. Algae

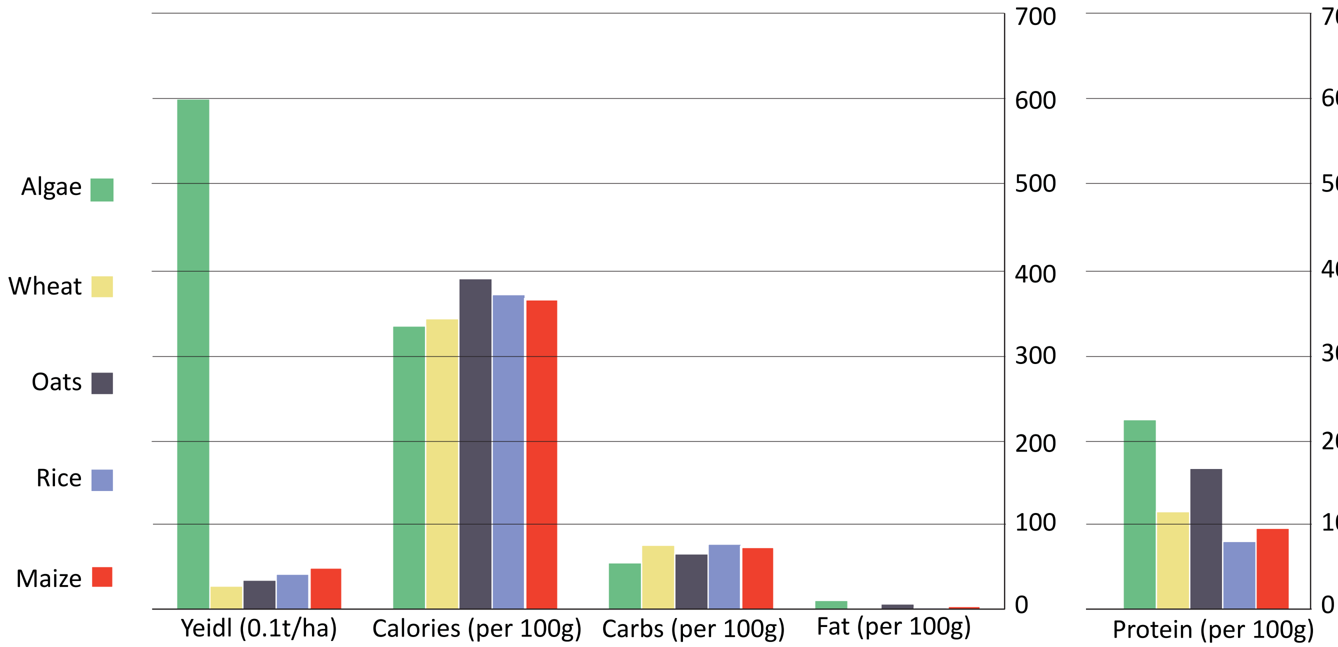
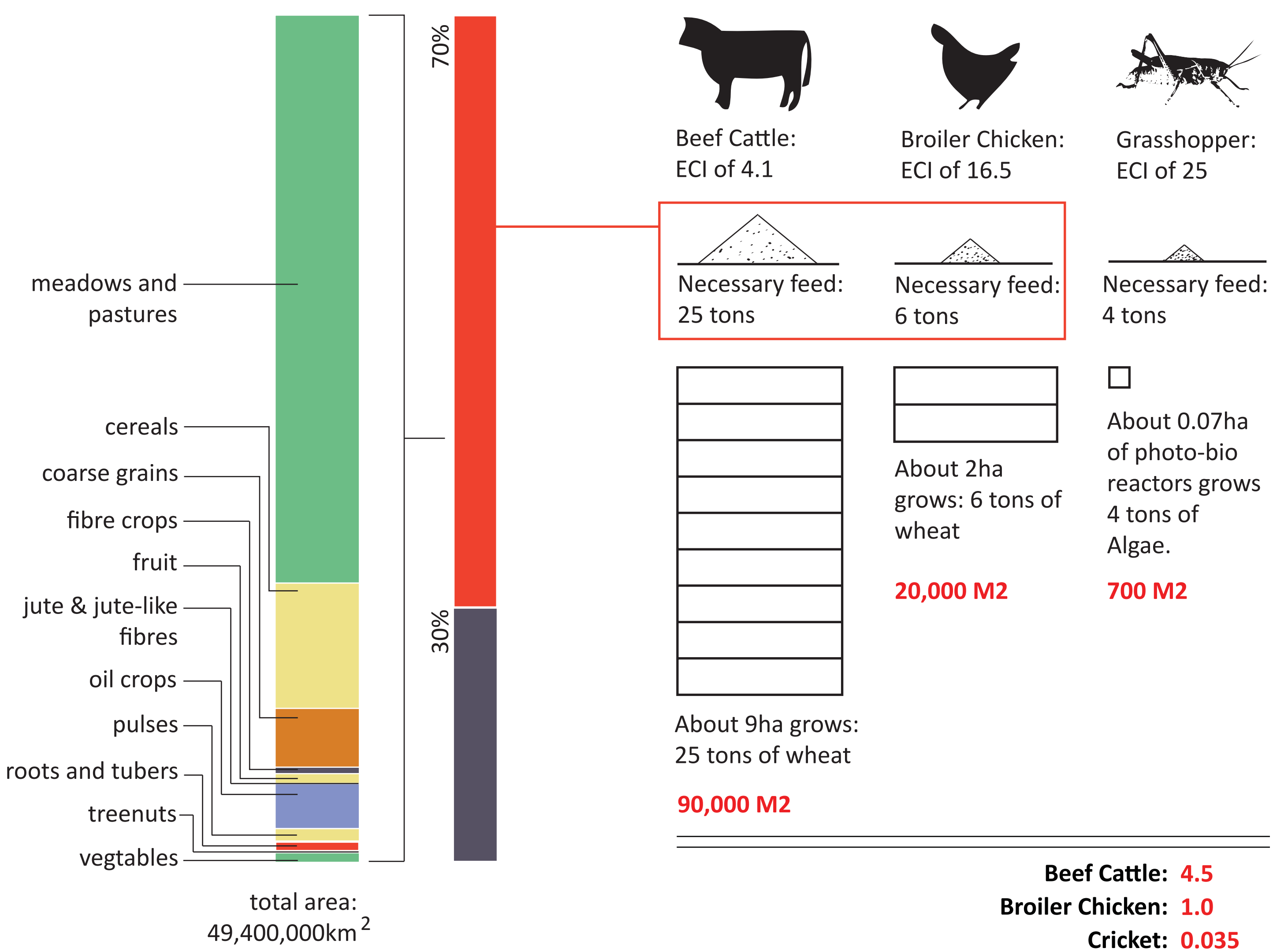


Diagram 4.2: Feedstock Footprint



5.0 CULINARY ARTS

It's worth mentioning again that this report hinges on the assumption that future chefs and culinary experts will demonstrate unlimited creativity and innovation in using micro-livestock to whip out things from oozes to mousses, right down to a protein cookie which will feed a hungry child for a day.

The objective of 3MF is not to convert everyone into happily eating bugs just to save the world. It's not necessary to completely abandon the meats we love, like beef, pork and chicken; but maybe we can substitute some of the meat products we eat with micro-livestock products without having to sacrifice the things we like. For many readers this point is the critical flaw of 3MF, and at best they may think "it's a neat idea, but not for me". For North Americans and Europeans there is no easy way to address this point. Below are some facts about insect meat and livestock meat, and few basic ideas of how we might begin to employ micro-livestock as a food source.

Nutrition: As is shown in Table 5.1 the nutritional and caloric content of micro-livestock is comparable to that of livestock.

Health: Krill oil is quickly becoming a very popular, and scientifically proven, health supplement. It contains Omega 3 fatty acids, and the most concreted known amounts of a unique antioxidant called astaxanthin (Wong). The health benefits of krill oil range from protecting against cardiovascular conditions and strokes, to reducing the risk of various forms of cancer and chronic disease (Council). Krill obtains these uniquely high levels of astaxanthin from the algae it eats. It's possible that insects, which are physiologically similar to krill, could produce omega 3 fatty acids and similar levels of astaxanthin when farmed using algae as a food source.

Daily Ration Cookie:

One of the simplest applications of insect food may be to feed malnourished or starving people. The basic idea would be to make a cookie, using insect flour that would contain a single person's daily nutrition and caloric requirement (Food Factory Foundation). These cookies would then be sealed in a way that would make them non-perishable, unlike flour or many other basic foodstuffs that are transported to malnourished and starving populations.

Protein Flour: Micro-livestock can be turned into flour by simply baking and grinding the insects into a fine powder (Food). This can be used in baking and should have a significantly higher nutritional and caloric content than traditional flour, made from cereal crops. Baking with this flour would allow for the creation of dense (nutrition and calorie), non-perishable foods.

Fast Food:

daily ration cookie

- one day food ration
- 3500 calories
- non perishable
- costs 1 cent

Just because you eat a hamburger doesn't mean you want to meet the cow. The same thinking should go for eating micro-livestock – eating whole bugs is not the idea. When eating fast food it isn't always obvious what part of the animal you're eating and how it was processed to look and taste the way it does. Fast food excels at taking foods that at one point would be undesirable and turning them into something appetizing. Can the same idea also be used to turn micro-livestock be turned into something appetizing? The flavors would be different, but maybe micro-livestock has its own pallet of flavors to be discovered and crafted by chefs.

Table 5.1: Livestock vs Microlivestock Nutrition

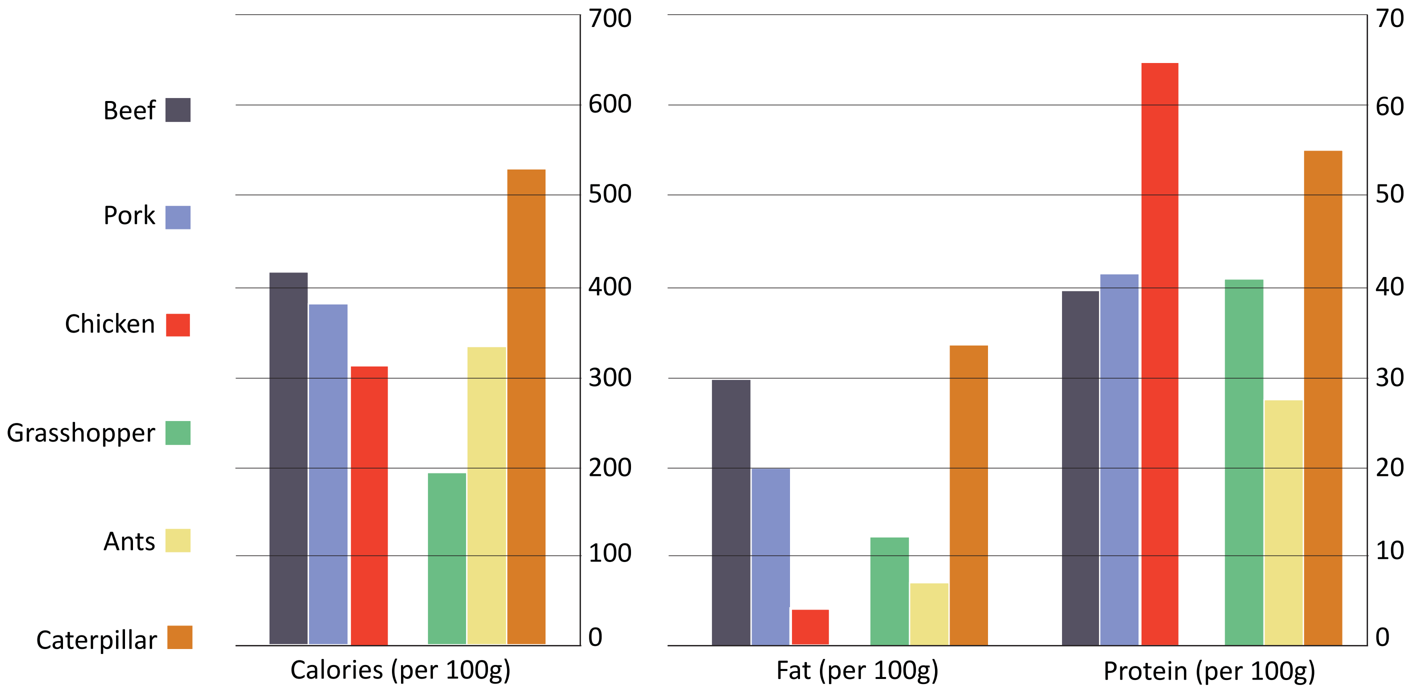
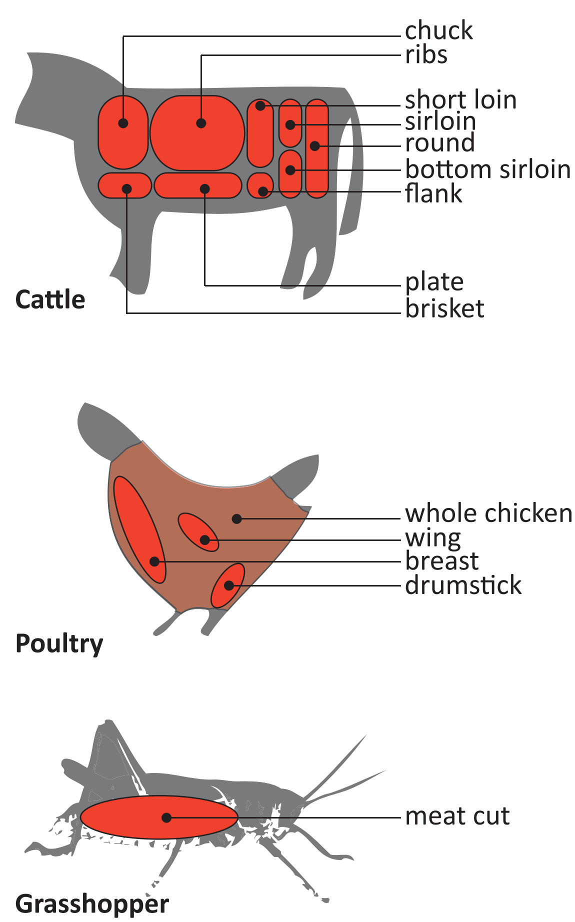


Diagram 5.2: Meat Cuts



***Above:** as can be seen in Table 5.1, micro-livestock meat is nutritionally comparable to the meat we get from livestock.*

See section 6 for methods and sourcing.

***Right:** the idea behind eating micro-livestock isn't to convince people to eat whole bugs. As can be seen in Diagram 5.2, livestock animals contain a variety of meat cuts, with specific methods of cooking and preparation associated with each one. Instead, insect meat will also have to be extracted from various parts of the insect's body and then prepared, by chefs and other culinary experts, into a variety of tasty and visually appealing foods.*

6.1 METHODS

2.0 FOODPRINTS and FARMING REVOLUTIONS

Table 2.1: World Population

The data from 1960 AD to 2000 AD for this table was obtained from The Global Education Project (http://www.theglobal-educationproject.org/earth/food-and-soil.php#2)

The source for the data for 10,000 BC for this table was Buringh, P.

Year	10,000 BC	1900 AD	1960 AD	1970 AD	1980 AD	1990 AD	2000 AD
Foodprint (hectars/person)	80	0.75	0.42	0.35	0.3	0.26	0.23

The trend line for this table was established as a line of best fit using the above mentioned points.

Table 2.2: World Population

The data from 10,000 BC to 1950 AD for this table was obtained from U.S. Census Bureau (http://www.census.gov/ipc/www/idb/worldpopgraph.php)

The data from 1950 AD to 2050 AD for this table was obtained from U.S. Census Bureau (http://www.census.gov/ipc/www/worldhis.html)

Table 2.3: World Agricultural Land

The following data was obtained from NationMaster.com

Year	World Agricultural Land (sq. Km)
1960	43,783,484
1965	44,200,915
1970	44,828,828
1975	45,473,821
1980	45,844,590
1985	46,674,389
1990	47,399,672
1995	47,524,823
2000	47,635,849

The trend line in Table 2.3 was established as a line of best fit, with the assumption that agricultural practice began around 10,000 BC and therefore there was no agricultural land in the world before that time.

3.0 MICRO-LIVESTOCK

Table 3.1: ECI Values for Livestock and Micro-livestock

Livestock:

FCR stands for Feed Conversion Ratio. The method for this measurement is to find the ratio between the amount of feed the animal consumes to the amount of liveweight the animal gains. For example 10kgs of grain fed to a cow add about 1kg of liveweight, giving cows an FCR of 10. This method of measurement does not take into account the weight of water in the animal's liveweight gain.

Insects:

ECI stand for Efficiency of Conversion of Ingested food. The method for this measurement is to find the ratio between the amount of food the insect consumes and the amount of weight the insect gains. For example for every 1g of feed eaten by a cricket it gains about 0.25g, giving crickets an ECI of 0.25. The problem with this method of measurement is that water consumption and excretion is difficult to measure in insects. As a result all quantities (food consumed, insect feces, and liveweight gain) are converted to dry-weights.

Table: Comparing Livestock FCRs to Insect ECIs

	FCR (liveweight)	**Water Content (% of liveweight)**	**ECI (liveweight minus water content)**
Chicken	**2** (FAO, 2006, p. 45)	**67%** (United States Department of Agriculture, 2007)	**16.5**
Pigs	**2.5** (Soest, 1982)	**67%** (Lewis & Souther, 2001, p. 13)	**13.2**
Cow	**7** (FAO, 2006, p. 45)	**71%** (United States Department of Agriculture, 2007)	**4.1**
Cricket			**25** (Slansky, 1985)
Krill			**12** (Brandon, 2003, p. 125)
Southern Army Worm			**37** (Waldbaur, 1968)
Leek Moth			**58** (Slansky, 1985)
Large Milkweed Bug			**64** (Slansky, 1985)

** To convert livestock FCR values to ECI values I subtracted the animal's water content from its liveweight gain. I also had to assume the animal's feed contains negligible water content.*

Information on the improvement of livestock:

- Chickens have improved from an ECI of 7.1 in 1975 to 16.5 in 2009 (Hocking, 2009)
- Pigs have improved from an ECI of 5.3 in 1910 to 13.2 in 1989

    Recalculated from - FCR of 6.3 in 1910 to 2.5 in 1989 (Soest, 1982), and subtracted water content

- Cows have improved from an ECI of 1.4 in 1960 to 4.1 in 2010

Calculated from statement "cows have about tripled their FCR over the last 50 years" (Hume & Dalrymple, 2008)

Table 3.1 ECI Values for Insects - Continued

Insect	ECI Value	Source
Coleoptera		
Ladybog (Coccinella septentpunctata)	**4**	(Slansky, 1985)
Colarado Potato Beetle (Leptinotarsa decemlineata)	22-37	(Slansky, 1985)
Yello Poplar Weevil (Odontopus calceatus)	**10**	(Slansky, 1985)
Toroise Beetle (Paropsis charybdis)	**14**	(Slansky, 1985)
Mustard Beetle (Phaedon cochleariae)	**17**	(Slansky, 1985)
Leaf Beetle (Phytodecta pallidus)	**25-37**	(Slansky, 1985)
WheatWeevil	**15**	(Slansky, 1985)
Hemiptera		
Small Milkweed Bug (Lygaeus kalmii)	**49-68**	(Slansky, 1985)
Large Milkweed Bug (Oncopeltus fasciatus)	**64-78**	(Slansky, 1985)
Homoptera		
Aphid (Macrosiphum liriodendri)	**19**	(Slansky, 1985)
Hymenoptera		
Willow Oak Sawfily (Arge)	**10**	(Slansky, 1985)
Leek Moth (Diadramus pulchellus)	**58-60**	(Slansky, 1985)
Alfalfa Leafcutting Bee	**47**	(Slansky, 1985)
Organpipe Mud Dauber Wast (Trypoxylon politum)	**43**	(Slansky, 1985)
Lipidoptera		
Forked Dagger Moth (Acronicta fucifera)	**12**	(Slansky, 1985)
Redbanded Leafroller (Argyrotaenia velutinana)	**17-25**	(Slansky, 1985)
Red-spotted Purple (Basilarchia astyanax)	**11**	(Slansky, 1985)
Silkworm (Bombyx mori)	**14-31**	(Slansky, 1985)
Promethea Moth (Callosamia promethia)	**15**	(Slansky, 1985)
Scallop Shell Moth (Hydria undulata)	**11**	(Slansky, 1985)
Moth (Cyclophragma leucosticta)	**14-15**	(Slansky, 1985)
Milkweed Butterfly (Danaus plexippus)	**16-29**	(Slansky, 1985)
Virginian Tiger Moth (Diacrisia virginica)	**10**	(Slansky, 1985)
Milkweed Tussocks (Euchaetias egle)	**15**	(Slansky, 1985)
Tortricoid Moth (Exartema)	**14**	(Slansky, 1985)
Saddle Prominent (Heterocampa)	**13**	(Slansky, 1985)
Wild Saturniid Silk Moth (Hyalophora cecropia)	**16**	(Slansky, 1985)
Cherry Scallop Shell Moth (Hydria prunivorata)	**16**	(Slansky, 1985)
Fall Webworm (Hyphantria cunea)	**13**	(Slansky, 1985)
Eastern Tent Caterpillar (Malacosoma americanum)	**25**	(Slansky, 1985)
Winter Moth (Operophthera brumata)	**2-7**	(Slansky, 1985)
Northern (beech) Winter Moth (Operophtera fagata Scharf)	**12**	(Slansky, 1985)

Modest Sphinx (Pachysphinx modesta)	**14**	(Slansky, 1985)
Eastern Tiger Swallowtail (Papifio glaucus)	**13**	(Slansky, 1985)
Black Swallowtail (Papilio polyxenes)	**14-28**	(Slansky, 1985)
Ochrewinged Hag Moth (Phobetron pithecum)	**10**	(Slansky, 1985)
Cabbage Butterfly (Pieris brassicae)	**14-22**	(Slansky, 1985)
Cabbage White (Pieris rapae)	**6-18**	(Slansky, 1985)
Diamondback Moth (Plutella xylostella)	**27**	(Slansky, 1985)
Fluid Arches (Polia latex)	**15**	(Slansky, 1985)

Beef Cattle Reproduction Rate: "Beef Cattle = 0.2/year (see section 6 for methods and sourcing)"

- "About half of the feed in beef production systems is used to maintain the breeding herd. Of the remaining 50%, about 20% is used by the breeding cow for pregnancy and lactation and 30% is used by the growing calf." (Pitchford)
- Cows reproduce at a rate of about 1 calf/year (DeLaval Staff)

Given the above statements, if 1/5 of the herd is in reproduction mode, and the reproduction rate is 1 calf/year, this means the herd increases by 1/5 its population every year - or has a reproduction ratio of 5:1.

4.0 CROPS

Table 4.1: Food Crops vs Algae

Raw Data	Yeild (tons/ha)	Per 100g Cal.	Carbs.	Prot.	Fat
Wheat	**28**	**342**	**76**	**11**	**2**
Oats	**35**	**389**	**66**	**17**	**7**
Rice	**42**	**370**	**77**	**8**	**3**
Maize	**50**	**365**	**74**	**10**	**5**
data from: (Nutrition Data, 2009)					
Algae	**600**	**333**	**56**	**22**	**11**
data from; (The Daily Plate, LLC, 2009)					

5.0 CULINARY ARTS

Table 5.1: Livestock vs. Micro-livestock Nutrition (per 100g)

	Calories	Fat (g)	Protein (g)
Beef (Canadian Beef, 2009)	**210**	**15**	**20**
Pork (Pork, Sask., 2009)	**192**	**10**	**21**
Chicken (Chicken Farmers of Canada)	**159**	**2.1**	**33**
Grasshopper	**97** (Ramos-Elorduy, Moreno, Prado, Perez, Otero, & Guevara, 1997)	**6.1** (Department, 2000)	**20.6** (Department, 2000)
Ants	**168** (Ramos-Elorduy, Moreno, Prado, Perez, Otero, & Guevara, 1997)	**3.5** (Department, 2000)	**13.9** (Department, 2000)
Caterpillar	**268** (Ramos-Elorduy, Moreno, Prado, Perez, Otero, & Guevara, 1997)	**17** (Ramos-Elorduy, Moreno, Prado, Perez, Otero, & Guevara, 1997)	**28** (Department, 2000)

6.2 WORKS CITED

Agriculture, S. M. (2004, March). *Beef Cattle Feeding Systems*. Retrieved October 12, 2009, from http://www.agriculture.gov.sk.ca/Beef_Cattle_Feeding_Systems

Animals, C. C. (n.d.). *Facts about our food - Battery Hens.* Retrieved October 12, 2009, from Canadian Coalition for Farm Animals: http://www.humanefood.ca/

Australia, A. (n.d.). *Broiler Chicken Fact Sheet.* Retrieved October 15, 2009, from Animals Australia: http://www.animal-saustralia.org/factsheets/broiler_chickens.php#top

BBC News. (n.d.). *Eating Insects in Thailand*. Retrieved October 12, 2009, from http://news.bbc.co.uk/2/shared/spl/hi/picture_gallery/07/asia_pac_eating_insects_in_thailand/html/7.stm

Beutler, A. (2007, November). *General Brooding and Rearing Fact Sheet*. Retrieved October 12, 2009, from http://www.agriculture.gov.sk.ca/General_Brooding_and_Rearing

Beutler, A. (2007, November). *General Nutrition Fact Sheet*. Retrieved October 12, 2009, from http://www.agriculture.gov.sk.ca/General_Nutrition_poultry

Black, R. (2006, November 2). *'Only 50 years left' for sea fish.* Retrieved November 8, 2009, from BBC News: http://news.bbc.co.uk/2/hi/6108414.stm#graphic

Brandon, M. (2003). *Environmental Changes: Global Challenges.* Glasgow: The Bath Press.

Bruckner, M. (2008, October 6). *The Gulf of Mexico Dead Zone*. Retrieved August 15, 2009, from Microbial Life: http://serc.carleton.edu/microbelife/topics/deadzone/

Bureau, U. C. (2008, December 12). *Historical Estimates of World Population*. Retrieved June 19, 2009, from http://www.census.gov/ipc/www/worldhis.html

Buringh, P. (1989). Availability of Agricultural Land for Crop and Livestock Production. *Food and Natural Resources* , 69-83.

Cabaduab Coalition for Farm Animals. *Facts about our Food - Battery Hens.* Toronto.

Chicken Farmers of Canada. (n.d.). *Nutritional Values*. Retrieved October 16, 2009, from Chicken Farmers of Canada: http://www.chicken.ca/DefaultSite/index.aspx?ArticleID=105&lang=en-CA

Chown, S., & Nicolson, S. W. (2004). *Insect physiological ecology: mechanisms and patterns.* Oxford: Oxford University Press.

Classroom, C. (n.d.). *COOL Classroom*. Retrieved October 15, 2009, from http://www.coolclassroom.org/cool_projects/lessons/biology/resources.html

Council, I. F. (2008, June). *Functional Foods Fact Sheet: Omega-3 Fatty Acids*. Retrieved October 16, 2009, from http://www.ific.org/publications/factsheets/omega3fs.cfm

DeLaval Staff. (2007, March 18). *Cow comfort: 6) Reproduction*. Retrieved November 14, 2009, from Milkproduction.com: http://www.milkproduction.com/Library/Articles/Cow+comfort_Reproduction.htm

Department, I. S. (2000, February 25). *Nutritional Value of Various Insects per 100 grams*. Retrieved October 16, 2009, from Depertment of Entomology: http://www.ent.iastate.edu/Misc/insectnutrition.html

District, C. R. (n.d.). *Wastewater Treatment Made Clear*. Retrieved October 9, 2009, from How Wastewater Treamtent Works: http://www.wastewatermadeclear.ca/what/howitworks.htm

FAO. (2009). *Crops*. Retrieved 11 11, 2009, from FAO STAT: http://faostat.fao.org/site/567/default.aspx#ancor

FAO. (2006). *livestock's long shadow.* Rome: Food and Agricultural Organization.

FOA. (n.d.). *The Green Revolution*. Retrieved June 19, 2009, from http://www.fao.org/kids/en/revolution.html

Food and Agricultural Organization of the United Nations. (2008). *The state of Food Insecurity in the World 2008.* Rome: Food and Agricultural Organization of the United Nations.

Food and Agricultural Organization of the United Nations. (2009). *What FAO Does*. Retrieved August 15, 2009, from Food and Agricultural Organization of the United Nations: http://www.fao.org/kids/en/revolution.html

Food Factory Foundation. (n.d.). *Food Factory Foundation*. Retrieved October 16, 2009, from http://www.foodfactory-foundation.org/index.html

Food, I. a. (2009). *Inscets are Food*. Retrieved October 16, 2009, from http://www.insectsarefood.com/index.php

Ghann, C. A. (n.d.). *Ghann's Cricket Farm*. Retrieved October 12, 2009, from http://www.ghann.com/insect_care.cfm

Ghann, C. A. (n.d.). *Ghann's Cricket Farm*. Retrieved October 12, 2009, from http://www.ghann.com/faq.cfm

Gupta, A. K. (2004). Origin of agriculture and domestication of plants and animals linked to early Holocene climate amelioration. *Current Science* , 54-59.

Haniffa, M., & Jose, S. S. (1987). Inhibition of egg production and fertility in the house cricket Gryllodes sigillatus Walker (Orthoptera, Gryllidae) following topical application of cythion. *Anzeiger für Schädlingskunde* , 136-138.

Hinks, C. F., & Erlandson, M. A. (1995). The Accumulation of Haemolymph Proteins and Acitivity of Digestive Proteinases of Grasshoppers (Melanoplus sanguinipes) Fed Wheat, Oats or Kochia. *Journal of Insect Physiology* , 425-433.

(2004). In J. M. Hobson, *The Eastern Origins of Western Civilisation* (pp. 29-30). Cambridge: Cambridge University Press.

Hocking, P. (2009). *Biology of Breeding Poultry.* Bodmin: MPG Books Group.

Hume, D., & Dalrymple, J. (2008, October 22). *Ontario Agricultural College.* Retrieved October 16, 2009, from University of Guelf: http://www.oac.uoguelph.ca/news/documents/Livestock_Industry_in_Ontario_102208.pdf

Lewis, A. J., & Souther, L. L. (2001). *Swine Nutrition.* Boca Raton: CRC Press LLC.

NationMaster.com. (2009). *Agricultural Statistics*. Retrieved November 13, 2009, from Nation Master: http://www.nationmaster.com/graph/agr_agr_lan_sq_km-agriculture-agricultural-land-sq-km&date=1961

Nutrition Data. (2009). Retrieved October 16, 2009, from Nutrition Data: http://www.nutritiondata.com/facts/cereal-grains-and-pasta/5706/2

Overton, M. (2002, September 19). *British History*. Retrieved June 19, 2009, from http://www.bbc.co.uk/history/british/empire_seapower/agricultural_revolution_04.shtml

Pementel, B. (2004). Water resources: agricultural and environmental issues. *BioScience* , 909.

Perry, T. W. (1995). *Beef Cattle Feeding Nutrition.* San Diego: Academic Press.

Pitchford, W. (2004). Genetic improvement of feed efficiency of beef cattle: what lessons can be learnt from other species? *Australian Journal of Experimental Agriculture* , 371-382.

Pork, Sask. (2009). *Nutrition*. Retrieved October 16, 2009, from Sask Pork: http://www.saskpork.com/html/consumer_info/nutrition/index.cfm

Ramel, G. (2009, October 10). *What is Warm Blooded?* Retrieved October 10, 2009, from http://www.earthlife.net/mammals/warm.html

Ramos-Elorduy, J., Moreno, J. M., Prado, E. E., Perez, M. A., Otero, J. L., & Guevara, O. L. (1997). Nutritional Value of Edible Insects from the State of Oaxaca, Mexico. *Journal of Food Consumption and Analysis* , 142-157.

Rayburn, E. (2005). *Pasture Management for Pasture-Finished Beed.* March.

Rosa, A. (2005). *Fundamentals of Renewable Energy Processes.* San Diego: Elsevier Academic Press.

Rotberg, R., & Rabb, T. (1983). *Hunger and History.* Cambridge: Cambridge University Press.

Scott, D. P. (n.d.). *Meat - Being Competitive.* Retrieved September 8, 2009, from abare Nation Outlook Conference 2008: http://www.abare.gov.au/interactive/Outlook08/files/day_1/Scott_meat.pdf

Scriber, M. (1981). Sequential Diets, Metabolic Costs, and Growth of Spodoptera eridania (Lepidotera: Neoctuidae). *Oecologia* , 157-180.

Slansky, F. J. (1985). Food utilization by insects: Interpretation of observed differences between dry weight and energy differences. *Entomology* , 47-60.

Soest, P. J. (1982). *Nutritional Ecology of the Ruminant.* New York: Cornell University.

The Daily Plate, LLC. (2009). *Algae*. Retrieved October 16, 2009, from The Daily Plate: http://www.thedailyplate.com/nutrition-calories/food/generic/algae

The Global Education Project. (n.d.). *Food and Soil*. Retrieved November 13, 2009, from Earth: A Graphic Look at the State of the World: http://www.theglobaleducationproject.org/earth/food-and-soil.php#2

Turnbull, T. (2007, December 31). *Never mind organic, feel the food print.* Retrieved June 19, 2009, from Times Online: http://www.timesonline.co.uk/tol/life_and_style/food_and_drink/real_food/article3114744.ece

U.S. Census Bureau. (n.d.). *World Population: 1950-2050*. Retrieved November 13, 2009, from U.S. Census Bureau: http://www.census.gov/ipc/www/idb/worldpopgraph.php

U.S. Census Bureau, Population Division. (n.d.). *Historical Estimates of World Population*. Retrieved November 13, 2009, from U.S. Census Bureau: http://www.census.gov/ipc/www/worldhis.html

United Nations. (2009, March 11). *World Population Prospects: 2008 Revision*. Retrieved August 15, 2009, from United Nations Population Devision: http://esa.un.org/unpp/

United States Department of Agriculture. (2007, August 6). *Fact Sheets*. Retrieved August 9, 2009, from Food Safety and Inspection Service: http://www.fsis.usda.gov/Factsheets/Water_in_Meats/index.asp

University, N. D. (1999, January). *Value-Based Beef Cattle Production*. Retrieved October 12, 2009, from http://www.ag.ndsu.edu/pubs/ansci/beef/as1163-2.htm

US Department of Argriculture. (1994, September). *Grasshoppers: Their Biliogy, Identification and Management*. Retrieved October 12, 2009, from http://www.sidney.ars.usda.gov/grasshopper/ID_Tools/F_Sheets/mormoncr.htm

Wageningen University. (2009). *Technologies*. Retrieved November 8, 2009, from Research on microalgae within Wagneningen UR: http://www.algae.wur.nl/UK/technologies/

Waldbaur, G. P. (1968). The Consumption and Utilization of Food by Insects. In J. W. Beament, & J. E. Treherne, *Advances in Insect Physiology* (pp. 253-260). London and New York: Academic Press.

Watson, A. M. (1974). The Arab Agricultural Revolution and Its Diffusion, 700-1100. *The Journal of Economic History* , 8-35.

Wong, C. (2008, January 8). *Krill Oil*. Retrieved October 16, 2009, from http://altmedicine.about.com/od/herbsupplementguide/a/krilloil.htm