From Trout to Mollusks: Life Cycle Assessment, Socio-Economic Attributes and Ecosystem Services Surrounding Sustainable Aquaculture

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by

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This dissertation of Lubia N. Cajas de Gliniewicz, submitted for the degree of Doctor of Philosophy with a Major in Environmental Science and entitled "From Trout to Mollusks: Life Cycle Assessment, Socio-Economic Attributes and Ecosystem Services Surrounding Sustainable Aquaculture," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

This dissertation uses economic, environmental, social and cultural criteria to address the sustainability of three food production systems. Virtual water content and land use of beef cattle and trout production system in Idaho, USA were estimated in Chapter 1. The estimates showed that most resources were allocated to feed production. On average, one kg of edible boneless beef required about 20,000 L of water in mixed systems and 1,060 m^2 of land. This production was estimated to release about 24 kg of CO_2 equivalents. The average water and land resources needed to produce one kg of boneless trout were estimated at 5,500 L and 4 m^2, respectively. The trout production was estimated to release trace amounts of CO_2 equivalents.

Chapter 2 and 3 were conducted as a case study of a marine mussel farm in Washington state, USA. An input-output economic model captured transactions from the mussel farm, and the results highlighted environmental attributes and simulated the potential value from increased domestic mussel production. The farm harvested 550,000 kg of live mussels/year that generated $1.33 in direct and indirect economic contributions for each dollar of final demand at farm gate within the state of Washington. If all expenses occurred within the USA, mussel farms could contribute $1.58 per dollar of demand from purchases within industrial sectors, excluding employee compensation, taxes and revenues. The case study estimated the water, land and carbon footprints, socio-economic attributes (e.g. demographics, income, job stability and safety) and cultural aspects of the domestic and global distribution, production, and processing of mussels. Fresh water use per kg of whole mussel cultured and processed at the farm was estimated at 73-94 L, based on the annual production of 550,000 kg. The carbon footprint was estimated at 1.85 kg of CO_2e/kg of mussels (or 3.7 kg of CO_2e/kg of edible mussel meat).

The results and review of the sustainability highlight potential benefits and risks of increasing domestic mussel production and consumption, boosting national economic and social stability. The potential future expansion for mussel production was placed within a framework of harvest, socio-economic factors, and protection of natural ecosystem services.

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Dedication

I dedicate this work to my parents: Jose Victor Cajas and Clarita Cano de Cajas for their guidance, love, support and for being the best parents and grandparents. To Magaly Cajas for being the best sister and companion, to Sergio Castro for his support and love through the years and for giving me the best nephew- talented, loving, and a great example to my sons.

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General abbreviations and acronyms

A: area or land use

as: animal stage

BC: beef cattle

CO2: carbon dioxide

CO2e: carbon dioxide equivalent

d: day (s)

EBM: edible boneless meat

FCR: food conversion ratio

FI: food intake

h: hour (s)

kg: kilogram (s)

km: kilometer (s)

L: liter (s)

LCA: life cycle assessment

M: methane emissions

NA: not applicable

PS: potato slurry

RA: range of area (S)

RW: range of water

S: soybeans

SO: soybean oil

SWD: specific water demand

T: trout

US: United States

USDA: United States Department of Agriculture

VWC: virtual water content

Wf: final weight

Wo: initial weight

yr: year (s)

$: US dollar (s)

CHAPTER 1: Comparison of water and land footprints and associated environmental attributes of beef and trout production in the Western US

Abstract

The ecological footprints based on estimations from virtual water content, area of land used, and methane emissions from animal (beef cattle and trout) production systems were evaluated. Estimations focused on food manufacture and animal production systems converted into 1 kg of edible boneless meat (EBM). Most water and land resources were allocated for the production of foods rather than the animal production. Different production and marketing systems used in Idaho (USA) used to rear beef cattle showed a wide range of values. A grazing only system may take from two to five years to complete production. Animals only grazing required the highest food intake resulting in the highest average of water footprint, land use, and methane emissions. On average beef production resulted in about 16,250 L water per kg of EBM and 1,000 m^2 of land per kg of EBM. On average, trout production requires 4,500 L per kg of EBM and 4 m^2/kg of EBM. When fish is marketed as a whole dressed presentation a kg of it requires less water and land. However, if water used in raceways is not treated and it is released immediately the volume of water will be detrimental to the water footprinting content. Additionally, methane emissions and phosphorus emissions from beef and trout respectively are identified as a potential source of pollution and degradation of these productions. Methane emissions from beef can be controlled by the type of diet ingested and the use of additives to reduce digestion. Phosphorous effluents from trout production were limited by discharge permits, and mitigated through the on farm settling ponds. Additional opportunities to reduce ecological productions in these productions is evaluating the use of fertilizers, natural and artificial hormones, and other chemicals as well as genetically modified products, in animal protein production.

Introduction

Consumption of natural resources, emissions and effluents from food production have been estimated using various tools such as the ecological footprint (Rees, 1992; Wackernagel and Rees, 1996, Hoekstra et al., 2011), input and output models, and the life cycle assessment (LCA) (Halberg et al., 2005; Vigon et al., 1994; Samuel-Fitwi et al. 2012), that combined can offer a holistic approach to improve our understanding of human demands on the environment, and assist in prioritizing consumer choices and production alternatives. Such assessment tools have become increasingly important to understanding all the sectors of food production (e.g. production, transportation, transformation).

We evaluated two iconic animal protein production systems in the state of Idaho that are important to the food production sector and the economic productivity of the state. The methodology, tools, and assumptions estimated resource use and compare food intake, quantities of water and land needed, and emissions within direct and indirect production systems associated with beef cattle (*Bos taurus*) and farmed rainbow trout (*Oncorhynchus mykiss*) production in Idaho, USA. Both systems have been criticized for their use of natural resources and by using the combined assessment tools to examine resource use, released effluents, and meat yields in the summary comparison. Both production systems are leading agricultural industries for Idaho, and increasingly these two industries are often in conflict regarding allocation of water rights within the agricultural sectors (Mathews, 2015; White et al. 2015).

In 2008 and 2012, beef production was the second largest agricultural commodity in Idaho, with 44 % of Idaho lands classified as rangelands and normally 70% of these as public lands with grazing access (USDA, 2013). Idaho is considered the largest producer of rainbow trout in the United States, produces almost 75% of the trout consumed in the country (Hinshaw et al., 2004; USDA, 2007). Hutson et al. (2005) reported that Idaho used nearly 50 % of the total freshwater used in US aquaculture (Hutson et al., 2005). However, water used in trout production in Idaho is released to surface waters in compliance with water quality standards that require solids, phosphorus and nitrogen reduction (USEPA 2002; 2003, 2006; Fornshell, 2003; Brit et al., 2004; Engle et al., 2005).

For comparison between systems, comparisons between water and land showed volumes and areas required for the major feed ingredients, animal operations using assumptions based on production systems in the State and provided with a range of values to express results using a kg of whole dressed fish and edible boneless meat (EBM).

Using these tools to specified a range of minimum and maximum natural resources used in these productions as an ecological footprint. Revisions of other factors that influence the magnitude of these ecological footprints such as meat consumption, demand, and nutritional value were included in the analysis. The goal of the study was to elucidate the extent of land use and freshwater subsidy for animal protein production.

Literature review

The concept of a human “Ecological Footprint” (EF) can help to identify the resources used to sustain population and human activities. This concept was first introduced by Rees (1992), and has become widespread. The EF is a tool that measures human demands on natural resources along with the Earth’s ecological capacity to regenerate and assimilate wastes and degradation produced by human activities (Wackernagel and Rees, 1996). The ecological footprints can be divided into water, land and energy. With increasing water scarcity, many scientists, regulators, and international organizations are focusing on rationalization of water use and conservation. The UNESCO-IHE Institute for Water Education, the World Water Council, the International Water Management Institute, University of Twente, in the Netherlands are all engaged in understanding and standardizing the water footprint method for natural resource visualization. Articles and special projects have been underway to examine water footprints and water traded among countries (Chapagain and Hoekstra 2004a; 2004b), as well as the water flows between nations in relation to crop trade (Hoekstra et al., 2007) and among different activities and products including livestock production (Chapagain and Hoekstra, 2003).

The water footprint is further divided into three components: blue, green, and gray (Allan, 1998). Blue water is the quantity of evaporated or embodied water withdrawn from ground or surface water, wells, rivers, and reservoirs, for irrigation and other uses that occur during the production processes. Green water is the quantity of rainwater that evaporates or is incorporated in the product during the production process. Gray water is considered the polluted form of water that results from processes of production or a target activity. Globally, green water is the most locally relevant value, because it is the water that if not evaporated by crops or productions will eventually return or refill aquatic systems; aquifers and groundwater systems (UNESCO-IHE, 2008). Most agricultural activities use larger amounts of water from rain-fed sources than from irrigated sources (Rockstrom et al., 1999), and thus ecosystem services and the varying values of blue, green and gray water need to be addressed during the production cycle (Hoekstra et al., 2011).

Galli et al. (2012) expressed that carbon and water (ecological) footprints provided measures to highlight human pressures on natural resources. Additionally, understanding and reducing human consumption can decrease ecological footprints (Wiedman et al., 2006; Ercin et al., 2013; Vanham et al. 2013). Environmental emissions, energy, water, and land used for producing animal diets are indicators helpful in evaluating resource efficiency and environmental sustainability (Boyd et al., 2007). Large volumes of water, land, and carbon have been attributed to animal protein production, especially products from cattle (Hoekstra and Chapagain, 2007; Steinfeld 2006; Pimentel et al., 2004; Gerbens-leenes and Nonhebel, 2002). Ridoutt et al. (2012a) compared water footprints of different beef production systems, and Schafer and Blanke (2012) evaluated the relationship between water and carbon footprints associated with farming techniques and marketing presentations.

Methods and assumptions

Models used here were based on assumptions from data in peer reviewed literature, publicly accessible databases and reports from the Idaho Department of Agriculture, the United States Department of Agriculture (USDA), the Food and Agriculture Organization (FAO), United Nations Educational, Scientific and Cultural Organization (UNESCO). Other data were obtained from site visits and communications with farmers in southern Idaho, University of Idaho extension agents, governmental regulators, and scientists. Data used included a range of sources to obtain values and assure consistency throughout the sources and compensate for errors present in the data sources.

We focused on estimations of land and virtual water used for food manufacture and animal production systems and included other estimations to strengthen the analysis, such as the main greenhouse gas emissions, food consumption choices, and nutritional value. The functional unit was a kg of edible boneless meat. The calculations for the feeding stage included evaluation of major diet ingredients, calculation of the units of food required per unit of animal live weight gained, expressed as a food conversion ratio (FCR), daily average weight gained per animal, and the animal production system from birth to slaughter, for Idaho in the US.

Input and output models were built in Microsoft Excel. The inputs for the models included data relevant to each sector and initial values for animal production as well as food conversion ratios and proportions of the major feed ingredients. The outputs were converted to the area of land (m^2) and volume of virtual water (L) used per kg of whole dressed fish and edible boneless meat (EBM) for beef and fish filets. Additionally, factors that decrease or increase ecological footprints from these productions, such as human consumption, diet choices and relevant greenhouse gas emissions were considered.

<u>Animal systems evaluated</u>

Beef production systems in Idaho

Globally, beef production takes an average of three years from birth to slaughter (Hoekstra and Chapagain, 2007). In Idaho, beef cattle are produced mainly in mixed systems with grazing and feedlot stages and it may take an average of 18 months. Some farmers maintained beef cattle on grazing systems during the animal lifetime. In Idaho, there are large areas for grazing in rangelands, managed by state and federal agencies or private sector that are available for grazing with minimal fees for ranchers. Generally, cows with calves start grazing from 7 to 8 months or when a calf reaches 180 - 200 kg. Then, the young animals could be transferred during 6 months to feedlots, or until they reach their desired final weight of 550-600 kg, or animals continue grazing to reach 250-300 kg or more during 3 to 4 months (or 100 days) and then they go to a finishing stage in feedlots (Carl W. Hunt, professor and head department of animal and veterinary science, University of Idaho, personal communication). The usual age at slaughter time is 15 to 18 months. A typical feedlot (Celvin Jones, personal communication) in southern Idaho starts with a calf of 180 kg of live weight in the production system for 6-8 months to reach a final weight of 568 kg.

Three production system were evaluated:

System I analyzed cattle in grazing systems for their life span, either on a managed, fertilized and irrigated land (FCR 13:1), with grow out for 2 years, or in a more extensive system (FCR 30:1) with grow out up to 4 years.

System II included a long period of grazing during cow-calf and weaning, with a minimum time in feedlots, with the cycle ranging from 16 to 20 months (488-610 days).

System III assumed grazing only for cow-calf stage and a longer period of time in feedlots, ranging from 14 to 18 months (427-549 days) (Figure 1).

Trout production systems in Idaho

The trout production system in Idaho varies and is unique when compared to other finfish systems. Rainbow trout in Idaho are generally raised in a series of concrete raceways supplied with spring water with year around optimal temperatures for rearing trout (15°C). Fish density and number of times of water reuse depend on water conditions such as temperature and dissolved oxygen, slope and farm topography. The common system for trout production includes incubating eggs for about 10 days or until they hatch. Then, the young fish, or fry, are transferred to indoor ponds for about a month. Next, they are transferred to outdoor ponds or concrete raceways, for eight months or more to reach market size. Fish are graded about five times during eight months and placed in different raceways to allow homogeneous sizes for harvest (Fornshell, 2002; Tuomikoski and Hinshaw, 2006).

In the United States, initial weight of trout is around 0.2 g and is harvested from 0.3-0.4 kg/fish after 8.5 to 10.5 months (Fornshell, 2002). Tuomikoski and Hinshaw (2006) evaluated trout production in four states: Idaho, North Carolina, Pennsylvania, and West Virginia, and reported that trout harvested between 9 and 14 months had a final weight ranging from 0.44 to 1 kg/fish, respectively. In 2005, USDA reported Idaho trout had an average live weight of 0.45 kg. The trout life cycle assumed a production cycle of one year to harvest an average fish of 0.5 kg with an initial weight of 0.2 g. The results showed an analysis of one system of rearing (raceways) but included and evaluation for two models for trout production marketing: system Ia - trout to be marketed as a whole (dressed fish) and system Ib - trout to be marketed as filets. The production cycle used 10 to 12 months to reach the final marketing size (0.5 kg/fish).

Variables used to estimate edible boneless meat yields $Y_{(EBM)}$

Worldwide, a beef cow produces around 200 kg of EBM (Hoesktra and Chapagain, 2007). In the US a 568 kg live weight animal will produce around 45% of EBM (USDA, 2007), resulting on 255 kg of EBM/animal. For trout, USDA (2006) reported an average 0.45 kg at the time of slaughter/fish. The percentage of EBM on a dressed fish presented after removal of entrails, head, tail and fins is 75%, representing 0.34 kg of EBM/animal and for fillet presentations, 50% of the live animal weight (USDA, 1992), resulting in 0.23 kg EBM/fish.

Virtual water content (VWC) for beef and trout productions

Water usage analyses were modified using different assumptions, values and models from the water footprint concept (Chapagain and Hoekstra, 2003). Chapagain and Hoekstra (2003) expressed the various components in cubic meters of water/ton of live animal. The following equation helped to estimate the total virtual water content for 1 kg of edible boneless meat (EBM):

$$VWC_{(EBM)} = (VWC_{feed} + VWC_{drink} + VWC_{maintenance})* Y_{(EBM)} \quad \text{(Equation 1)}$$

where, *VWC* is virtual water content (L), $_{(EBM)}$ edible boneless meat (kg), *feed for* feeding ingredients, *drink* for animal drinking water, *maintenance* for animal maintenance in the farm, and $Y_{(EBM)}$ represents animal yields for edible boneless meat (kg). Feeding components assumed that farms were using ingredients grown within the US and the results were estimated in L/animal and divided by yields of kg of EBM. Additional equations were needed to estimate the different components from equation one.

Virtual water content for feeding (VWC_{feed})

The virtual water content of the feed ingredients was estimated as the amount of water required to produce 1 kg of food, and the ratio required to produce 1 kg of EBM was as follows:

$$VWCfeed= [WD\{\sum (RW*C_{(IS)}\} [FI_{as}{}^{(birth)}\int_{(slaughter)} \{(W_f - W_o)*FCR_{(r)}\}] \quad \text{(Equation 1.1)}$$

where WD is the summary of the water range (RW) used in the different ingredients involved in the animal diets (Table 1), and it was then multiplied by $C_{(IS)}$ which denotes the proportion of the different ingredients, forages, crops and grains contained in a kg of animal diet for the different animal stages (Table 2). $FI_{(as)}$ is food intake during the different animal stages from birth to slaughter (kg of food/animal) (Table 3), and it is calculated by final weight (W_f) during the stage evaluated and the initial weight (W_o) in the stage per animal. *FCR* is food conversion ratio (x:1) (kg of food/1 kg of weight gained) and its range $_{(r)}$. Results were expressed in liters (L) of virtual water required to produce a kg of diet and multiplied by the range of food conversion ratio ($FCR_{(r)}$).

Most of our values were compared with water usage/kg of different ingredients using virtual water content (VWC: Falkenmark, 2003) or specific water demands (SWD) provided by different authors (Pimentel et al. 2004; Hoekstra and Hung 2002; Chapagain and Hoekstra 2004b). The VWC is the quantity of water needed throughout the process of obtaining the product. Generally, it is retained in the product, goods or service at the end of the process but it has been evaporated through the process and cannot be used instantly in other activities. SWD is the quantity of water required in crops according to the evapo-transpiration value under optimal growth conditions and the yields harvested per country. SWD will vary depending on weather conditions, equipment used for transporting the water and the technology systems. However, it can also be used to visualize the volume of water needed in each of the crops.

The range of VWC for forages and pastures varies depending on different climatic factors, rainfall, weather conditions, soil, species, management, etc. In the literature, the average for specific water demand for pasture in tropical climate by Chapagain and Hoekstra (2003) was 450 L/kg, and the average for the specific water demand for forages used in Wyoming, neighbor of the State of Idaho, was 1,473 L/kg (USDA and NRCS, 2003). Some of the water used to grow vegetation may be compensated by the ecological services that grazing provides to the area such as decreasing wild fires (Taylor, 2003). Therefore, a range of values spanning from 250 L/kg (grazing on wild rangelands, low vegetation coverage, no irrigation systems and proper management) and 1,473 L/kg were used as the maximum value, even though the latter was shown as an average.

The range value for soybean oil (So) was based on the fraction concept of Chapagain and Hoekstra (2004b). A kg of soybean (S) may produce 0.18 kg of So and 0.79 kg of So cake. The global average market price registered by the authors for a ton of So is $502/ton, and for So cake was $219/ton. Therefore, by the proportion of product obtained/kg of S, the fraction value for the So equals $ 90/ton ($502*0.18), and for So cake $173/ton ($219 *0.79). Therefore, the fraction value equals to the ratio of the marketed value of the fraction product to the aggregated market value of the primary crop ($90/ ($90+$173)) 34.3% or 0.343 of So from the total value of 1 unit of soybean. Then, the minimum and maximum value of water was 1,521 L/kg of S (Hoekstra and Hung, 2002) and 2,060 L/kg of S (Pimentel et al., 1997) to produce a kg of soybean. Equivalent to (1,521 L/kg of S × 0.343 fraction value)/0.18 kg of So; equal to 2,900 L/kg of So and (2,060 L/kg of S × 0.343 fraction value)/0.18 kg of So; equal to 3,925 L/kg of So.

Potatoes produce around 35% of waste co-products (Stanhope et al., 1980), the best way of using this waste, also called potato slurry (PS), is by including it into beef cattle diet, otherwise it becomes an environmental burden and affects economically potato processing facilities (Nelson, 2010). To estimate water and land footprints for the potato slurry used in feedlots in Idaho used the same concept as for the soybean oil and estimated the proportion for the fraction portion with the economical aggregated value. On average, USDA 2013 reported an average of $9/45 kg of all potato for the US. The value of potato slurry was reported to be at around $11.1/ton (Drake et al., 1994). Both values converted to kg resulted to be $0.198/kg of potato and $0.012/kg of potato co-product. Therefore, the fraction value/kg of PS was $0.0042/kg (0.012/kg*0.35) and for potatoes $0.1287 (0.198/kg*0.65) then, 0.032 {0.0042/(0.0042+0.1287)} will be the fraction value for PS from 1 unit of potato. Using our water range of values of minimum 117 L/kg (Chapagain and Hoekstra, 2004b) and maximum value of 858 (Hoekstra and Hung, 2002), the range for PS results on 10.7L/kg of PS{(117*0.032)/0.35} and 78 L/kg of PS{(858*0.032)/0.35}.

The list of crops included in $C_{(IS)}$, for beef cattle production included data found for general forages for the grazing stage and the major ingredients for feedlots, including a comparison between beef cattle and trout diet ingredients in Table 2. For beef cattle in feedlots, one of the two experimental diets reported by Szasz et al. (2005) was used with different proportions: 14 % of potato slurry by-product; 70 % of dry-rolled corn; 7% of alfalfa hay; 3.5% of soybean meal; and 5.5% of other ingredients including dry supplements, urea and limestone. Comparable diets may include 78.4 % corn, 7% ground alfalfa, 32 % of protein and 7.83 % of silage (Campbell et al., 2001). A typical trout diet may include 5% corn, 15% soybeans, 10-15% soybean oil and 10-15% fish oil, 20% wheat, 5% yeast, 5%

vitamins, and minerals, and 25% of fishmeal. These calculations did not estimate ecological footprints for fishmeal but substituted soybean oil for the fish oil in the production.

In the input model for beef cattle, to estimate FI, it was used *Wo* of the cow with calf as the standard weight of 454.54 kg for the cow and 32 kg at birth for the calf, this value was based on 7% of cow's weight (Morris et al., 1986), values supported by other authors (Johnson and Johnson, 1995; Pruitt et al., 2005). Based on the assumptions and data collected for the general beef cattle system to use an average *Wf* reached in each stage as follows: calf during cow-calf stage reached 200 kg, heifer 275 kg, and final weight of 568 kg, average live weight at the slaughter time in the US for 2007 (USDA, 2007). The weight of the calf for the analysis was based on food intake and data based on the cow's weight. In the models, there were not evaluations for extra food (grains) added sometimes during the grazing stage or estimations of the use of hormones or additives, therefore the final weights by stage may differ and be lower than those stated in the literature or reached in farms.

The FCR in grazing systems varies depending on factors such as vegetation type and quality, species, slope, weather, initial weights, water quality and availability. The models included a conservative range for FCR of 13:1 (Alberta Food and Agriculture, 2007) and 30:1 (personal communication with Mr. Lonie Austin, the animal handler at the University of Idaho). For feedlots, we maintained a range from 6:1 to 10:1 (De Wit et al., 1996), which is inclusive to the range given by a personal communication with Mr. Celvin Jones, who said that in Idaho the average FCR in feedlots is estimated as 7:1 or 8:1.

To calculate FI for the trout system, we used *Wo* of 0.2 g fish (Fornshell, 2002) and *Wf* of 0.45 kg (USDA, 2007) and used a range of FCR reported in different farms in Idaho from 0.7:1 to1.26:1 (Tuomikoski and Hinshaw, 2006).

Virtual water content for animal drinking (VWC_{drink})

The estimation of VWC required for drinking was a subsection to obtain the total VWC and it was obtained from the water requirements/animal for their life cycle of production; this step was estimated only for beef cattle. The range of drinking requirements for beef cattle were taken from USDA and NRCS (2003) with a range of 22.5 to 67.5 L/day/beef cattle then, this number was multiplied by the total animal's lifespan (days), using the following equation:

$$VWC_{drink} = {}^{Birth}\int_{slaughter} (Dw * dt) \quad \text{(Equation 1.2)}$$

where *Dw* represented the range of drinking water consumed by animal/day and *dt* the total days spent in the system.

The number of days spent by animals in the different systems varies depending on type of food, FCR, type of the system used and other factors. We used a general range of time spent by animals according to the Idaho literature, USDA and NRCS (2003), and the farm visits. Considering the following variables, for System I, only grazing, we assumed a range of 2-3 years (730-1460 days) equal to 16,425 -73,913 L/animal, for system II and III, mixed systems, a range of 16-20 months (488-610 days) equal to 10,980 – 41,175 L/animal and 14-18 months (427-549 days) equal to 9,608 to 37,058 L/animal, respectively.

Virtual water content for maintenance ($VWC_{(maintenance)}$)

The virtual water content in maintaining animals was the volume of water used daily for cleaning operations, food trays, washing, and used in raceways in fish farms, and it was considered a subsection of estimating the total VWC. The calculation was based on Chapagain and Hoekstra (2003) and modified to incorporate fish systems evaluation. Using the following formula:

$$VWC\ maintenance = \{ {}^{Birth}\int_{slaughter} [(qmaint) * dt]\} \quad \text{(Equation 1.3)}$$

where *VWC maintenance* is the total virtual water content required per animal within the farm; *qmaint* is the volume of water used for animals from birth to slaughter in the operations and *dt* days spent in the system.

The assumptions for water volume maintaining beef cattle and trout vary depending on the type of system, animal age, and farm size. Commonly, beef cattle farms used 1 to 15 (L/a/d) liters of water/animal/day (Chapagain and Hoekstra, 2003). Considering Idaho's weather and systems, we determined for system I, grazing only, (730-1,460 days) a range of 1-10L/a (730-10,950 L/a), for system II and III, mixed systems, a range of 16-20 months

(488-610 days) equal to 2,440 – 6,100 L/a and 14-18 months (427-549 days) equal to 2,135 to 8,235 L/a, respectively.

The water quality regulations for the aquaculture industry require farmers to treat the volume of water from raceways before release into the public waters to remove excess suspended solids and nutrients (USEPA, 2002; 2006). These regulations were developed as a general aquaculture permit to consider the collective nature of the aquaculture industry in Idaho. Because of these regulations, we removed the volume of water that used in the production raceways with sediments removed as water released and not consumed. For our estimates, we considered that VWC for maintaining fish was 1% of water that evaporates during the raceways (Fornshell, 2002). The remaining volume was not considered to be part of the ecological water footprints because the water is drained and treated to be reusable and considered non-polluted.

In Table 4, incremental daily weight during 360-365 days served to calculate production of 0.5 kg/fish, with a flow of 2,180 to 4,796 L/day/kg of fish (Hinshaw et al., 2004), Then, we estimated a range of values for VWC maintenance/fish using 4 to 6 reuses of water in Idaho by Tuomikoski and Hinshaw (2006). An average flow for Idaho raceways was about 92.69 L/s the results showed 1 to 3 L/fish/day. Therefore, our assumption was that 94-311 L/fish/day were treated and reused and 1-4 L/fish/day were evaporated and considered as a VWC for trout production in the maintaining of the fish.

<u>Land use estimations for beef and trout productions</u>

In the study, we estimated land footprints from the area required to produce ingredients for the feed included in the animal production as well as the area allocated/animal in operations/farms. Data used were provided by the annual production or yields and the area needed, therefore the estimations were calculated by area (A)/yr.

For estimating the area used/animal in Idaho, we used the previous calculation/kg of EBM and estimated land for food and then calculate the space required/animal in the farm. Using the following formula:

$$A_{(EBM)} = \int_{\text{Birth}}^{\text{Slaughter}} \{A\ feed_{(EBM)} + A\ operation_{(EBM)}\} \qquad \text{(Equation 2)}$$

where $A_{(EBM)}$ is the area in square meters (m^2) used by kg of EBM in Idaho. $A feed_{(EBM)}$ the area required for the food expressed in m^2/yr for producing the food ingredients in the animal diet per animal and per kg of edible boneless meat. $A operation_{(EBM)}$ represented the area used in the animal farms to produce a kg of edible boneless meat. Additional equations where needed to estimate the components for this equations.

Land use estimations for feeding (A feed(EBM))

For estimations of the area used for the feeding, we used a similar calculation as equation (1.2) for water estimations for feeding and substitute VW for A (area) and AD for range of area estimated for the different diets as follows:

$$A\ feed_{(EBM)} = [(FI_{(EBM)}) * AD]\quad AD = \sum RA * C_{(IS)} \qquad \text{(Equation 2.1)}$$

where A*feed* expresses the total area required by feeding and it was expressed in m^2/year/kg of EBM.

The range value for crops is well studied and was taken from the literature and compiled in Table 5. Assumptions included that all ingredients were grown in the US and provided with a range of land area used during a year by a kg of the major crops included in animal diets from FAO (2007), USDA (2008), Chapagain and Hoekstra (2004b) and Pimentel et al. (2004). Some calculations and conversions were needed in order to obtain the final value/kg of a given ingredient, as most of the data provided values were provided by 0.4 hectares/yr/kg of product. Additional assumptions were used for soybean oil and forages described as follows.

For estimating the area required for producing a kg of soybean oil, we used the same assumptions for minimum and maximum values from $VWC_{(feed)}$ estimations for soybean oil and multiplied the area required to produce the fraction value for a kg of soybean oil. For the minimum value of soybean oil, we used the fraction value from Chapagain and Hoekstra (2004b) equals to 3.12 $m^{2/}$kg and the maximum value of 3.87 m^2/kg from USDA (2008). The range of values was considered from 5.93 m^2 to 21.52 m^2 to produce a kg of soybean oil.

For the potato slurry (PS), as this is a byproduct from Idaho, we used also a product fraction and economical aggregated value described in VWC for feed for PS and estimated the range of land required/kg of potato as follows:

The minimum range of land required to produce a kg of potato/yr was 0.23 m^2/kg of potato (USDA, 2004), and maximum value of 0.25 m^2/kg of potato (Chapagain and Hoekstra, 2004b). Then, using fraction values of 0.032 for PS from 1 unit of potato and 0.35 as the % estimated to be wasted or considered PS. Results showed a total of 0.021 m^2/kg of PS from {(0.23*0.032)/0.35} and 0.023 m^2/kg of PS from {(0.25*0.032)/0.35} per year.

To estimate land and nutritional contents of forages, we estimated the range of values based on the literature and type of systems evaluated. Federal and state livestock grazing permits are generally based on the quantity of vegetation that one animal can graze in a month, expressed as the animal unit month, AUM. The grazing permits are given depending on the quantity of AUMs obtained/0.4 hectare. One AUM is the amount of forage required/month by the standard cow with the calf and it is equivalent to 345.5 or 366 kg of dry matter (DM) from the glossary of range management terms no. 6.105 (USDA and NRCS, 2003; Alberta, 2007). The AUM in rangelands varies according to different conditions, including average of grazable pasture or forage, type and productivity of the vegetation, grazing intensity allowed, amount of area, and distance from the grazing area to water. A range of 0.3 AUMs/0.4 hectare was used as the minimum value found for the western US (Merrit, 2002), and for the maximum range 9 AUMs/0.4 hectare as maximum value found for Utah forages, and expressed into kg of DM/0.4 hectare and converted into m^2/kg of DM, resulting on 56.17 and 1.25 m^2/ kg, respectively (using 360.25 kg of DM/AUM).

Land use estimations for operations (A operations$_{(EBM)}$)

The area used in operations is the land required/yr/kg of EBM expressed in square meters for the different stages. For the assumptions, we created a range of values that included basic information required/animal in the operations. Information was found for animal requirements, assuming that this value will be the one that matter for animal production when needed or in the worst case scenario and when the uses of land would be prioritized. Using the following formula:

$$A\ operation_{(EBM)} = {}^{Birth}\int_{Slaughter} \{(RA\ (as) * (time\ spent/stage)\}/Y_{(EBM)}\} \qquad \text{(Equation 2.2)}$$

For beef cattle, we provided a range of values required for each animal in the different stages. We could not obtain specific data of space required by animals in farms that graze on open areas therefore we used values from feedlots, shade, and area of protection from the cold (Stewart et al. 2006) and used them for all the stages (Table 6). Then, we estimated the range from the area required/animals in the different stages per year. The estimations assumed a range of 60-98 m^2/animal/year.

For trout production, we obtained estimates of the area needed using the recommended density for rearing fish in trout farms 20-80 kg of fish/$meter^3$ and converted into $meters^2$ (0.042-0.0052 m^2) (Hinshaw et al., 2004), using the total volume/raceways (Fornshell, 2002) for the state of Idaho and using a total biomass/raceway, and then divided by the area of the raceways to obtain the area required to maintain a fish of 0.5 kg, the assumptions are detailed in Table 7 and the range of values estimated for trout production area was 0.042 to 0.0052 m^2/fish.

For beef and trout, we estimated the space required for maintaining the animals without considering food storage area, farmstead, and other buildings included in the farms.

Results

<u>Food production</u>

The results obtained from different diets used for animal production systems are shown in Table 8, including the range of virtual water and land needed to produce a kg of each diet used for beef and trout production. Diet I, grazing ranges from 250 L with about 57 m^2/kg of food or 1,473 L with less than 1 m^2/kg of food. Diet II, grains in feedlot, required from 66-77 L and less than 1m^2/kg of food, and diet III used for trout ranged from 864 to 1,217 L and less than 3 kg of food. The ranges of values depend upon the ingredient and the proportion included in each food formula. For forages and pastures the area required resulted to be inversed to the water used to keep the forage growing. In rangelands, the area increased considerably as the yields of dry matter in open lands resulted lower than the yields in irrigated pastures are higher therefore, high volumes of water and low area required. In the feedlot diet, the highest values for virtual water and land were estimated for the corn ingredients in the diet, as it comprised 70%. For trout diet, the ingredient with the highest virtual water and land value was soybean oil.

The food required for producing 1 kg of EBM in the three beef production systems ranged on average of 16 to 37 kg of forage and 7.78 to 12.96 kg of grains, with a minimum of 8.56 kg of forage in system III and maximum of 63.06 kg of forage in system I. The minimum of 6.89 kg of grains was estimated needed for system II and the maximum of 14.43 kg of grains for system III. For trout the average of food required to produce 1 kg of fish resulted on average of 1.28 to 2.30 kg of grains. The minimum value resulted on 1.03 kg of grains in system (Ia) and a maximum of 2.78 kg of grains in system (Ib) (Table 9).

Virtual Water Content

Calculation of virtual water to obtain 1 kg of EBM involved three steps: estimation of feeding, drinking, and maintaining. We used an edible boneless kg as a unit value because the methodology of water footprints is focused on human consumption for the understanding of people's demand on natural resources, especially on land, water and energy. Additionally, for fish consumption, we showed values to obtain a kg of whole dressed fish.

Table 10 showed the estimations to obtain virtual water content (VWC) for feeding the animals while Table 11 showed the values of VWC for drinking and for maintaining animals. Based on animal yields, we calculated the virtual water content embedded in a kg of EBM for beef and trout. Table 12, showed the final values for beef and trout based on the total VWC used for feeding, drinking, and maintaining the animals and the conversion to edible boneless meat (EBM). For trout presentations there was an additional estimation (trout Ic) that included the total water used in raceways. The results of virtual water content for the three different systems of beef cattle range from 8,110 to 93,150 L/kg of EBM, with an average of 31,872 L/kg of EBM. These models differed due to the amount of time each animal spends in each system. System I took the longest, up to four years, and the mixed systems rear production size cattle in more than a year but less than two years. In addition to the type of diet and FCR affects the outcome. System I presented a significantly higher FCR compared to the mixed systems indicating almost double amount of water. The average virtual water content for the mixed systems was estimated at 20,964 L/kg of EBM. The average for system I, only grazing, was 20,400 L/kg of EBM and for mixed systems (II and III) the virtual water content average resulted in 14,200 L/kg of EBM. For the trout the systems evaluated for Idaho (Ia, Ib) the range was from 900 to 8,360 L/kg of EBM. For whole-dress fish the range was from 1,800 to 5,700 L/kg of edible meat and for filets from 2,640 L to 8,360 L/kg of EBM. The virtual water content for fish did not include the amount of water that can be reused/released into surface waters; if this water is included then the total amount of water used may range from 99,500/kg of whole dressed fish or up to 487,520/kg of EBM for fish as evaluated in system Ic (Table 12).

Land use

The quantity of land represents the area used to produce the animals on the farm and the food without accounting for land degradation or rotation. Table13 shows in detail the estimations needed to calculate the area required to produce the major ingredients included in the food consumed by animals in the different systems and models. Estimations of land footprints in the animal operations were expressed in square meters per year. Animal production systems differ in time and it is important to express the area needed to maintain the animals and extrapolate the area into those years. The results for the area required on the farm were based on the estimation of years that animals would need to spend on the farm to reach the final slaughter weight, and we calculated an approximation of the value for land footprints in farm operations. System I production required a larger area per animal, which is relative to the time that animals would spend in a system with grazing only. In that system the use of water and land is an inverse relation, with more land used, less water is needed and vice versa. The range of land required per EBM for beef ranged from 17 to 1,125 with an average of 176 m^2/kg of EBM. For trout the range for producing a kg of whole dressed fish range from 2 to 5 m^2/kg and for fish filets from about 3 to 7 m^2/kg.

Discussion

This study presented estimates of virtual water content (VWC) for beef and trout reared in Idaho by quantifying the food consumed by animals throughout the rearing, the drinking and maintenance water used. The estimations included the land area (A) required to provide the food and the farm operations. The evaluation performed an analysis from the use of water and land to grow major ingredients from the food animal diets and the use of water and land within the animal production facilities. The results helped identify opportunities to maximize the environmental sustainability of beef cattle and trout production systems. We agreed with Galli et al., (2012) that any country working towards sustainability needs to apply multiple tools and indicators to address human pressures and the risks and benefits of different choices. Using tools such as ecological footprints including pressures on land, water, and tracking carbon footprints can help provide a better understanding of human consumption.

Worldwide, beef production system takes an average of 3 years to raise a beef cow to slaughter with an average of 253 kg at the end of the animal life time (Mekonnen and Hoekstra, 2012). In the US, the average beef cow slaughtered weight is 560 kg and yields around 255 kg of EBM (USDA, 2007). The average trout production takes about one year to reach 0.5 kg per fish. To process one kg of whole dress fish takes about three whole fish and to process a kg of fish fillet almost four and a half fish

Food production

Food production is responsible for the majority of land and water used in animal production systems (Aubin et al., 2009; Roque d'Orbcastel et al., 2009). In our results, feed water used in beef cattle and trout represented more than 90% and 50% of water used, respectively. Corn for beef and soybeans used for trout diets had the largest ecological footprints (both water and land). On average, main land-based ingredients used for beef production feeds take about 1,100 L and 2.4 m^2/kg, except for forages and pastures.

When considering substituting ingredients, it is important to evaluate water, land and also energy efficiency. For example, if fishmeal is substituted with soybeans, the VWC will significantly increase because soybean is among the top ingredients with the highest water footprint (around 2,000 L/kg). The footprint of beef production changes when corn is substituted by wheat. According to our range of values (Table I) barley results in higher water and land footprints than corn. However, methane emissions showed to be 32% greater when corn was added in the weaning stage and no apparent differences were showed when corn or barley was added into the finishing stage (Beauchemin and McGinn, 2005). The overall animal ecological footprints are affected by the animal age but especially by the chosen ingredients in the diet (Pahlow, et al., 2015).

From our results, the analysis from a whole fish resulted in the lower food intake (an average of 0.35 to 0.63 kg of grains required per fish. If we estimate how much it takes to produce a kg of whole dress fish or a kg of filets (EBM), the range is from 1 to 2.8 kg of grains. Sheep meat takes about (1.5-2 kg of grains) per kg, chicken (2 kg of grains/kg of chicken meat), goat meat (2.75 kg of grains/kg of goat meat) and beef (6.5 kg of grains/kg of beef) (Mekonnen and Hoekstra, 2012). Food intake for animal production, food conversion ratio (FCR), age and time spent in animal production systems are key factors to decrease environmental footprints altogether with human consumption, especially feed production (Boyd et al., 2007; Aubin et al., 2009). Other considerations need to be made when comparing ecological footprints with other animal productions, especially with the use of antibiotics, hormones and greenhouse emissions. Most animal productions use different type of hormones and antibiotics that trout do not use during the production system (Moffitt, 2005; MacMillan et al., 2006). Therefore, further research in this area is essential for learning and understanding the costs and benefits of these additives and their results to the environment and human health.

Virtual Water Content

The estimation for virtual water content (VWC) in beef cattle production helped us to better understand the differences in ranges and methodologies applied for the estimation of water used by other authors. Worldwide, estimations for water content for 1 kg of EBM of beef varied from 40,000 L/kg of edible boneless beef (Hoekstra and Chapagain, 2007) to 100,000 L/kg (Pimentel, 1997). For the US, Beckett and Oltjen (2003) estimated 4,000 L/kg of beef while Hoekstra and Chapagain (2007) estimated an average of 13,200 L/kg of boneless beef and Pimentel et al. (1994) has estimated 43,000 L/kg of boneless beef. These variations depend upon the type of system evaluated (only grazing or mixed), the scale of the system (extensive or intensive), the use of additives (fertilizers, hormones), quality and quantity of grains included in the diets, as well as the water footprints allocated for rangeland and pastureland used in grazing systems. The presented results showed a range of values according to the type of systems and the assumptions ranged from 8,110 to 93,150 L/kg of EBM. It is possible to reduce the minimum value if we reduce the amount of water allocated to the rangelands. In most beef cattle systems evaluated, the feeding production required most of the water included in the VWC/kg of EBM produced, corresponding to about 98% of the total VWC for beef cattle.

When trout results are compared with global water averages to produce land-based meats such as chicken, goat, pork, and beef from Chapagain and Hoekstra (2006), on average to produce 1 kg of dressed trout (3,750 L/kg of EBM) required lower than the worldwide average water for producing a kg of chicken (3,900 L/kg), a kg of goat meat (4,000 L/kg), pork (4,800 L/kg) and sheep (6,100 L/kg). The average of water needed for producing 1 kg of trout as filet resulted in about 5,500 L/kg, a value lower only to the ones for sheep and beef. The amount of virtual water content for producing a kg of beef differed depending on the system and may take as low as 8,110 L/kg of EBM.

When calculating the water footprint for aquaculture, it is important to evaluate the system, regulations, and farm practices to define the total virtual water content to incorporate in the fish water footprint. The approach was to estimate virtual water content without including the volume of water that is treated and drained with EPA standards of good quality of water (EPA 2002, 2006). It is necessary to assess the fish production system and separate the volume of water that can be treated and reused from the raceways, as well as to define/explain all the indicators considered, and use of energy for aeration when required. Boyd et al., (2007) compared the consumptive and used water values, using data from Yoo and Boyd (1994); they reported an overall water value of more than 85,000 L/kg of trout in un-aerated systems and more than 16,000 L/kg of trout in mechanically aerated systems. From Boyd et al. (2005), presented consumptive water used in un-aerated raceways for trout as 35 L/kg, which represents less than the 1% value that we used as evaporated water from raceways. Roque d’Orbcastel (2009) presented data to show the interdependence of water reduction and increase of energy use to increase aeration, as well as estimated a water dependency of 98,804 L per kg of live weight fish. Aubin et al., (2009) used 52.6 L/kg of live weight fish with a trout flow-through system with liquid oxygen and water-cleaning drum filters at the outlet and flow of 550 L/s, concluding that decreasing water dependence increased energy and cost in the system. When considering water dependency and adding the volume of water required for the feed, the range of water results to be around 65,000 L to 250,000 L/kg of live weight trout for a non-aerated system with an average of 92.69 L/s of flow.

The ranges for grazing systems in Idaho for beef cattle production may result in conservative estimates of water inputs when compared to systems that use full grazing on irrigated forages for the beef cattle lifecycle. For Idaho feedlots the use of potato by-products resulted in lower input and outputs from the feeding production. However, some authors (Ridoutt et al., 2012a; Beckett and Oltjen, 1993; Taylor, 2002) argued that the volume of water used for rangelands or waste products should not be considered as water footprints, but it is important to understand and estimate the overall ecological footprint of these products and other costs and benefits.

Further evaluations to estimate the economic value of the ecosystem services provided by clean water are necessary to make a fair decision and help protect water resources. Even though trout production systems in raceways are highly dependent on water (Fornshell, 2002; Aubin et al., 2009), these systems can significantly reduce their water footprint if post-treatment is included within the production, especially through regulations, as it is in the State of Idaho. Environmental benefits need to be accounted for during the production systems to justify the costs of treating water from small trout operations, instead of the treatment being an economic burden (Engle et al., 2005). In other words, the incentive on tax reduction as suggested by León-Santana and Hernandez (2008) could help aquaculture and also beef producers to apply best management practices and assist in reducing their water footprint.

Land use

The quantity of land occupied by beef cattle production on average resulted to be hundreds of times larger (~1000 m^2/kg of EBM) when compared with other values to produce crops or other plant protein (average 2.41$m^{2/}$kg of plant protein), other values are expressed in Table 6. Among plant based protein sources the highest values for land were for soybeans (4 m^2/ kg) (USDA, 2008). Countries were livestock are produced, especially cattle, are highly demanding on their land and water resources with animal production footprints being higher compared with other foods or beverages (Gerbens-Leenes and Nonhebel, 2002).

According to Boyd et al. (2007) the amount of land required to produce basic ingredients for trout production is around 0.81 $m^{2/}$kg of live animal. In our results, including feed and land in farms, the overall average range was from 1.4 to 3.5 m^2/kg of live weight animal. Compared to other plant-based ingredients (from Table 6), the average value of land required per kg of trout EBM is lower than the average area required for most plant-based ingredients.

Overall, the relationship between use of water and land requirements seems to be inverted; probably because the more intensive systems (less land) the greater volumes of water are needed. However, when rangelands are not well managed (large areas) it may also increase the overall footprint, as it needs more energy to transform the feed, more time to reach the desired animal weight, more additives required in the animal system, and possibly more water when water estimated. It is important to maintain high vegetation coverage in rangelands to obtain higher yields of dry matter and decrease the water footprint allocated to ecosystem services in beef production. Careful evaluation of practices to reduce water usage need to be studied as Roque d'Orbcastel et al. (2009) presented in their comparison the two types of trout production systems, concluding that re-circulating systems decrease amounts of water but increase energy use. However, it is important to evaluate the possible trade-offs of best management practices not only in the environmental sector but also in the socioeconomic costs and benefits.

The biology of fish, the type of systems used, raceways, and the quantity of feed required to produce fish are some of the advantages of the production of animal protein for human consumption over other types of livestock. Additives such as insecticides, fertilizers, antibiotics, and use of hormones are applied in beef cattle production and plant production for feed to keep control of the system and obtain more efficiency, decrease greenhouse emissions, and also to control pathogens in feedlots (Mathews, 2001; FDA, 2002). Further research is needed to estimate wastes and pollutants that damage the quality of soils and water associated with use of these additives, as well as their overall impacts on quality of the environment and human health (Steinfeld et al., 2006). Overall water and land footprints increased almost double when fish are presented as filets instead of as a whole.

Environmental factors included in the ecological footprints of trout and beef production

Feed production for animal production system is responsible for major changes in global warming and potential for acidification (Aubin et al., 2009). Roque d'Orbcastel et al. (2009)

and others identified that FCR plays an important role as an indicator for the use and effects of environmental results. The FCR for trout production is significantly lower when compared to the FCR for beef cattle, therefore to produce equal amount of final product, trout will result in lower quantity of emissions and overall water and land used.

The process of evaluating ecological footprints can aid in exploring choices in consumption from foods to goods and services. Through this project we provided a general analysis instrument that can help resource managers and the public comprehend the nature of the resources needed for production of their food. However, this project has not included social and economic resources into the models, nor have we considered changing values and regulations. Further explorations of these attributes can assist in a more complete evaluation of sustainability. Fleischhauer et al. (1998) defined three factors for evaluating the sustainability of animal production. The first factor is the relationship between the use of resources and oriented goal as marketing or subsistence. The second factor is socio-cultural influences and food preferences affecting the production demand; and the third factor is consideration of agro-ecological conditions, including the environmental and the human resources available. An additional factor, not included by Fleischhauer et al. (1998) is the change in population growth and food preferences that can occur through pricing, availability or consumer choice (Auestad and Fulgoni 2015). Renault and Wallender (2000) estimated that changing half of beef consumption to chicken would result in a 13% decrease of water use, while a vegetarian diet would decrease water used by 81%. The availability, quality of resources regulations and infrastructure will affect not only the operational use patterns in any region but water in the most limiting factor in agricultural or aquaculture production. Recent estimates report that global water withdrawal will continue to grow under stress from consumption and climate change (Ercin and Hoekstra 2014).

From our results, the average quantity of water and land used for beef production was between 20-32,000 L and about 1,060 m^2/ kg of EBM for beef, compared with an average of 3-6,000 L and about 4 $m^{2/}$kg of EBM for trout, respectively. Therefore, substituting 50% of beef consumption with trout may decrease 40-47% of water, depending on the trout system and presentation.

Other factors included in the ecological footprints of trout and beef production

Other factors affect ecological footprint of trout and beef production and understanding them provides a better picture of human pressures on the Earth. In my results, consumption patterns, portion sizes, nutritional value, and advantages and disadvantages of including beef and trout in human diets from the literature reviewed are included. I summarized some health and demographic data to illustrate the extent of beef consumption in the US.

In 2010, the consumption of beef reported by USDA and FAO for the US was around 40 kg/per capita. Overall consumption during the past decade has been maintained around 12 billion kg/yr for the US. Trout consumption is less than a 0.5 kg/person/yr in the US, and no separate statistics were available.

A suggested serving of 85 g (3 oz) of beef contains 24 g of protein, and a trout serving of 85 g contains 21 g protein. Drummond and Brefere (2004) reported that 85 g of beef contained 14 g of fat of which 5.4 g are saturated, while trout contained 6 g of fats including 1.8 g of saturated fats. In a beef portion there are 82 mg of cholesterol and 58 mg of cholesterol in trout. In addition, the consumptive size portion of beef compared with fish is normally higher than 85 g. In a restaurant in the US the average portion size for beef is around 340 g (12 oz).

Excessive consumption of red meat and related products (~1 kg/week) is linked to a higher risk of diabetes, colon cancer, heart disease, obesity, arteriosclerosis, and stroke (Cummings and Bingham, 1998; Chao et al., 2005). In 2008, US statistics showed that the average beef consumption was 41 kg of beef/person/yr, equivalent to 1 kg in 9 days (USDA, 2010). These statistics are divided by the total US population and not by meat-eaters only; thus by including meat-eaters only, this value is likely higher. According to Davis and Biing (2005), age, gender, culture, race, ethnicity, and income determine/capita beef consumption. In the US, beef consumption in 2005 averaged 30 kg/person/yr, with men eating more beef than women; their average was 39 and 22 kg/person/yr, respectively. Young males between 20-39 years ate the most beef 50 kg of beef/yr.

Including fish in human diet offers health benefits and decreases risk of cancer, heart disease, Alzheimer’s disease and rheumatoid arthritis (Cummins and Bingham, 1998; He et al., 2002; Hu et al., 2002; Chao et al., 2005; Geelen et al., 2005). Trout raised through aquacultural methods in Idaho presented less than 1ppm of mercury, which is lower than the permissible value for fish (Santerre et al., 2001). Another concern from animal protein consumption is the risk of zoonotic diseases, which is more common in beef than in trout production (Davis et al., 2007; Madden et al., 2007).

Greenhouse gas emissions for beef cattle production

Carbon dioxide, methane, and nitrous oxide are the main greenhouse gas emissions (GHG) responsible for global warming and climate change, and CO_2 is considered as a common unit to estimate carbon footprints. Evaluating GHG emissions could be the key to control emissions that impacts the environment, especially for livestock. GHG are associated with the production of animals as well as the production of the feed ingredients, including type of transportation used, fuels, fertilizers, herbicides, wastes and management practices (Flessa et al., 2002; Vergé et al., 2007). Livestock and cattle production itself are responsible for a large quantity of these emissions (Gerbens-Leenes and Nonhebel, 2002; Pimentel et al., 2004; Steinfeld et al., 2006; Hoekstra and Chapagain, 2007).

Worldwide methane emissions from enteric fermentation from ruminants were estimated in 2000 to reach 1.6 Gt CO^2equivalents, and cattle were responsible for ~77% of that amount. Mixed crop-livestock systems produce the majority of these emissions (61%), while grazing contributed about 12% of the emissions (Herrero et al., 2013). Based on 2003-2005 data, GHG emissions for the beef sector for the European Union (EU-27) were estimated at 0.192 Gt CO2e (36% coming from entering fermentation) (Lesschen et al., 2011). On per kg of beef basis, GHG emissions were assessed as 22.6 kg CO2e/kg. It has been estimated that global average emission intensity for all livestock commodities was 41 kg CO2e per 1kg of edible animal protein. However, local emission intensities from livestock depend on the production system, feed type and quality (better food = less emissions), and on geographical location/climate (Herrero et al., 2013; Lesschen et al., 2011). Additionally, proper manure management or application of manure to pastures may also result in different GHG emission intensities. Introduction of intensive grazing and rotational grazing could reduce GHG emissions by 10% (Pattey et al., 2005; Phetteplace et al., 2001). When combined with best management practices for pastures and rangelands, soil carbon sequestration could also increase by 15-30% (Phetteplace et al., 2001, Smith et al., 2008).

FAO in 2006, presented data about livestock production being responsible for 18 % of GHG emissions, and was concluded to be a larger problem for warming the atmosphere than the carbon emissions produced by land transportation, in some countries (Pitesky et al. 2009). If we based on Johnson and Johnson, 1995 we estimated that one kg of EBM of beef produced on average 0.5 kg of methane, if compared the effect of methane with the effect of the CO2 in a hundred-year cycle (1:22) (Intergovernmental Panel on Climate Change, 2001; Steinfeld et al., 2006), this value will result to be equivalent to 11.03 kg of CO2. This is estimating the digestion from the animals only. Different authors have studied and reviewed greenhouse gases in beef production systems and in trout, and depending on the extend of the evaluations, the results from a life cycle assessment showed a range from 10.7 to 30 kg CO_2 eq per kg of live weight (Cederberg and Stadig, 2003; Beauchemin et al., 2010; Lesschen et al., 2011; Stackhouse-Lauson et al., 2012).

Methane emissions showed a significant difference between the stage of the animal (cow-calf, heifer or adult) and the feeding system, grazing or feedlot. Adults emitted the highest value of methane/day when compared to the younger animals and during the grazing systems. Therefore, cow-calf stage presents the highest amount of methane emitted (Stackhouse-Lawson et al. 2012) but also heavy-adult animals staying longer in pastures, as in our system I. Farmers may be able to decrease beef cattle methane emissions, with possible solutions coming from use of genetically modified animals, feed additives or feed ingredients substitutes, and growth promotion additives to intensify the system and improve animal productivity (Machmüller et al., 2003; Alford et al., 2006; Beauchemin et al., 2008; Stackhouse et al., 2012; among others).

The unique nature of trout farms concentration in the region of southern Idaho has allowed for effluent guidance of discharges for the entire industry (USEPA 2002). However, some discussion of the typical releases is warranted. True et al., (2004) characterized five trout farms in southern Idaho and their effluents. Through regulation, phosphorous (P) discharge is currently limited to net concentrations of 0.1 mg/L, and best management practices are used for feeding, raceway cleaning and solid waste control with settling ponds (MacMillan et al., 2003), as well as use of reduced phosphorous feeds (Lellis, 2004). Most all facilities use quiescent zones located in the downstream section of the raceways, and then remove settled materials from production to basins for further settling. True et al., (2004) estimated that the flow through accounted for 85–99% of the total farm flow and was characterized by total suspended solids < 5 mg/L and total P less than 0.1 mg/L. The off line settling areas constituted 1 – 15 % of the flow. If none of this water was reusable or treated then, more than 94 to 311 L would be allocated for trout production water footprints per day during the production system (about 10-12 months).

Emissions of greenhouse gases (GHG) from fish aquaculture are difficult to assess directly. This is due to different fish production systems examined and waste post-treatment methods employed. With many confounding factors carbon emissions can vary and assessed values may be hard to compare between different systems and settings. It is postulated, however, that the majority of carbon footprint from fish aquaculture may come from fish feed, accounting for approximately 90% of carbon equivalents depending on the type of production and cultivated species. Besides greenhouse gases emissions, about 25% of carbon may be accumulated in sediment from added feed (Adhikari et al., 2013). Importantly, average GHG fluxes in pond aquaculture may be season dependent, and differ based on geographic location of production (Yan et al., 2015). Boyd and coworkers provided one example of GHG emissions from a US aquaculture system. They estimated total carbon emissions for US farmed catfish as 1.64 kg CO2/kg of live fish but there is potential carbon sequestration in sediment assessed as 1046.5 kg CO2/ha/yr (Steeby et al., 2004, Boyd et al., 2010). According to the authors, catfish had lower C footprint than pork (1.81-3.63 kg CO2/kg) or beef (5.44-7.26 kg CO2/kg).

As sediments and waste generation are important for carbon footprint estimations, methods are being developed to limit waste and sediment accumulation from aquaculture production systems. Integrated dynamic aquaculture and wastewater treatment modeling with recirculation systems provide alternatives to traditional fish rearing in ponds and raceways. Reported reductions of nitrate levels can reach up to 75%, and when combined with reduced carbon footprint of the system, can be important for future growth of aquaculture industry (Wil et al., 2009). Use of recirculation systems may also decrease pressure on marine ecosystems from marine aquaculture, are it is possible to develop environmentally sustainable land-based marine aquaculture (Tal et al., 2009). System described by Tal and coworkers offers 99% waste reduction and water recycling, combined with 99% fish survival and faster growth of gilt-head seabream (~4.5 months) when compared to the traditional system. Their saline recirculation system may be site-independent, biosecure, without t releasing environmental contaminants (biological waste treatment and water recycling) and suitable for different cultivated species. Use of recirculation systems may provide a promising alternative to sustainability of aquaculture and increase of food security, especially when compared to traditional net-pen aquaculture.

Finally, fish production can be used to decrease carbon footprint of beef and agricultural production by direct integration as described by Ogburn and White (2011). In their example from Philippines, sugarcane residues from farming were used in silage production and cattle feedlots. After biodegradation and processing, silage is used in feedlots and saline treated wastes are used for algae production (algae and cyanobacteria then are used in feedlots, fertilization of sugarcane fields and fish feed). Integration of these different production types and resource/waste reuse provides opportunities for waste reduction and significantly decrease emissions of greenhouse gases. It was estimated, that this type of integrated production might save about 12.9 tons of CO_2e/cow after 300 days. Milkfish (*Chanos chanos*) production from that system was estimated at 3 tons of fish/ha, which was 8 times the national average, with additional output being beef and sugarcane products.

Use of an integrated system not only has contributed to improved social and economic development the local community (employment provided to approximately 400 local families) but also decreased carbon footprint of beef production. This type of system has a great potential for application in many regions of Asia-Pacific, Africa and the Americas for food production and development of local rural communities, diversifying income otherwise coming only from only sugarcane or beef production.

Limitations of this study

The objective of this study was to evaluate and compare ecological footprints for beef and trout for human consumption using the virtual water concept and land estimations. This study did not evaluate the capacity to increase either of these industries or systems, and clearly in the state of Idaho, water resource allocation will limit expansion. One challenge of this assessment was the lack of uniformity of units. All units were converted to the international system. Virtual water was a tool to estimate the volume of freshwater embedded in the manufacture of human products and meat production. Land use estimates were difficult to obtain because of the wide range of use patterns.

Also, this study did not provide estimates for water and land for the processing of meats or secondary products from the reuse edible or “waste” products of beef and fish, such as leather or sausages. Use of “waste” products and by-products require additional resources, and not only water, land and energy but also costs and benefits need careful review. The evaluations for food in the grazing stage were complicated as the information provided through interviews and in the literature does not specify the type of pastures and/or roughages utilized per system. The term forages was used to identify all type of vegetation involved in the grazing stage. In the trout production estimations, other environmental concerns such as effects from escaped fish or use of genetically modified fish were not considered (Moffitt, 2004).

Conclusions and personal assessment

An average steak plate (9 ounces, 0.25 kg) consumed represents 4,000 L of water, greater than the average global water footprint per person of 3,795 L/day (Hoekstra and Chapagain, 2007). The emissions are equivalent to driving around 10 miles in an average mid-size car. Consuming 3 ounces (0.083 kg) represents 1,350 L per plate and driving around 3 miles. When evaluating environmental indicators from human activities indicators of the socioeconomic sector need to be addressed. Mauerhofer (2008) suggested the 3 pillars of sustainability development and I suggest the need to address them within a life cycle assessment framework. Fresco and Steinfeld (1998) proposed that the direct or indirect values of the environment in goods should be added to the final price.

Beef and trout protein are high quality, add to the economy and provide other social benefits, such as job security, foreign exchange and others. In addition, regulations in the United States focus on reducing wastes and pollution for both productions and benefit the ecological footprints of animal production systems (EPA, 2003, 2006a). There is asymmetry between use of land and water, especially for beef production; as the increment on demands from water grows more rapidly than the demand for land in Idaho. Irrigated pastures significantly reduced the value for land, but put more demand on water, as well as fertilizers and probably other additives in the production system. Further comparisons between water, land and energy need to be considered when substituting a product included in diets. Substitutes for fishmeal and fish oil with additional soy products will result in higher demand on agricultural products, higher amounts of freshwater and additives used, and increment in price. When substituting corn with other ingredients such as barley, water and land use, as well as methane emissions increase significantly.

Meat consumers and countries that produce large quantity of livestock leave a larger footprint than others (Gerbens-Leenes and Nonhebel, 2002; Chapagain and Hoekstra, 2003). Animal protein production has measurable and un-measurable social, economic and environmental effects. However, when implementing best management practices, it is possible to decrease some of the environmental footprints created by the animal production (Godfray et al., 2011). LCA tools can help understand better long-term effects of natural resources used and provide with a good tool for measuring and standardizing sustainability (Aubin et al., 2009; Ayer et al., 2009; Boyd et al., 2007).

Human and environmental benefits should be considered, in addition to costs as well as marketing presentations. Increased research and evaluations regarding ecological footprints will help managers and the public understand the complexities of the many production systems used for animal and plant based proteins.

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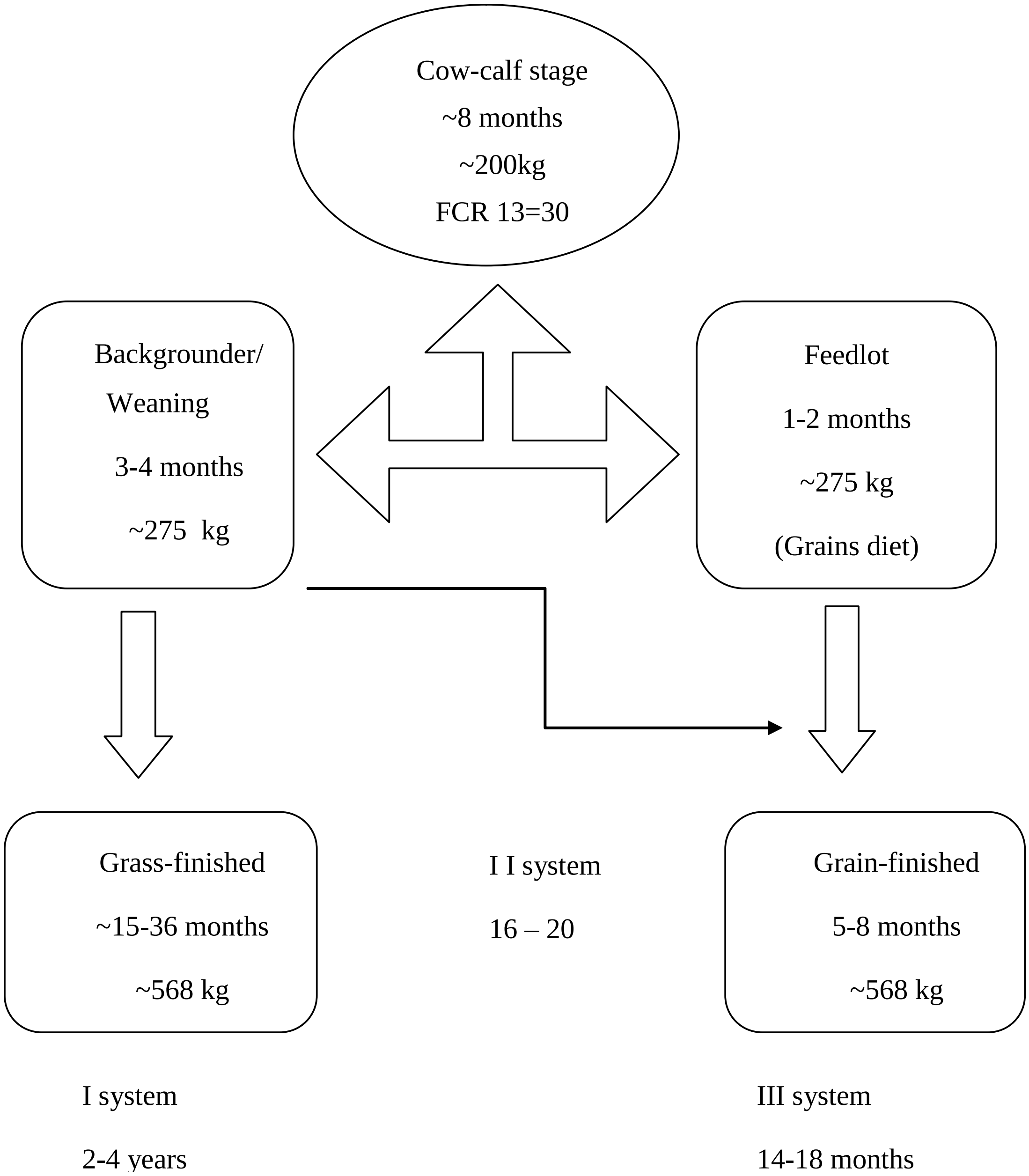

Figure 1. Different systems to produce beef cattle from birth to slaughter.

Table 1. Range of virtual water content (VWC) needed to produce different ingredients (L/kg) used for feeds for beef cattle and trout production grown in the United States.

Ingredient	Range of VWC (L/kg)
Forages	250[a] - 1,473 [b]
Alfalfa	900 [c] - 1,100 [d]
Barley	774 [e] - 1,232 [f]
Corn/maize	416 [f] - 650 [d]
Potatoes	117 [e] - 858 [f]
Potatoes slurry	11 [a] – 78 [a]
Sorghum	656 [f] - 1,300 [d]
Soybeans	1,521 [f] - 2,060 [a]
Soybeans crude oil	2,900 [a] - 3,925 [a]
Wheat	900 [d] - 1,435 [f]

[a]based on our assumptions defined in the virtual water content for feeding section, [b]USDA and NRCS 2003h, [c]Pimentel et al., 1997 a, [d]Pimentel et al., 2004b, [e]Chapagain and Hoekstra 2004b, [f]Hoekstra and Hung 2002.

Table 2. Different proportions of grains are included in beef cattle and trout diets, including beef diets with a range of FCR of 6-10 and trout diets with a range of FCR 0.74-1.26. (For the grazing diet we used a 100% of a variety of pastures).

	Proportion of ingredients (%)	
Ingredients	Beef cattle diet (feedlot)	Trout diet
Alfalfa	7	
Corn/maize	70	5
Potatoes	14	
Soybeans	4	15
Soy crude oil		15
Wheat		20
Fish meal [a]		25
Fish oil [a]		10
Miscellaneous ingredients	6	10
Total	100	100

[a] We did not estimated values for fish meals or fish oil, however to include inputs from oils we substituted the proportion of fish oil into soy crude oil.

Table 3. Food intake per animal (beef cattle or trout) in the different stages based on the food conversion ratio (FCR) (kg of food to gain 1 kg of weight) and weight.

Production	Diet type	Weight Wo kg	 Wf	 FCR kg	 Food Intake (FI)[a] kg food/ animal
Beef Cattle Production					
Cow-Calf	pastures	32	200	13-30	2,184 – 5,040
Backgrounder	pastures	200	275	13-30	975 - 2,250
Backgrounder	grains	200	275	6-10	450 - 750
Finishing	pastures	275	568	13-30	3,809 – 8,790
Finishing	grains	275	568	6-10	1,758 – 2,930
Trout Production	grains	0.0002	0.5	0.74-1.26	0.37 – 0.63

[a] Using formula FI(as)=[(Wf – Wo)*FCR].

Table 4. Estimation of virtual water content (VWC) for maintaining fish in Idaho trout farms. Based on a range of VWC per fish.

Time	Fish Weight		VWC (Maint) /fish[1]	
Days	kg		L/fish/day	
	10 months	12 months	10 months	12 months
0	0.0002	0.0002	4-10	4-10
100	0.16	0.13	344-757	288-634
200	0.32	0.27	701-1,543	587-1291
305	0.50	0.41	1,077-2,368	900-1981
365	-	0.50		1,080-2,375
Average			532-1,169	572-1,258
Reuses (4)			133-292	143-314
Reuses (6)			89-195	95-210
Range of water used			95-314	
Reusable water (99%)			94-311	
VWC (maint) evaporated 1%			1-4	

[1]Assumptions: incremental daily weight during 305 or 365 days to produce 0.5 kg per fish; carrying capacity of 2-9 kg/lpm (Hinshaw et al., 2004). Flow of 2,180 to 4,796 L/kg of fish/day. 4-6 reuses of water per raceway (Tuomikoski and Hinshaw, 2006) and an average of 1% of water evaporated through the system (Fornshell, 2002).

Table 5. Range values for area required (m^2/kg) for forages and different crops grown in the United States included in animal diets per year.

INGREDIENTS	RANGE m^2/yr/kg
Forages	1.25 a - 56.17b
Alfalfa	0.88 c - 0.89 d
Barley	2.87 e - 3.13 f
Corn/maize	0.69 e - 1.08 f
Potatoes	0.23 d - 0.25 e
Potato slurry	0.021 g - 0.023 g
Sorghum	2.02 c - 2.44 e
Soybeans	3.12 d - 3.87 h
Soybeans crude oil	5.93 g - 21.52 g
Wheat	1.97 d - 3.58 e

Sources: [a] Stenquist, 2002, [b] Merritt, 2001, [c] Pimentel et al., 2004, [d] USDA 2004, [e] Chapagain and Hoekstra 2004(b), [f] FAO 2007, [g] based on our assumptions defined in land use estimations for feeding section , USDA, 2008 [h].

Table 6. Range of area required per beef cattle during the different stages based on values provided by Stewart et al. (2006). Values for cow-calf stage were based on areas used in feedlots.

Areas required	Cow-calf m^2/animal	Backgrounder	Finishing	Total
Feeding area[a]	15-28	14-23	18-28	47-79
Shelter or shade area	2-3	1-2	2-3	5-8
Cold confinement	4-5	2-3	2-3	8-11
Range per stage	21-36	17-28	22-34	60-98

[a]Feeding area based on good drainage, unsurfaced

Table 7. Range of values for area required to produce one fish (0.5 kg) in raceways.

Factors used for estimating trout production area	Range (m^2/animal)[a]
Carrying capacity (kg/m^3)	20-80
Length (m)	18-40
Wide (m)	2.5-6
Water depth (m)	0.6-1.2
Area (m^2)	45-240
Volume (m^3)	27-288
Biomass (kg/raceway)	540-23,040
m^2/fish	0.042-0.0052

[a]Assumptions: carrying capacity of 20-80 kg of fish per cubic meter (Hinshaw et al., 2004) and range of raceways sizes from Fornshell (2002) to converting values into biomass (kg/raceways) and then, we estimated the area required by a fish (0.5kg) into m^2 per fish.

Table 8. Range of virtual water content (RWC) and range of area (RA) required by the major ingredients included in the three different diets.

	Proportion kg	RWC[a] L/kg	RA[a] m^2/kg
Diet 1 (grazing)			
Forages and pastures [b]	1.00	250-1,473	1-57
Diet 2 (feedlot)			
Alfalfa	0.07	6 6-77	0.06-0.07
Corn/maize	0.70	291-455	0.48-0.76
Potatoes	0.14	16-120	0.03-0.04
Soybeans	0.04	53-72	0.11-0.14
Other ingredients (not evaluated)	0.06		
Total	1.00	423-724	0.69-0.99
Diet 3 (trout production)			
Corn/maize	0.05	21-32	0.03-0.05
Soybeans	0.15	228-309	0.47-0.58
Soybean oil	0.15	435-589	0.89-1.11
Wheat	0.20	180-287	0.39-0.72
Other ingredients (not evaluated)	0.35		
Total	0.90	864-1,217	1.79-2.46

[a] The results from RWC and RA based on $\sum\{Rx*C_{(IS)}\}$; x equals to RW or RA from equation 1.1 and equation 2.1, where *RW* is the range of water required (L) per kg of pastures or crops included in the animal diets, $C_{(IS)}$ is the proportion of the different ingredients contained in a kg of animal diet in each of the animal stages (kg of each ingredient/kg of food) and RA is the range of land required per year per kg of

[b] Values for forages and pastures where inverse, the lowest value of water required was for the largest amount of area.

Table 9. Food intake per animal (beef cattle or trout) from birth to slaughter and per kg of EBM for the three beef cattle production systems and for Ib trout fillets systems the two type presentations for trout production. Empty cells denotes none considered for the models.

System	Food per animal (kg)				Food per kg of EBM (kg)			
	Pastures		Grains		Pastures		Grains	
Beef Cattle production								
I	6,968	16,080	-	-	27.33	63.06	-	-
II	3,159	7,290	1,758	2,930	12.39	28.59	6.89	11.49
III	2,184	5,040	2,208	3,680	8.56	19.76	8.66	14.43
Average	4,104	9,470	1,322	2,203	16.09	37.13	7.78	12.96
Trout production								
Ia			0.35	0.63			1.03	1.85
Ib			0.35	0.63			1.52	2.74
Average			0.35	0.63			1.28	2.30

[1]For beef cattle an animal is about 568 kg and for trout is about 0.5 kg per animal.
[2]A beef cow yields about 255 kg of EBM and one kg of whole dressed trout required 2.94 fish and a kg of EBM for trout 4.35 fish.

Table 10. Range of forages and grains required per animal in the different systems and grains required per fish in raceways with its range of virtual water content (VWC).

	Food Intake (kg/animal)		Range of VWC (L/animal)[1]	
System	Forages	Grains	Forages	Grains
I	6,968 - 16,080	0	10,263,864 - 4,020,000	-
II	3,159 - 7,290	1,758 - 2,930	4,653,207 - 1,822,500	745,067 - 2,121,965
III	2,184 - 5,040	2,208 - 3,680	3,217,032 - 1,260,000	935,784 - 2,665,130
Trout		0.35 - 0.63		302 - 767

[1]Assumptions: grazing diet (250-1,473 L/kg of forages and pastures), feedlot diet (423.82-724.22 L/kg of grains diet) and trout diet (1,153.95 -3,492. L/kg).
Based on VWCfeed =[(birth)∫(slaughter) (FI(EBM))*∑ { (RW*C(IS))] (equation 1.1)

Table 11. Range of values for VWC for drinking and maintain animals. Range of values provided in the different systems evaluated, I, II, and III for beef cattle and for trout.

System	Days		Ref [1] L/animal		VWC drinking[2]		Ref [3]		VWC maint	
Beef production										
I	1,095	1,460	23	68	24,638	98,550	1	10	1,095	14,600
II	488	610	23	68	10,980	41,175	5	10	2,440	6,100
III	427	549	23	68	9,608	37,058	5	15	2,135	8,235
Trout	305	365					1	3	291	1,148

[1] USDA and NRCS (2003)
[2] modified from Chapagain and Hoekstra (2003). Based on $VWC\ drink = {}^{Birth}\int_{slaughter} (Dw * dt)$. (equation 1.2).
[3]Based on $VWCmaintenance = \{ {}^{Birth}\int_{slaughter} [(qmaint)*dt]\}$(equation 1.3).

Table 12. Final range of virtual water content (VWC) per kg of EBM [1]for beef and whole dressed fish and EBM (filets) for trout.

	Range of VWC[2] Feeding	Drinking	Maintaining	Total	Average	Special average[3]
Beef cattle production						
I (min)	14,141	68	15	14,224		
(max)	92,571	474	105	93,150		
II	8,823	42	9	8,874	31,872	
	34,262	159	35	34,457		20,965
III	8,068	35	8	8,111		
	32,252	136	30	32,418		
Trout production[4]						
Ia	900		900	1,800		
	2,400		3,300	5,700		4,625
Ib	1,320		1,320	2,640	99,487	
	3,520		4,840	8,360		
Ic3	900		90,000	90,900		
	3,520		484,000	487,520		

[1]Assumptions: using conversion factors for yields of EBM per animal: where beef cattle yields are 255 kg of EBM per beef animal in systems I to III and trout 0.34 kg for a whole fish presentation (Ia) and 0.23 for filets (Ib).
[2]VWC(EBM) = {VWC feed + VWC drink + VWC maintenance}Y(EBM) (equation 1), where VWC is virtual water content required for feed, drink and maintenance per kg of edible boneless meat Y(EBM).
[3]Special averages were estimated for mixed systems for beef cattle (system II and III) and Idaho systems for trout (Ia and Ib)
[4]System c denotes the total of water used in the raceways without estimation of reusable water or treated. Minimum value is provided for a kg of whole fish trout and maximum for fillets

Table13. Range of area (RA) required for producing animal feed for different production systems for beef and trout from birth to slaughter. Empty cells have no value.

	Area required		Total Range[1]
	m^2/forages	m^2/grains	m^2/animal
Beef cattle production			
System I	8,710 - 903,213		8,710 - 903,213
System II	3,949 - 409,479	1,206 – 2,897	5,155 - 412,376
System III	2,730 - 283,096	1,515 – 3,639	4,245 - 286,735
Trout production		0.63 – 1.55	0.63 - 1.55

[1]Based on $A_{feed} = [\int_{Slaughter}^{Birth} (FI_{(EBM)}) * AD]$ $AD = \sum RA * C_{(IS)}$ (equation 2.1).

Table 14. Final Range of Area (RA) per animal and per kg of edible boneless meat (EBM) for the different systems evaluated.

Range of Area required								
Systems	Afeed/animal		Aoperations/animal		Total per animal		Total per EBM	
	m^2							
Beef cattle production								
I	8,710	903,213	156.7	350.71	8,867	903,564	34.7714	3543.39
II	5,155	412,376	96.7	158.71	5,252	412,535	20.5949	1617.78
III	4,245	286,735	96.7	158.71	4,342	286,894	17.0263	1125.07
Trout production								
Trout a	0.63	1.55	0.01	0.02	0.64.	1.57	1.87	4.61
Trout b							2.76	6.82

[1]$A_{(EBM)} = \{A\ feed_{(EBM)} + A\ operation_{(EBM)}\}$ (Equation 2)

Table 15. Range of methane emissions per animal (RMa) based on [a] the methane loss per animal per day from Johnson and Johnson (1995).

System		Liveweight in kg	out	Time (days)		Methane kg/day	RMa[1] kg/a	
Cow-Calf	pastures	32	200	244		0.21	51.19	
Backgrounder	pastures	200	250	92	122	0.14	12.42	16.56
Backgrounder	grains	200	250	31	61	0.09	2.81	5.63
Finishing	pastures	250	568	730	1,095	0.17	124.79	187.18
Finishing	grains	250	568	153	244	0.10	15.71	25.14

CHAPTER 2: Input-Output Analysis of Economic Contributions from Mussel (*Mytilus* spp.) Aquaculture Production Provides Insight into the Value of Ecosystem Services

Abstract

Unlike finfish, aquaculture of marine and estuarine bivalves requires few inputs except a high quality natural and productive ecosystem. The production outputs include carbon storage, nutrient cycling and improved water quality. Marine bivalve mussels possess high nutritional profile including omega 3 fatty acids and are protein rich. However, aquaculture production of mussels is not widely recognized for these attributes. An input-output model (gate-to-gate) was used to capture economic flows from primary data obtained from a mussel farm of one of the largest US shellfish producers. The model was used to highlight the environmental attributes from the farming and simulate the values from increased domestic mussel production. The farm harvests an average of 550,000 kg of live mussels per year with a range of marketing sizes from 20–78 g per mussel. These data served as a baseline to extrapolate values to estimate Washington state, and US economic contributions if all mussels were produced as in case of the study site, and all purchases made by the farm were within the Washington state or the US. The analysis showed that each dollar of final demand at the farm gate from mussels within Washington generated $1.33 in direct and indirect economic contribution. Assuming that all expenses occurred within the nation, when extrapolated to the total production for the US, mussel farms could contribute $1.58 per dollar of mussel aquaculture output. Output included purchases from the farm within industrial sectors, excluding employee compensation, taxes and revenues. Additional purchases made from the hatchery, processing distribution and consumption, would provide an estimate for final demand, imports, and total contributions from the mussel industry within the US economy and society.

Introduction

Aquaculture provides opportunities to increase production of animal and plant proteins and lipids that can offer efficient ways to improve food security, alleviate poverty, and augment land based production systems (Ahmed and Lorica, 2002; Allison, 2011; Arthur et al., 2009; Ayer et al., 2009; Bell et al., 2009; Godfray et al., 2010). Critics of aquaculture development have emphasized the negative attributes of finfish aquaculture, especially production of higher trophic carnivorous species such as salmon and tuna (Boyd et al., 2005; Guggisberg, 2016; Naylor and Burke, 2005). Aquaculture occurring in marine or brackish environments decreases demands on freshwater resources and reduces pressure on land (Asche, 2008; Naylor and Burke, 2005; Naylor et al., 2000). Additionally, development of lower trophic systems, especially those with little need for feed inputs (bivalve aquaculture) can supply high quality animal and plant proteins, and add value to maintaining health of near shore environments such as contributing to carbon sequestration through shell calcification (Barros et al., 2009; Hickey, 2009). In this study, site visits were used to collect data from a large Washington state mussel producer to create an input-output model to evaluate potential economic contributions from mussel farming. Additionally, the environmental attributes of the beneficial use of ecosystem services were highlighted to emphasize the importance of clean water resources for mussel aquaculture. General information from bivalves served as a baseline to better understand and analyze the mussel industry.

Marine/Estuarine Bivalve farming

Bivalve farming of clams, oysters, and mussels may play an increasing role in the future of aquaculture because of their potential for food provision, carbon sequestration, and replacement for fishmeal inputs (Newell and Mann, 2012; Wolff and Beaumont, 2011). Oysters dominate farmed shellfish production in volume and price, especially on the west coast of the United States, followed by manila clams and in third place, mussels. In 2010, the State of Washington spent about $101.4 million in direct expenses for shellfish aquaculture including: production of oysters (3.9 million kg), clams (3.7 million kg), mussels (1.3 million kg), and geoducks (614 thousand kg). Production of these bivalves generated $184 million in economic activity, resulting in an economic multiplier of 1.8. In California, the shellfish industry spent about $12 million and generated $23.3 million showing an economic multiplier of 1.9, a value comparable to 1.8 from Washington State (Northern Economics, 2013). A previous study on finfish and shellfish in 2008 evaluated a mussel industry including all sectors involved (farm, offshore shipments to wholesalers, grocers and restaurants (Kirkley, 2008) and they predicted that a single blue mussel operation with a $1.2 million in sales may generate a total of $6.49 million in total economic effects (the farm generated $2.67 million and restaurants $3.5 million in economic contributions).

Mussel aquaculture in brackish and marine environments

A marketable size of mussels is about 4-5 cm and is normally reached in an average after 6-15 months, depending on cultivated species and water conditions. Several mussel species are used in the aquaculture but the mussel industry worldwide is dominated mainly by the four mussel species cultivated in marine or brackish waters. The blue mussel species (*Mytilus edulis*) is extensively cultivated in Europe, the Americas, Asia and Australia with aquaculture production of 197,831 t in 2013. Mediterranean mussels (*Mytilus galloprovincialis*) have been grown mainly in Europe, but were also adapted to aquaculture operations in the Americas and Australia. These species yielded in 2013 a total of 116,574 t. The Asian green mussel (*Perna viridis*) is cultivated in the Indo-Pacific region, with the biggest aquaculture facilities located in Southeast Asia. In 2013 FAO report, global production of these mussels was estimated at 162,933 t. Finally, the New Zealand green shell mussel, or the Greenshell, (*Perna canaliculus*) is cultivated mainly in New Zealand with reported production of 83,561 t (2013).

Traditionally, mussels have been harvested from wild beds or cultured on intertidal or subtidal culture plots with nets and cages. Various technologies also enabled off-bottom culturing of mussels with the use of wooden poles in intertidal area (bouchots), suspended ropes (longlines) and floating rafts. Mussel seed for aquaculture may come from the wild as collected spat (e.g. from seaweeds or from submerged ropes) or from mussel seed farms.

Mussel triploids were also developed that have the advantage of maturing faster and having more meat than normal diploid mussels. Triploids are also sterile, which may make them more desirable by seafood consumers as mature gonads might yield unwanted flavors (Allen and Downing, 1991; Piferrer et al., 2009).

Mussel farming utilizes inputs from natural ecosystems for rearing and nutritional sources, without incurring in the input of feed, which reduces pollution and economic costs (Iribarren et al., 2010b; Irisarri et al., 2014; Lozano et al., 2010; Shumway et al., 2003). Mussels are filter feeders depending on nutrients and plankton, including bacteria, phyto- and zoo-plankton among other organisms from the water column. Blue mussels showed filtration rates between 1.2-5.2 L per hour depending on water temperature, salinity and nutrient load (Strohmeier et al., 2015). In laboratory setting, Mediterranean mussels may filter up to 2.42 L per hour depending on water temperature, velocity, food quality and quantity (Denis et al., 1999).

Mussels reduce suspended solids, sequester nitrogen, phosphorous and carbon from the ecosystem converting these nutrients into usable protein and shell materials (Gibbs, 2007; Iribarren et al., 2010c; Lozano et al., 2010; Petersen et al., 2012; Stadmark and Conley, 2011). As they graze and digest their food mussels are releasing some nutrients or pseudofeces, including phosphorus and nitrogen that can be easily available for other microorganisms or plant growth (Jacobs et al., 2015; Peterson and Heck, 1999, 2001). Their production does not use additives, antibiotics or hormones. Use of these lower trophic species that grow without additional feed inputs and additives provides a largely positive outcome in regulatory requirements of aquaculture. It is in contrast to finfish aquaculture systems and concerns regarding waste loading, use of fish meal for feeds, risks to habitats and native aquatic resources, consumption of energy and water pollution (Frankic and Hershner, 2003; Olin, 2002).

There are many benefits from mussel production, however, they require good ecosystem quality. Increased CO_2 concentrations, ocean acidification and water pollution can negatively affect production of mussels due to a decrease in larval survival and increased shell malformations (Gazeau et al., 2007).

Ecosystem services as value

Marine and estuarine environment provides many services that are poorly understood by the public and when degraded can result in economic, cultural, and biological losses. Tools that help us to understand the value of natural resources are needed to improve and support management and sustain human welfare. The ecosystem service value (ESV) of the ocean and surrounding areas account for about 63% of the global total ESV (Costanza et al., 1998; Martínez et al., 2007).

North America (US, Canada, and Mexico) environments are considered among the nations with the highest ESV for both terrestrial and aquatic environments (Martínez et al., 2007). Ecosystem services are very important to understand and value as they might offer an estimated economic value higher than the GDP in a country. For example, in China ecosystem services were valued 1.73 times higher than the GDP in 1994 (Chen and Zhang, 2000), providing with a different socio-economic perspective of the environment's value. China depends on aquatic environments and ecosystem services largely as they consume most of the animal protein from aquaculture or fisheries. An evaluation of annual ecosystem services value per year in the wetland areas of China was estimated at $5,380 per hectare (Zhao et al., 2005). It is important to understand the ecosystem services of all species from charismatic to less known components (Orford et al., 2015) and their interactions with their ecosystems regionally and globally (Mace et al., 2012; Wossink and Swinton, 2007). Some species may be critical indicators of the ecosystem health but the functional relationships are essential to maintaining the integrity of the ecosystem (Valiente-Banuet et al., 2015).

Proper evaluation tools may allow for identification of options to achieve higher environmental quality and increased ecosystem services (Metzger et al., 2006; Olin, 2002; Turner et al., 2007). Improved understanding of the value and components of the ecosystem services involved in land based traditional agriculture and other food production systems such as apiculture or marine aquaculture can help prioritize use of land, water, energy, and its contributions (Metzger et al. 2006). The ecosystem services valuation can be used to highlight opportunities for promoting more environmentally friendly industries (Olin 2002), estimate the value of natural functions, specific habitats, and species as in case of the marine ecosystem of the Caribbean (Schuhmann and Mahon, 2015). It is important to understand economic costs and benefits from food production to create more sustainable human food sources and to secure the quality of the environment and human well-being (Bolund and Hunhammar, 1999; Costanza, 2000).

Ecosystems services from marine and estuarine bivalves

One of the ecosystem services provided by bivalves (clams, mussels, oysters and scallops) is improvement of water quality through filtration and stabilization of sediments in estuaries and in the marine environment. Removal of nitrogen and phosphorus (1.4% and 0.14% by weight, respectively) not only contributes to improved nutrient cycling but also reduces risk of harmful algal blooms (Shumway et al., 2003). By feeding on toxic algae, bivalves have the potential to mitigate poisoning of wild animals (e.g. sea lions) with algal toxins, such as domoic acid (Cook et al., 2015). Additionally, removal of excess nutrients and aggregation of phytoplankton by bivalves can mitigate habitat degradation due to low dissolved oxygen levels in waters from otherwise accumulating and decomposing organic matter (Bricker et al., 2008; Commission, 2007).

Algal blooms can be a challenge to human safety of consumption, and their absence is part of the valuation process that is difficult to estimate. In general, algae blooms are monitored and many areas in the Northwest have been closed for wild and aquaculture shellfish harvest, but in the area of study where our farm was local there has never been a shutdown of the production, only precautionary measures and extensive monitoring (personal communication with personnel from our visited farm). Importantly, depuration strategies exist and can limit impacts from toxic algae blooms on shellfish produced for human consumption (Lee et al., 2008). In the United States, especially in the Northwest, the water quality for mussel farming is certified and monitored by the state departments of health.

Another benefit from bivalves is protection of shoreline from wave and wind erosion and this feature of being living breakwater has been recognized in literature (Commission, 2007; Meyer et al., 1997; Piazza et al., 2005). Recently, more attention and research are focused on development of new shoreline protection systems that combine marsh grasses and oyster reefs that work better than traditional “gray” concrete seawalls, rock groins and flood gates (Popkin, 2015). Mussel species may have a potential to be used in development of these “green structures” as a defense against rising seas and storm surges too. Besides shoreline stabilization, a functional bivalve species system can contribute to enhancement of habitat biodiversity by providing support and refuge to numerous species, plants and animals (Coen et al., 2007; Henderson and O'Neil, 2003).

It is known that oceans hold the largest capacity for carbon storage and in terms of carbon sequestration, due to calcium carbonate in shells, bivalve production may play a role in carbon sequestration reducing concentration of this greenhouse gas during their production and disposal (Peterson and Lipcius, 2003; Wolff and Beaumont, 2011). $CaCO_3$ has a molecular weight of 100g with carbon (C) being 12% of that weight. As calcium carbonate ($CaCO_3$) is the main chemical compound of shells, it can be stated that carbon constitutes 12g for every 100g of shell. Additionally, small quantities of impurities in the shell are also trapped from water and sediments. Because of the composition of mollusks, mussels may have a sequestration potential for being a sink for inorganic carbon. Analysis of carbon footprint of suspended blue mussels in Scotland stated that cradle-to-gate carbon footprints of harvested shellfish might reach approximately 252 kg of CO_2 equivalents (kg CO_2-eq) per ton of suspended mussels and for intertidal oysters that value may go up to 1,821 kg CO_2-eq per ton (Meyhoff Fry, 2012). Studies of a combined scallop seaweed aquaculture system in China showed a reduction in dissolved inorganic carbon that in turn may possibly limit ocean acidification (Jiang et al., 2014; Jiang et al., 2015).

Mussel consumption and sales

Mussels can be an excellent source of food and they are efficient in transforming nutrients from water to edible meat, providing 35-50% of edible weight (Hurlburt and Hurlburt, 1975). Blue mussels exhibit an excellent nutritional profile: a 100 g size portion has about 24 g in protein, 56 mg of cholesterol and 4.5 g of total fats. They are also extremely rich in omega-3 fatty acids and other nutrients such as iron and calcium. These qualities make mussels comparable in nutritional profile to important species such as salmon or beef (Table 1).

In 2005, mussel aquaculture in the US accounted for about 2.56 million kg of food or market size live mussels (average of 33 live mussels per kg), and were sold for about $5 million dollars ($1.95 per kg). In 2013, the US produced about 2.23 million kg of food or market size live mussels (average of 44 live mussels per kg), but in value, it accounted for more than double when compared to 2005, reaching about $12 Million dollars ($5.50 per kg) (USDA, 2014). Maine and Washington produce the largest quantity of mussels. In 2013, Washington produced about 60% (1.3 million kg) of the national production. In the past decade, the availability and economic contribution from mussel aquaculture has increased in the US and additional sources come from wild harvested mussels, however more than 90% of mussels consumed have been imported (including farmed and wild). In 2012, 34.3 million kg of mussels were imported with a value of 108 million dollars ($3.16 per kg). Most mussel imports were frozen/dried/salted mussels dominated by product from New Zealand (NOAA, 2015) (Table 2). In Table 2, live mussels showed their origins either farmed or wild harvested, for other presentations statistics presented may be a combination of farmed and wild. Overall there is a clear significant decrease in the harvesting of wild mussels from 2005 to 2012.

Overall, expansion of marine offshore aquaculture in the US has been restricted by regulations regarding waste and nutrient discharges to prevent pollution, and to protect and allow the propagation of a balanced population of shellfish, fish and other wildlife (e.g. Clean Water Act of 1977, Water Quality Act of 1987). These actions provide an opportunity to develop more environmentally compliant and sustainable industries, but it also results in lower volume of production and expensive products compare to those produced in other countries. Many foreign products may be available for consumption at a lower cost, likely due to fewer regulations (social and environmental) and/or lack of compliance (Clay, 2009).

In the US, no commercial aquaculture operations exist in offshore federal waters, but three offshore mussels farms presently operate with federal permits from the US Army Corps of Engineers as of 2015 : two in Massachusetts and one in California. However, in January 2016 NOAA announced that after 20 years of research, evaluations, and efforts with the Environmental Protection Agency (EPA), universities, non-profit organizations, and others there will be an opportunity for US aquaculture expansion in federal waters of the Gulf of Mexico. The Gulf of Mexico offers suitable sites, water quality, and habitat to allow aquaculture expansion in the US. The US government has the proper institutions and people to enforce regulations and monitoring of the practices, and use of adequate species, feeds and control methods (such as vaccinations, production and harvesting practices) to secure and protect the habitat, biodiversity, and maintain the health of the marine environment. These inputs need to be accounted once estimations of costs and benefits will be approached in future evaluations from the US marine aquaculture.

Input-Output model framework

Input-output models (IO) have been developed using the Leontief model that provides an analytical framework to estimate the interdependence of industries in an economy (Leontief, 1936; Miller and Blair, 2009). The traditional IO analysis is a tool to measure economic effects of an industry or commodity, using a matrix approach to record money paths and flows within a specific region. This concept was first introduced by in the 1930’s (Leontief,

1936) and it uses an input-output account to estimate direct, indirect, and induced effects of any economic activity within other industries or sectors. The basic Leontief IO is developed from observed data and contributes to understand the flow of products from each industrial sector, producer, consumer, and includes the inputs required from the sector involved to estimate the economic activity within a region or a country.

An IO model includes inter-industry sectors and sales from each sector to their final demand. Each output from "final demand" can be broken down into different markets such as households, personal consumption purchases, sales to federal government, domestic trade, imports or exports. An IO model also includes the "value added" sector to account for non-industrial inputs such as labor, depreciation, taxes and imports (Miller and Blair, 2009). An example of a conceptual IO model is provided in Table 3.

A source data for creating an IO model can be based on the Social Accounting Matrix (SAM). The SAM serves as a baseline to create other accounts to evaluate the economic activity of a region or a nation. SAM was developed and explained by (Stone, 1961; Stone and Brown, 1962) as a means to use an double-entry/input-output account to represent buyers and sellers, and includes all institutional agents, including firms, households, government activity, and other economic sectors. It has been also adapted by (Miller and Blair, 2009; Watson et al., 2015) different industries.

IO models have been constructed from available data for various sectors such as the golf industry (Watson et al., 2008), and tourism (Briassoulis, 1991) and evaluations can be assessed using IMPLAN(Impact Analysis for Planning). IMPLAN® is software developed by the U.S. Department of Agriculture to estimate community economic impact (http://www.implan.com). A model for mollusks aquaculture was developed by the Pacific Shellfish Institute to evaluate shellfish aquaculture in three states of United States (Northern Economics, 2013) and a model to evaluate coastal fisheries was developed for NOAA (Leonard and Watson, 2011). The number of industries involved may vary depending on the detail needed and different industry codifications exist.

SAM and IO tables for economic models use codes to partition activities into the different industries. The most common codification system used in these models is the North

American Industry Classification System (NAICS) that classifies activities in businesses from Canada, US and Mexico in a consistent fashion.

The NAICS has been used since 1997 by federal statistical agencies and others to classify business activity for different purposes, but mainly for analysis of the U.S. business economy. In this system, economic activity is partitioned according to the products, processes, or services provided by each establishment, and each activity is allocated to the appropriate/related economic sectors. Each industry sector in NAICS is represented with a numerical code, with codes being based on 2 to 6 digits. Each additional digit represents a tree of subsectors or a different level of detail from the major industry with similar purposes.

For this research, a mussel production sector was created (Figure 1). For more information about descriptions, sectors and definitions please refer to the NAICS manual (Bureau, 1997) or website: www.census.gov/eos/www/naics (updated on November 2014 and accessed on July 2015).

Objectives and approach

The objectives of the study were to develop an input-output model to quantify the economic contribution of live blue mussels sold in their shell from the farm gate as a way to quantify natural ecosystem economic benefits. Primary data were obtained from the case study of the largest mussel farm in Washington State, and values from this producer were extrapolated to the state. A simulated value of increasing the domestic production was provide assuming all mussels consumed would be supplied within the United States. Using this economic approach, the value of the natural ecosystem services used for existing and potential expansion of domestic production was estimated.

Methods

The model created was a comprehensive input-output model that evaluated the inter-industrial flows and economic contribution analysis from the economic activity effects provided by the exogenous sales of a mussel aquaculture farm in 2013. The results used primary data obtained from the study mussel farm and additional data from peer reviewed sources and international and national organizations such as Food and Agriculture Organization of the United Nations (FAO), National Oceanic and Atmospheric

Administration (NOAA), and the US Department of Agriculture (USDA). All farm expenses were allocated to each economic sector using appropriate NAICS and non-NAICS codes and proportions. The foundations of the input-output model were followed to evaluate output from the case study farm and extrapolated to simulate output for Washington State and the US. The IO model was built in Microsoft Excel and applied the IO methodology (Miller and Blair, 2009) based on the Leontief multiplier matrix to estimate industrial economic contributions, detail in section 9.1 and improved by Watson et al. (2015).

It is important to clarify and understand well the economic concepts and terminology to provide with a clear picture of the economic activity analysis or contributions from an industry.

Economic activity is used to account for the money spent within an area from an specific industry or action (Watson et al., 2007)

Economic contributions by definition, refers to the gross change in the economic activity resulting from an industry, event or policy in an existing regional economy (Watson et al., 2007).

Direct effect: includes changes associated with the production of the good itself (e.g., financial transactions, expenses, wages, taxes, revenues), it is the initial transaction and it is considered to be exogenous to the model, also called direct economic contribution.

Indirect effect: involves secondary changes affecting or supporting industries involved in the primary industry input (e.g., additional input purchases to increase one unit of additional production), also considered as the effect resulting from the inter-industry activity provided by the main or primary industry. Figure 2 shows a conceptual overview of the economic activity provided by an economic analysis. From our data we obtained only direct and indirect economic contributions. There are other effects called induced effects but we did not have the appropriate data to estimate these contributions.

Induced effect: are considered to be all the changes involved in the expenses within the households by the employment generated or reduced by the direct and the indirect effects.

Study area and production system

The Puget Sound of Washington has the largest shellfish producers in the Pacific Northwest and the United States. The family owned company has been operated for five generations. The farm employs nearly 500 people in 44.5 square kilometers (4451ha) of tidelands in the Washington Coast and British Columbia. They also operate hatcheries and nursery facilities in Washington, Hawaii, California, distribute shellfish in Hong Kong and are partners with J. Hunter Pearls in Fiji. The representative mussel farm is located in Totten Inlet, Shelton, Washington (Figure 3).

In 2013, this farm produced 1.3 million kg of live mussels and harvest an average of about 0.55 million mussels per year. The output from mussels constitutes 41% of the Washington State production and about 25% of the US production (USDA 2013). The selected farm grows mussels on floating rafts held by wood and concrete. The farm obtained their mussel seed mainly produced in hatcheries (Washington, Canada and Hawaii). The rafts hang in the water column (4 m deep); mussels never touch the bottom or are exposed to the air. Each year they have about 50-67 rafts and every raft is about 3.05 km and there are about 1,000 ropes. Mussels reach marketable sizes from 6-12 months. During summer mussels grow faster reaching market size in about 6 months however, on average and for the purpose of our model we considered a cycle production of one year. Mussels were harvested almost daily (1,800 kg of live mussels a day). When mussels were harvested they were sent to a processing plant for packaging, selecting, and distributing.

The processing plant cleans and selects the mussels and sells four marketing sizes, maintaining an average of the following parameters: small (4.5 cm = 20 g per mussel; 48 mussels in their shell per kg), medium (5-7.6 cm = 25 g per mussel; 40 mussels in their shell per kg), large (7.6-10 cm = 28 g per mussel; 35 mussels in their shell per kg) and jumbo (12-15 cm = 75 g per mussel; 13 mussels in their shell per kg). They packed mussels in their shells in a plastic mesh bag (1.5-5 kg) and put them in a carton box (40kg) for their final destination. This farm distributes most of their product fresh, live in their shell by plane (~80%) to Chicago, New York, Texas, California and other States, with a portion of the production (5-10%) sold in Seattle, Portland and Canada and distributed by trucks. A small fraction is pasteurized and sold to China (<5%).

The water used in the processing plant is treated before release, and most is drained into an artificial wetland forest created by the farm to decrease their ecological footprint. Mussels in their shell from our farm provided an average of 50% of meat. In general mussels may provide 35-50% of edible meat (Hurlburt and Hurlburt, 1975).

Mussel farm expenses translated into input-output (IO) accounting

Mussel production includes different stages (Figure 4) and for the IO model economic expenditures were grouped into stages from purchasing the mussel seed, the raw materials required annually for the mussel production system, payments for off-site farm utilities and maintenance, and general expenses from the farm and the harvesting process such as labor, fuels, supplies, and yearly activities.

The farm provided us with available expenses per year, in Table 4 NAICS codes were selected for mussel farm expenses. An average from a five-cycle-year actual budget was used and translated into an IO account, summarized in Table 5. Expenses were combined and rounded up for costs of annual production to maintain their specific purchases and annually expenses confidentially and extrapolated them to a base production of a million kg of clean mussels in their shell. Before converting expenses into the specific industry sectors, specific/additional information was needed to understand some expenses from the annual budget provided, purchases that involved other industries and also expenses or materials involved in certain categories such as supplies. The following categories required additional information from the general budget provided:

Vehicle expenses: this category included renting cars, purchasing oil, gas, insurances and fuel for boats. We allocated 70 % for the petroleum refineries, assuming most of the expenses were for fuel; from the remaining 30% we allocated 10% for insurance and 20% for miscellaneous retailers.

Education and travel: expenses involved in travel and participation of professional meetings including local workshops.

Leases: were expenses to pay for using the public water within the mussel production system.

Supplies: materials that all supplies were made of (plastic, metal, or textile).

Farm expenses allocated to industrial and non-industrial sectors

The methodology detailed in Willis and Holland (1997) was used to convert expenditures from enterprise budgets to input output accounts.

All farm expenses have to reflect direct values from the appropriate economic sector or sectors involved. For all purchases that required two or more economic sectors within the purchase, retailer purchases, we used proportions based on IMPLAN®, Leonard and Watson (2011), and supported with information provided in the primary data obtained from the farmers (table 11). For the non-industrial expenses, the value added accounts were included to report labor, taxes, depreciation and revenues to include 1) employee compensation (wages, health insurance and bonuses); 2) proprietor income or gross operating surplus (all expenses including depreciation were subtracted from the sales and allocated the value to the proprietor income account); sales were valued using an average of $2.50 per kg, price based on an average provided by the farm manager and it reflected the price from farm-gate, and 3) taxes (allocated payroll taxes).

Economic sectors were coded based on the farm expenses categories. Table 5 summarizes the expenses and includes names of the sectors, their appropriate proportions and expenses were included into the value added accounts. The table was using a base production of 1 million kg of live mussels produced.

Based on the farm budget expenses, economic sectors were coded based on the farm expenses, included their sector name with their appropriate proportions, and expenses included into the value added accounts and summarized data in Table 5, using a base production of 1 million kg of live mussels produced. The respective values and proportions were estimated for the different sectors involved in mussel farm expenses, and extrapolated as values to show final input-output values for each region, Washington or the US and detail of values are reported in Table 6.

Model assumptions for Washington and the United States

To generalize the models to the broader sectors of state and nation, the USDA reported contributions for mussel production in 2013 were used. Production from the selected farm was extrapolated and used it as if all mussels produced in the US spent similar values, similar materials, and systems. Direct and indirect economic contributions were estimated from the farm and provided with two scenarios: (1) based on the potential economic contributions within the State of Washington and (2) potential contributions for the US, if all mussel farms used similar systems and showed similar pattern of purchases and materials required.

For Washington, the 1.339 million kilograms of live mussels produced in the State was used. Expenses were reviewed to allocate different proportions to estimate the most significant economic contribution provided by the mussel farm within the State (Table 7) and for the US, the final production in 2013 was reported as 2.232 million kilograms of live mussels. The model included the assumption that mussel farms purchased all their materials in Washington or within the US and considered all sectors producing primary goods. The mussel sector was built into an IO model using a SAM, 2012 for Washington, Table 13 showed an excerpt of the SAM used. Table 14 showed an excerpt of the SAM, 2012 used for the model for the United States. The IO model for the US including the mussel sector used a hypothetical example from the local mussel farm and subtracted all mussel farm expenses from the livestock sector (112, NAICS code) into a SAM and created two sectors: mussel sector (112.1) and other livestock (112).

In the model, mussel farms sales were allocated directly to the final demand and final demand was considered exogenous for the model. Seed expenses were identified as the only expense allocated to the mussel sector and therefore subtracted from the final demand (Table 9). Once the values for the mussel sector were obtained, the Leontief Input-Output methodology was used described and modified by (Miller and Blair, 2009), where input and output per sector can be represented by:

$$a_{n,1}(X_1)+a_{n,2}(X_2)+\dots+a_{n,n}(X_n)+Y_n=X_n \qquad (1)$$

(a) represented the purchases of goods and services produced for use or consumption

(X) shows industries

(Y) final demand

The total output equals intermediate transactions plus final demand. Then, *A* is the matrix that represented the inter-industry flows and linkages between industries, or the intermediate activities and is the core of the Leontief model and the multiplier.

$$A = \begin{pmatrix} a_{11} & \cdots & a_{1,n} \\ \vdots & \ddots & \vdots \\ a_{n,1} & \cdots & a_{n,n} \end{pmatrix}$$

Following the IO account example, (a_{11}) would be the purchases from sector 1 to the same sector 1, for example from agriculture to agriculture or purchases of seed from mussels to mussel production, while ($a_{n,1}$) showed purchases from industry 1 to industry n, for example when agriculture buys from mining or services.

Then, the Leontief equation was used to obtain the economic contributions from the mussel farms:

$$[A][X]+[Y] = X \Rightarrow [X]-[A][X]=[Y] \Rightarrow [X]([I]-[A])=[Y] \Rightarrow \mathbf{X} = ([I]-[A])^{-1} [Y] \quad (2)$$

[X] is the vector of industry outputs or sales

[I] denoted the identity matrix

[A] represented the basic matrix converted into proportions of all expenses per each sector, these values were reported per dollar of sales (Leonard and Watson, 2011).

[Y] refers to the final output of the production from the mussel farm

Input and output in each industry were included and obtained the change of X as a function of all the activities in the changes of production for mussel sector. The total economic contributions per dollar in the sector as well as the different scenarios of final production within the US were estimated. Once an industry’s final demand is multiplied by the sector’s multiplier for a specific region (Washington and US) it provided the total economic contribution of the industry to the specific economy/region evaluated (Watson et al., 2007).

Results

Farm-gate mussel input

Based on five-year average expenses from the farm, the main categories for the industry expenses were highest for labor (43%), followed by the seed supply (13%) and professional expenses (10%). When evaluating economic contributions all value account, including labor, taxes and proprietor income was excluded. All farm expenses were converted into and IO account and assigned into the appropriate industry sectors, using NAICS codes. The expenses were separated to show industrial and non-industrial activity and we ran the IO model to show the ripple effects from the mussel sector within the economy in Washington and the United States. The economic contributions of mussel production involved analyzing the direct and indirect linkages of this production to other industries or commodities. By creating an input-output model economic contributions were estimated based on the inter-industrial purchases. The results showed how mussel farm supported the economy and other economic sectors within Washington State and the US.

Based on 2013 mussel aquaculture, extrapolated farm expenses showed that mussel farming in Washington State produced 1.339 million kg of live mussels spent an average of $2.82 million in farm expenses (including $0.8 million on industrial and about $2 million on non-industrial expenses) within the State and about $0.5 million on expenses outside the State. Total mussel production from the simulation for the nation was about 2.23 million kg of live mussels (including Washington production) resulting on a total of farm expenses equal to $5.54 million. This total included $2.17 million in inter-industrial expenses, $1.85 million in employee compensation and $1.52 million in non-industrial expenses or value added expenses.

Economic contributions of a mussel farm-gate model within Washington State

The model was created with 88 economic sectors coded with three digits from NAICS. The results were summarized into 9 groups (Appendix B) and showed that for Washington, every dollar of mussel farm final demand could result in a multiplier of 1.31. This multiplier would provide direct and indirect economic contributions within the State. These contributions were calculated among inter-industries or the intermediate economic sectors. Table 8 summarizes multipliers from the different sectors involved in the mussel farm sector and compared them to other type of livestock for Washington and for the US. If estimating $3 million of final demand, mussel farms in Washington could provide about $4 million from direct and indirect economic contributions within the intermediate sectors (Table 9). The major economic contribution from mussel farms was reflected in group # 5 (information, insurance, real estate and professional services), accounting for about $0.36 per dollar of final demand with an average multiplier for group #5 of 0.12. In Table 10 the detailed economic activity from group #5 is noticeable on professional services, accounting for $0.28 per dollar of final demand and a multiplier of 0.09.

Economic contributions of a mussel farm-gate model within the United States

The economic contributions for every dollar spent by mussel farms within the US may result in a multiplier of 1.58 per dollar of final demand. The proportions from the different sectors and a comparison of multipliers within mussel farms and other livestock are shown in Table 8. Multiplier resulting from the average activity from other livestock within the US resulted to be about 2.32 with its major indirect economic contribution in manufacturing industry.

If estimating a final demand from mussel aquaculture to be about $5 million for the US, all mussel farms may generate $7.91 million of economic contributions from inter-industrial expenses with an input of $5.54 million (including value added accounts). The main indirect contribution from mussel farms was reflected in group # 5 (information, insurance, real estate and professional services), accounting for $1.05 million (Table 9) and the detailed economic activity from group #5 is very significant for professional services representing about half of this contribution ($0.52 million) (Table 10).

Discussion

Farm-gate mussel input

Direct and indirect economic contributions were estimated from farm-gate mussel input/expenses and extrapolated the values from the farm to the State and to the country. Based on the literature review, the relevant environmental attributions and the potential for mussel aquaculture to expand and supply high quality animal proteins and nutritional products, were compared with high valued profile products such as salmon and beef (Table

1). According to the US Census of aquaculture in 2013 live weight mussels from aquaculture in the US reported sales for about $12 million, almost double since 2005, the mussel quantity produced remained almost the same. The US produced 2.56 kg and 2.23 kg in 2005 and 2013, respectively (USDA, 2014). Imported mussel products complemented the volume consumed in the country (representing more than 90%), including wild harvested and farmed produced in New Zealand, Chile and Canada (Table 2).

Farm-gate expenses and revenues accounted for about $3.3 million for Washington and $5.5 for the US. Mussel farms are usually not considered among the most consumed products, neither highly economically viable nor a major contributor to the economy. However, the results highlighted a significant direct and indirect economic contribution from the inter-industry economic activity of mussel farms, resulting in highly valuable socioeconomic contribution from the mussel aquaculture sector.

Economic contributions of a mussel farm-gate model within Washington State

The IO model resulted in a multiplier of 1.31 generated in economic activity from the mussel farms within the State. This multiplier accounted only for the inter-industrial activity showing direct and indirect effects: this multiplier is called “type I” in economy. Mussel farm multiplier type I showed a conservative-low end estimate and it was comparable to that obtained from wholesale trade, machinery manufacturing, social assistance, and food-services and drinking places sectors.

When comparing the 88 industry sectors from Washington included in the IO model, all industry multipliers ranged from 1 to 2.13; mussel farms resulted in a 1.31 multiplier ranking number 38. The multiplier accounting for direct and indirect effects from mussels is comparable and fits well with similar studies that have evaluated mussels in the bivalve group in the same State. Multipliers obtained from bivalves (oysters, clams, mussels and geoducks) from Washington production resulted in 1.8 including direct, indirect and induced effects in previous study (Northern Economics, 2013). If the mussel industry were analyzed (including the whole life cycle of this industry-hatcheries, processing plants, distribution and marketing and additional players), certainly the resulting multiplier within industries and other accounts would provide potential and significant industrial contributions to the local and national economies. For example in the blue mussel industry model simulated by

Kirkley (2008), the mussel production sector resulted in a multiplier of 1.2, and when including production, wholesalers, grocers and restaurants resulted in a potential multiplier of 6.49 including direct, indirect and induced effects (Kirkley, 2008). Table 9 provided with a comparison between mussels and other livestock sector evaluated and it showed the resulting multiplier per industries and among the sectors for similar industries. The multiplier I resulted from other livestock was 1.41 and 1.31 for mussel farms within the State.

Final demand for each sector determines the total economic contributions and that may differ greatly; mussel farm final demand was considered to be exogenous to the model and it was estimated high because we used all the final production from the farms. However, the final demand for the mussel sector was low compared to other sectors. It is important to understand that using combined sectors in three digit NAICS codes and as noticed in Figure 2 places mussels in livestock (112), otherwise they would be allocated below shellfish farming sector (112512) in another level. Additionally, in the case of Washington, inputs from the state Department of Health and its “Shellfish Program” responsible for sanitary control of oysters, clams, and mussels including bio-toxin monitoring, licensing and certification were providing over $8 million of economical input to function for two years (2013-2015), including $4.16 million in salaries and benefits.

<u>Economic contributions of a mussel farm-gate model within the United States</u>

Overall, the multiplier for other livestock was estimated to be 2 and for mussels 1.58 and the livestock industry contributes largely to the national economy from the model. From a case study in the US (Kirkley, 2008), using a blue mussel operation producing about 900 thousand kg a year and originating $1.2 million in sales the total multiplier for the production stage, including direct, indirect, and induced effects resulted in a multiplier of 2.67. Comparable to the results of the case study in this dissertation, the multiplier obtained from the production stage for output resulted in 1.31 for direct and indirect contributions. When considering producing sector, wholesalers, grocers and restaurants from the mussel industry, the resulting contributions from direct, indirect and induced effects resulted in a 6.49 multiplier for the total output (Kirkley, 2008). A similar study showed a resulting multiplier of about 4.7-4.8 from recreational fisheries in Maine, including direct, indirect and induced effects from sales, income, and employment contributions (Steinback, 1999).

In the study, when comparing economic activity from $1 of output from other livestock production with mussel farms, mussel production contributes more to sectors #8 (other services and repairs) and #9 (government). Economic activity within sector #4 (transportation and trade) and # 5 (information, insurance, real estate and professional services) were comparable for both, mussel and agricultural production. However, other types of livestock contribute more than mussel production to Sectors #1 (agriculture, forestry, fishing and hunting, #2 (mining) and #3 (manufacturing) and #7 (arts, entertainment and accommodation). According to the model, both mussel farm and other livestock contribute very little to Sector #6 (education services). On the other hand, other type of human activities such as recreation in a case study of an input-output model for golf in Colorado resulted in a multiplier of 2.13 and their largest suppliers where from building materials and gardening sectors (Watson, et al., 2008).

<u>Mussel production-additional economic and non-economic contributions</u>

Shellfish aquaculture of mussels and other species in the US is highly regulated, and monitored (Boyd et al., 2005). Mussels are filter feeding organisms, and inputs are derived from the water column, thus economic models do not include expenses for additional inputs of food. Moreover, the filtration capacity can be considered a positive attribute improving water quality, providing habitat for other submerged vegetation and sea grasses, and offer a net gain for the environment and society (Caroppo et al., 2012; Fuentes et al., 1994; Gibbs, 2007; Hawkins et al., 1998). It is especially displayed when there is no overstock of mussels within the farms. Generally, mussel production takes about 12-15 months to produce an average of mussels 4 cm shell-long (Figueras, 2006). Mussels that are always submerged in water, grow faster than those that may be exposed to the air with tidal fluctuation (Hurlburt and Hurlburt, 1975). The farm culture periods were from 8 -15 months, with mussels growing faster during the summer and reached larger marketable sizes (20-78 g; 4.5-15 cm per mussel in their shell).

The feed sources for other livestock rearing often account for about 70-90% of water, land and carbon foot-printing of the rearing systems (Cajas-Cano and Moffitt, 2008;

Mekonnen and Hoekstra, 2012). For mussels, water discharge, mussel purification and depuration require water resource inputs and effluents (Iribarren et al., 2010c). However, in the case study mussel farm, the freshwater used in the production and the processing stage was about 90 l per kg of mussel processed (detailed information from Chapter 3) and all freshwater used in the mussel processing plant passed through a post-treatment that allows the water to be reused for watering trees and recycled into natural resources or to be reused. Mussel production from this farm can thus be considered nearly as a neutral water industry according to most water footprint criteria (UNESCO, 2009). Mussels from the case study farm were harvested almost daily (1,800 kg of live mussels a day) and were processed without depuration because of the high quality rearing water. In majority of other aquaculture systems abroad mussels are depurated for 48 hours (Hurlburt and Hurlburt, 1975), requiring additional resources, time, and costs during the process. Also, from the marketing presentations, canning factories resulted in higher environmental emissions and negative contributions when compared to other presentations and even to the mussel farming process (Barros et al., 2009). Other results showed that small processing plants resulted in environmental unsustainable consumption of electricity when compared with large factories where their packaging occurred in higher volumes of production (Iribarren et al., 2010a). Mussels can be eaten raw or cooked and its flavor is comparable to the oyster taste and may be considered superior to clams (Hurlburt and Hurlburt, 1975). Moreover, mussels can be quickly steamed and barely cooked to reduce the energy input required at home and potentially decrease the negative impact resulting from the process of canning.

Overall attributes of mussel aquaculture systems related to low water and carbon footprints, and the potential role that mussels can play in the environment by purifying the nutrients in water are important values. Mussel aquaculture can provide a variety of ecosystem services may fulfill future food demands without increasing greenhouse gases (GHG) emissions (Meyhoff Fry, 2012). That last feature is especially important, when one of the challenges for agriculture expansion will be to minimize negative environmental effects and prevent greenhouse gasses emissions increase (Bajzelj et al., 2014). Mussel farms can fit into the required model for activities that may benefit from the “emissions trading scheme” (Johnson and Russell, 2004). Most environmental contributions have been valued for oyster farming (Dumbauld et al., 2009; Grabowski et al., 2012; Henderson and

O'Neil, 2003; Piazza et al., 2005), however mussels can compare to oysters and be more cost-benefit effective than the latter, and potentially many other aquacultural and agricultural production types.

Mussel production and additional challenges

Mussels are resilient species that exhibit high environmental tolerance and are less affected by ocean acidification and algal blooms compared with oysters and other aquatic species, such as crabs or mammals (Gazeau et al., 2007; Keppel et al., 2015; Thomsen et al., 2010). Within the Pacific Northwest there are more suitable habitats available for expansion when compared with the East Coast of the US and/or Central America (Callejas et al., 2015; Petitpas et al., 2015). Additional monitoring and health inspections of water and algal blooms secure the production of healthy shellfish that are safe for consumption. Important efforts for protection and reduction of toxins and effluents affecting water quality need to be addressed to ensure mussel aquaculture success. If mussel habitat is disturbed, many other species of animals and plant vegetation will also be affected, as mussels play a key role in security of many invertebrates and plant species (Saderne et al., 2015).

Mussel aquaculture helps to reduce nutrient related loading and when integrated within finfish systems, mussel can provide natural filtration services and are considered for integrated multi-trophic aquaculture systems (IMTA). Multi-trophic aquaculture production combines species with different attributes that benefit from and utilize wastes from finfish aquaculture (Chopin et al., 2001; Neori et al., 2004; Troell et al., 2009). Mussels and plants have been included in finfish production in marine and estuarine locations to create a more environmentally friendly industry (Olin, 2002; Reitan et al., 2008; Sarà et al., 2009; Soto and Mena, 1999; Troell et al., 2009).

The nutritional profile of mussels offers an excellent source of protein, balanced content and proportion of minerals, fats, and micronutrients. Mussels should be included in anybody’s diet, especially for those in more vulnerable groups (kids, seniors, and sensitive/ill people) (Table 1), unless a person has shellfish allergy. Nutrition profile of mussels is comparable to beef and salmon profiles and can be an effective substitution for one or more of animal protein portions requirements. Besides nutrition, mussel consumption shows a high potential of presenting a food source/product with a comparable or lower consumer price. In 2015, a kg of beef on average (different cuts with bone) cost $4.21; a kg of salmon (filet) $5.25 (Mundi, 2014); and a kg of mussels $5.48 (USDA, 2014). However, according to USDA beef prices can be on average $12 per kg (including beef cuts from ground to beef steaks) and prices of sold salmon fillets can reach up to $16 at the Pike Place market in Seattle, WA.

Understanding and learning about the environmental and economic costs and benefits from producing and consuming mussels may result in a higher demand for mussels and potential opportunity to expand this industry within the country. However, availability and expansion permits for mussel aquaculture may be a challenge for the US but it should be considered. It is especially important in the light of the current environmental “Net Benefit Goal” memorandum of Obama Administration, recently opened opportunity to develop marine aquaculture in federal waters, and the consistency of promotion of mussel systems as environmentally and economically viable.

As in case of any other type of industry, care should be taken with expansion of mussel production as improper techniques or overstocking may be detrimental to the ecosystem. Accumulation of sediments, tidal disturbances, decreased dissolved oxygen or increase in toxic sulfides from mats of sulfur bacteria may disrupt normal benthic processes and could be attributed to mussel production (Dahlbäck and Gunnarsson, 1981; Tenore et al., 1982). There are recommendations for expansion of mussel aquaculture in areas with good tidal flushing that may prevent overloading, sediment buildup, resulting on minimal environmental consequences (Crawford et al. 2003) or to culture mussels in integrated systems, especially the ones including plants or invertebrates that will use the sediments to grow, and in turn protect and increase mussel survival (Peterson and Heck, 2001). Moreover, development of technologies such as controlled water upwelling, may provide a simple but efficient ecosystem engineering approach for increasing mussel production in oligotrophic areas, that were not considered for mussel aquaculture in the past (Strohmeier et al., 2015). Overall mussel production and consumption can contribute to improved food security, strengthening of local economies and well-being of many human populations.

Conclusions

Based on this analysis, mussel aquaculture and consumption have high potential for increased economic contributions, improved nutrition and environmental health. The IO model in Excel demonstrated effectiveness in estimating multipliers of 1.31 and 1.58 for direct and indirect contributions from every dollar of mussel farm output within Washington and the US, respectively. Considering that the model accounted for the inter-industry expenses from the mussel farming, the mussel industry multipliers from direct, indirect, and induced contributions will be higher than those presented in these results.

This methodology can potentially be used to estimate total economic analysis and environmental attributes of small scale farms or organizations that have primary data from main sectors available. This study provides a limited but comprehensive list of economic expenses and ecosystem services that provides a scenario for development of a sustainable mussel industry from the economic and environmental point of view. Errors, assumptions and predictions may yield different contributions of the mussel industry, but the results predicted economic contributions from the farm and highlighted the opportunity to support mussel aquaculture and consumption.

Further research needs to focus on identifying relevant components from the human dimensions, to include social parameters for the evaluation of the sustainability of mussel production, and to incorporate similar evaluations of the systems that provide the mussel supply from imports. Data from Canada, Chile and New Zealand could be valuable to compare costs and benefits for local and imported productions.

It is possible to expand mussel aquaculture in the US in state or federal waters by determining the quality of the environment and the adequate biomass growth (Srisunont and Babel, 2015). Important research has been applied to study global land use for croplands, pastures, infrastructure, and wilderness (Alvarenga et al., 2015; Fontana et al., 2013; Metzger et al., 2006; Shao et al., 2016), and evaluations regarding human disturbance in arable lands, as well as on dry agriculture vs. irrigated agriculture and its significance in the future (Pielke et al., 2007). Similar analysis need to be applied for global water use and protection to support standardization of methodologies to maintain the capacity of the biosphere to sustain humans and nature in the long term (Foley et al., 2005).

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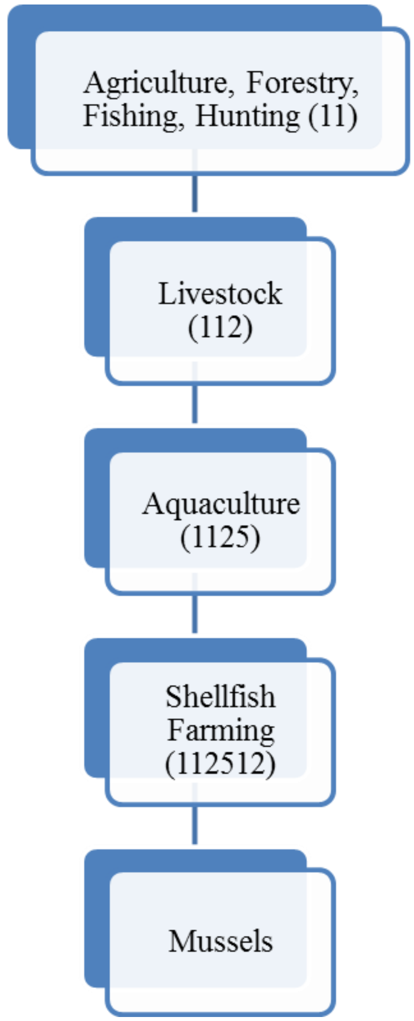


Figure 1. Mussel production sector originated from the industrial sectors based on NAICS codification. The IO model created including the mussel sector was based on a three-coded SAM model. Mussel sector was considered to be included in the livestock sector (112).

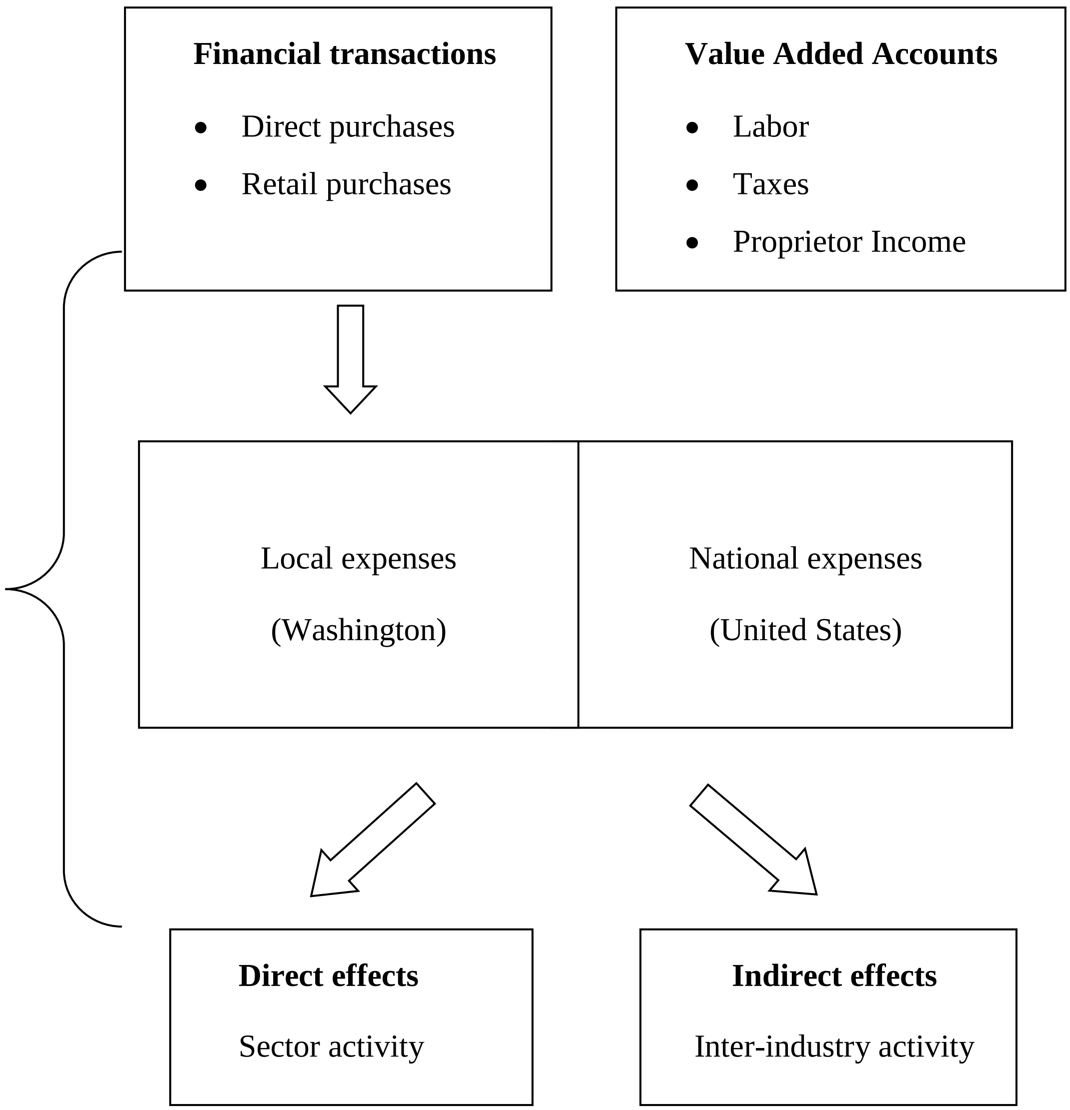
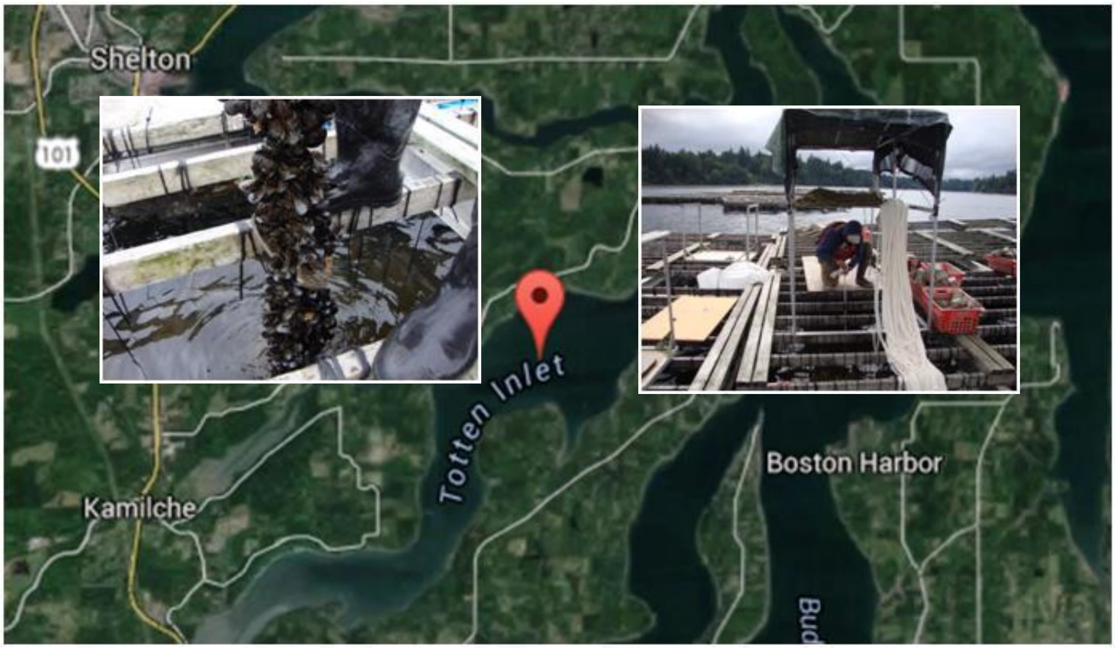


Figure 1. Overview of an economic contribution accounting for direct and indirect effects. Other effects can be estimated by the value added accounts (induced effects) but in the input-output model we estimated inter-industry economic activity to obtain direct and indirect effects generated by the mussel production farm.



Mussel farm located in Totten Inlet, Shelton, Washington.

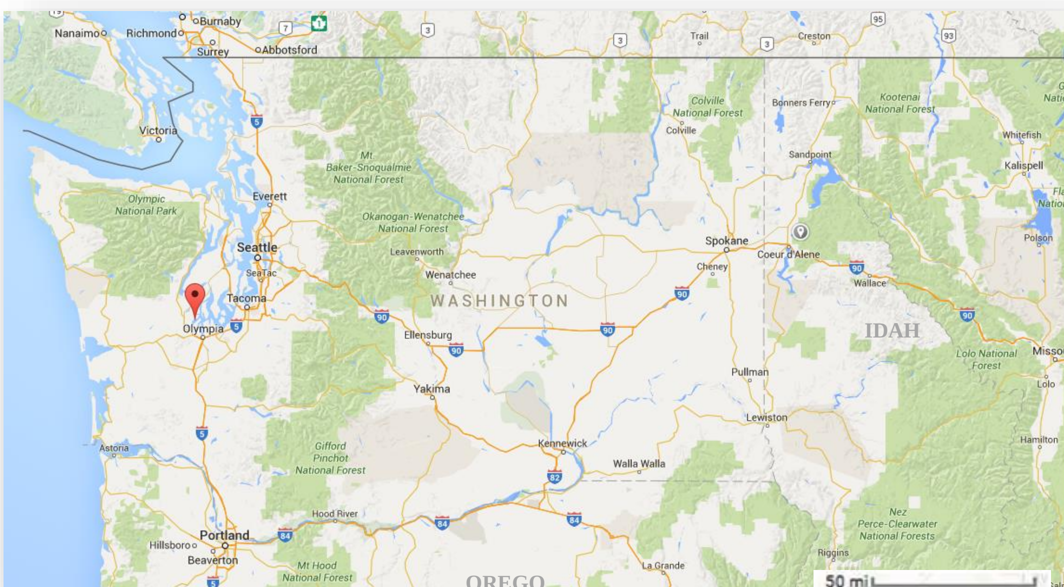


Figure 2. Location of the case study mussel farm within Washington State in the United States (Source: map data © 2016 Google).

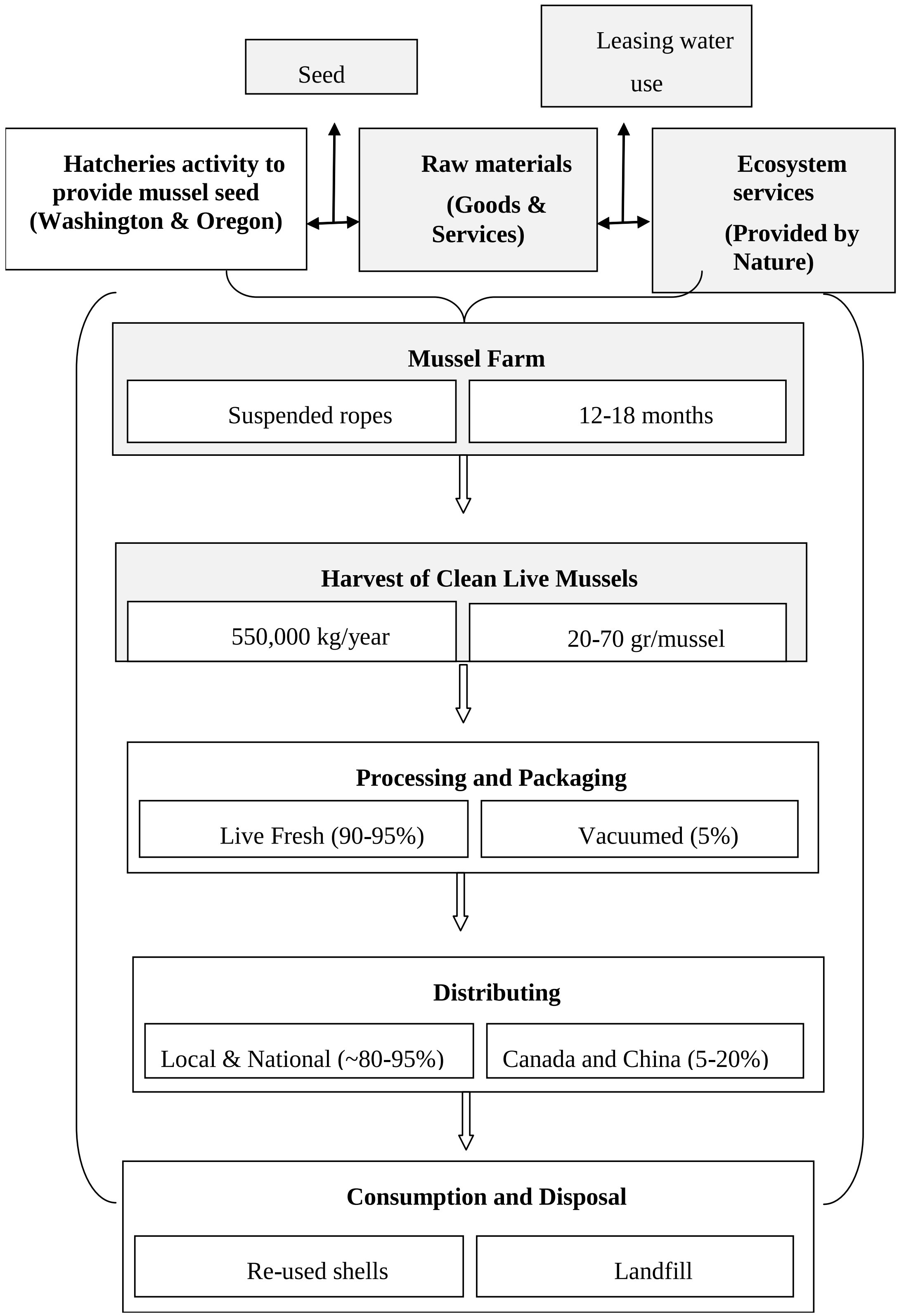


Figure 3. Conceptual model for the life-cycle of mussel production systems based on the case study farm. Shaded stages included in the IO model expenses evaluation.

Table 1. Selected nutrition facts for 100g portion for: mussel (blue, cooked, moist heat, #15165), salmon (coho, farmed, cooked, dry heat #15239) and beef (chuck eye roast, boneless, America's Beef Roast, separable lean only, trimmed to 0" fat, all grades, cooked, roasted #13821). Information in parenthesis identified the description of the animal protein products selected with their code (#) provided by USDA.

Nutritional Facts	Mussels	Salmon	Beef
Profile			
Protein (g)	23.8	24.3	26.7
Cholesterol (mg)	56	63	83
Total Fat (g)	4.5	8.2	8.5
Saturated fat (g)	0.85	1.94	3.42
Monounsaturated fat (g)	1.01	3.62	4.17
Polyunsaturated fat (g)	1.21	1.96	0.43
Total Omega-3 (g)	0.87	1.35	0
Total Omega-6 (g)	0.04	0.37	0
Minerals			
Calcium, Ca (mg)	33	12	19
Phosphorus, P (mg)	285	332	210
Iron, Fe(mg)	6.7	0.4	2.5
Magnesium, Mg (mg)	37	34	22
Potassium, K (mg)	268	460	344
Copper, Cu (mg)	0.15	0.09	0.08
Sodium, Na (mg)	369	52	80
Manganese, Mn (mg)	6.8	0.02	0.01
Selenium, Se (µg)	89.6	14.1	27.3
Vitamins			
Vitamin C, total ascorbic acid (mg)	13.6	1.5	0
Folate, total (µg)	76	14	6
Vitamin B-12 (µg)	24	3.17	3.24
Vitamin A, (IU)	304	197	5
Other Factors			
Energy	172	178	183
Fullness Factor	2.9	2.7	3.1
Nutrient Balance	62	38	36

Source: USDA National Nutrient Database for Standard Reference 28 Software v.2.3.2.
Other factors obtained from: http://nutritiondata.self.com/

Table 2. Mussel products imported into the United States showing different marketing presentations and subtotals with percentage contribution in parenthesis from different countries in 2005 and 2012.

Country	Volume (kg)		Sales ($)		Price $/kg	
	2005	**2012**	**2005**	**2012**	**2005**	**2012**
Frozen/Dried/Salted						
New Zealand	12,078,895	10,409,217	38,147,974	44,047,057	3.16	4.23
Chile	1,163,065	4,836,903	2,030,048	12,477,962	1.75	2.58
Canada	204,169	218,798	561,163	765,881	2.75	3.50
Other countries	217,749	43,912	527,265	294,422	2.42	6.70
Sub-total	**13,459,709**	**15,508,830**	**41,266,450**	**57,585,322**	**3.07**	**3.71**
	(58)	**(45)**	**(65)**	**(53)**		
Live/Fresh Farmed						
Canada	8,531,888	14,941,431	18,935,247	38,500,165	2.22	2.58
Other countries	63,640	188,363	220,534	704,506	3.47	3.74
Sub-total	**8,595,528**	**15,129,794**	**19,155,781**	**39,204,671**	**2.23**	**2.59**
	(37)	**(44)**	**(30)**	**(36)**		
Live/Fresh Wild						
New Zealand	768,185	148,860	2,254,618	516,559	2.93	3.47
Canada	348,481	22,454	958,547	64,779	2.75	2.88
Other countries	60,608	8,480	152,045	61,105	2.51	7.21
Sub-total	**1,177,274**	**179,794**	**3,365,210**	**642,443**	**2.86**	**3.57**
	(5)	**(1)**	**(5)**	**(1)**		
Other type of presentations (preserved and prepared)						
Chile		2,105,308		4,650,839		2.21
Other countries		1,375,870		6,134,553		4.46
Sub-total		**3,481,178**		**10,785,392**		**3.10**
		(10)		**(10)**		
TOTAL	**23,232,511**	**34,299,596**	63,787,441	108,217,828		

Table 3. Example of an input-output transaction table to estimate economic contributions. Inter-industry transaction table shaded. Industries and other account-names may vary from model to model.

<table>
<tr><th></th><th></th><th colspan="4">Producers as Consumers</th><th colspan="4">Final Demand</th><th>Total Industry Output</th></tr>
<tr><th></th><th></th><th>1</th><th>2</th><th>...</th><th>8</th><th>Households (C)</th><th>Private Investment (I)</th><th>Govern-ment (G)</th><th>Net Exports (E)</th><th>(X)</th></tr>
<tr><td rowspan="8">PRODUCERS</td><td>1. Agriculture</td><td colspan="4" rowspan="8">Inter-industries (Z) Transaction Table</td><td colspan="4" rowspan="8"></td><td rowspan="8"></td></tr>
<tr><td>2. Mining</td></tr>
<tr><td>3. Construction</td></tr>
<tr><td>4. Manufacturing</td></tr>
<tr><td>5. Trade</td></tr>
<tr><td>6. Transportation</td></tr>
<tr><td>7. Services</td></tr>
<tr><td>8. Other Industry</td></tr>
<tr><td rowspan="4">VALUE ADDED</td><td>Employee compensation</td><td colspan="4" rowspan="4"></td><td colspan="4" rowspan="4">Gross Domestic Product</td><td rowspan="4"></td></tr>
<tr><td>Taxes on production and imports</td></tr>
<tr><td>Proprietor income</td></tr>
<tr><td>Imports</td></tr>
</table>

Source: Based on examples from Miller and Blair (2009) and Watson et al. (2015).

Table 4. Structure of the industry codes based on NAICS 2012 for an input-output account using the main sectors involved in mussel farm expenses.

Title (Code)
Agriculture, Forestry, Fishing and Hunting (11)
Livestock (112)
Mining, Quarrying, and Oil and Gas Extraction (21)
Oil and Gas Extraction (211)
Utilities (22) (221)
Manufacturing (31-33)
Textile Product Mills (314)
Petroleum and Coal Products Manufacturing (324)
Plastics and Rubber Products Manufacturing (326)
Fabricated Metal Product Manufacturing (332)
Miscellaneous Manufacturing (339)
Wholesale Trade (42)
Retail Trade (44-45)
Miscellaneous Store Retailers (453)
Transportation and Warehousing (48-49)
Rail Transportation (482)
Water Transportation (483)
Truck Transportation (484)
Transit and Ground Passenger Transportation (485)
Pipeline Transportation (486)
Information (51)
Telecommunications (517)
Finance and Insurance (52)
Insurance Carriers and Related Activities (524)
Real Estate and Rental and Leasing (53)
Real Estate (531)
Rental and Leasing Services (532)
Professional, Scientific, and Technical Services (54)
Professional, Scientific, and Technical Services (541)
Educational Services (61)(611)
Other Services (except Public Administration) (81)
Repair and Maintenance (811)
Public Administration (92)

Table 5. Farm expenses with the initial value in dollars ($) based on one million kg of live mussels produced, their appropriate NAICS code, description, and proportions allocated to local expenses (occurring in Washington State) and non-local expenses occurring anywhere other than Washington but still in the United States.

Farm expenses	$/Million kg	Code No.	NAICS Descriptions	Proportions Local	Proportions Non-local	Values ($) Local	Values ($) Non-local
			Retail Expenses[1]				
Mussel seed	297,395	**112**	**Mussel**	0.7	0.10	208,177	29,740
		420	Wholesale trade	0.05	0.05	14,870	14,870
		484	Transportation (truck)	0.05		14,870	
		483	Water transportation		0.05		14,870
Vehicle expense	73,322	**211**	**Oil & gas extraction**		0.150		10,998
		324	Petroleum & coal prod		0.280		20,530
		420	Wholesale trade		0.250		18,331
		482	Rail Transportation		0.010		733
		483	Water transportation		0.004		293
		484	Transportation (truck)		0.003		220
		486	Pipeline transportation		0.003		220
		453	Misc. retailers		0.100		7,332
		524	Insurance carriers & related		0.200		14,664
Textile products (e.g. rope)	114,740	**314**	**Textile products**		0.50		57,370
		420	Wholesale trade		0.10		11,474
		453	Misc. retailers		0.30		34,422
		484	Transportation (truck)	0.02		2,295	
		483	Water transportation		0.08		9,179
Plastic products (e.g. disks, frames)	15,489	**326**	**Plastics & rubber prod**		0.50		7,745
		420	Wholesale trade		0.10		1,549
		453	Misc. retailers		0.30		4,647
		484	Transportation (truck)	0.02		310	
		483	Water transportation		0.08		1,239

[1]Retail expenses showed the specific proportions identified based on different authors and farm information summarized in table 11. Sectors in bold are considered the main sector for each expense.

Continuation-Table 5.

Farm expenses	$/Million kg	Code	NAICS Descriptions	Proportions Local	Proportions Non-local	Values ($) Local	Values ($) Non-local
Metal products (e.g. chain, weights)	4,524	332	Fabricated metal prod		0.50		2,262
		420	Wholesale trade		0.10		452
		453	Misc. retailers		0.30		1,357
		484	Transportation (truck)	0.02		90	
		483	Water transportation		0.08		362
Other expenses (Miscellaneous)	3,615	339	Miscellaneous		0.50		1,808
		420	Wholesale trade		0.10		362
		453	Misc. retailers		0.30		1,085
		484	Transportation (truck)	0.02		72	
		483	Water transportation		0.08		289
			Direct Expenses[2]				
Utilities	2,787	221	Utilities	1.00		2,787	
Phone bill	6,213	517	Telecommunications	1.00		6,213	
Insurances	76,204	524	Insurance carriers and related	1.00			76,204
Equipment rental	6,278	532	Rental and leasing services	0.50	0.50	3,139	3,139
Professional fees	193,811	541	Professional-scientific and technical services	1.00		193,811	
Education & travel	2,511	611	Educational services	0.50	0.50	1,256	1,256
Repairs & maintenance	100,509	811	Repair and maintenance	0.75	0.25	75,382	25,127
Water leases	75,889	920	Government and non NAICS	1.00		75,889	
			Value Added Accounts[2]				
Wages and benefits	829,584		Employee compensation	1.00		829,584	
Payroll tax	91,013		Indirect business tax	1.00		91,013	
Depreciation	16,975		Proprietor income	1.00		16,975	
Income	572,166		Proprietor income	1.00		572,166	
Total	**2,483,02**					**2,108,898**	**374,127**

[2] Non-retail expenses and value added accounts are included to show total output of mussel sector.

Table 6. Final values for sectors involved in the mussel production farm.

Code	NAICS Description	WA	US
		$/ 1.339M kg	$/ 2.232 M kg
112.1	Mussels	278,749	531,029
211	Oil & gas extraction	-	24,548
221	Utilities	3,732	6,221
314	Textile Products	-	128,050
324	Petroleum & coal prod	-	45,823
326	Plastics & rubber prod	-	17,286
332	Fabricated metal prod	-	5,049
339	Miscellaneous	-	4,034
420	Wholesale Trade	19,911	138,176
453	Misc. retailers	-	109,017
482	Rail Transportation	-	1,637
483	Water transportation	-	58,551
484	Transportation (truck)	23,616	39,857
486	Pipeline transportation	-	491
517	Telecommunications	8,319	13,867
524	Insurance carriers & related	-	202,818
532	Rental & leasing services	4,203	14,012
541	Professional- scientific & tech services	259,513	432,586
611	Educational service	1,682	5,605
811	Repair & maintenance	100,936	224,336
920	Government & non NAICS	101,615	169,384
	Employee compensation	1,110,813	1,851,631
	Proprietor income	788,860	1,314,963
	Tax on production, Imports	121,866	203,141
	Sub-Total	2,823,816	5,542,112
	Non-Local	500,956	-
	Total	3,324,772	5,542,112

Assumptions: the values extrapolated for Washington State are based on the local expenses for 1.339 million kg of fresh live mussels produced stating a value for those expenses that occur outside of the State. For the US based on the total expenses (local and non-local) for 2.232 M kg for the total US production.

Table7. Mussel sector as a sub-division of the mussel sector to the other livestock.

2012 SAM ($ Million) (Modified)	**112.1 Mussels**	**112 Other Livestock**	**Final Demand**	**Total Industry Output**
	Intermediate Industries (X)		**(Y)**	
112.1 Mussels	0.16	0.00	3.05	3.21
112 Other Livestock	0.00	162.96	...	2,305.53
	Value Added Accounts			
Employee Compensation	1.11	232.84	...	203,168.21
Proprietor Income	0.79	96.49	...	25,987.80
Tax on Production and Import	0.12	(19.81)	...	30,462.30
Grand Total	3.21	2,305.53	...	2,147,712.87

Assumptions: Based on Washington State for 2012 in million dollars. We divided sector 112 (Livestock) and converted it into two sectors Mussels (112.1) and Other Livestock (112). The final demand reflected all expenses minus the 0.16 value allocated for mussel to mussel expenses to avoid duplicates. We showed the grand total column to reflect the balanced input-output accounts. Three dots in final demand denote values to be included from other sectors. Values for the model may vary but here it is an example. Dots in the model provide with additional values/data.

Table 8. Results for the multipliers from mussel and other livestock for each group (including various sectors) for Washington and the US. Values were summarized from the results obtained in our IO model using three sector digits and summarized in 9 groups.

		Washington		United States	
Group	Group	Mussels	Other Livestock	Mussels	Other Livestock
1	Agriculture, forestry, fishing, and hunting	1.09	1.13	1.106	1.478
2	Mining	0.003	0.02	0.017	0.069
3	Manufacturing	0.004	0.12	0.072	0.453
4	Transportation and trade	0.02	0.05	0.083	0.103
5	Information, insurance, real estate and professional services	0.12	0.08	0.21	0.216
6	Education and services	0.001	0.001	0.001	0.002
7	Arts, entertainment and accommodation	0.002	0.002	0.004	0.006
8	Other services and repairs	0.03	0.002	0.047	0.006
9	Government	0.04	0.01	0.04	0.013
	Total	1.31	1.41	1.58	2.345

Assumptions: results based on Multiplier: ([I]-[A])-1). Description of all sectors included in each group are in more detailed in Table 12.

Table 9. Economic activity after multiplying mussel farms multipliers [$([I]-[A])^{-1}$] by final demand (y) for Washington and the US. The multiplier for WA resulted to be 1.31 and the final demand \$3.05 Million. For the US the multiplier was 1.58 and the final demand \$5.01 million.

		Washington State		United States	
Group	Sectors included	Multiplier	Economic Contribution ($)	Multiplier	Economic Contribution ($)
1	Agriculture, forestry, fishing, and hunting	1.09	3.33	1.106	5.544
2	Mining	0.003	0.01	0.017	0.083
3	Manufacturing	0.004	0.01	0.072	0.359
4	Transportation and trade	0.02	0.06	0.083	0.418
5	Information, insurance, real state and professional services	0.12	0.36	0.21	1.052
6	Education and services	0.001	0.002	0.001	0.006
7	Arts, entertainment and accommodation	0.002	0.01	0.004	0.019
8	Other services and repairs	0.034	0.1	0.047	0.235
9	Government	0.04	0.11	0.04	0.199
	Total	1.31	3.98	1.58	7.914

Table 10. Detail of multipliers and economic activity from mussel farms group 5.

	Washington		United States	
	Multiplier	Economic Contribution ($)	Multiplier	Economic Contribution ($)
511 Publishing industries	0.0018	0.0056	0.0011	0.0056
512 Motion picture & sound recording	0.0001	0.0004	0.0005	0.0025
515 Broadcasting	0.0002	0.0005	0.0011	0.0055
516 Internet publishing and broadcasting	0.0003	0.0011	0.0005	0.0026
517 Telecommunications	0.0061	0.0187	0.0082	0.0412
518 Internet & data process services	0.0001	0.0004	0.0003	0.0016
519 Other information services	0.0000	0.0001	0.0000	0.0001
521 Monetary authorities	0.0023	0.0071	0.0057	0.0283
522 Credit in mediation & related	0.0002	0.0006	0.0008	0.0039
523 Securities & other financial	0.0009	0.0027	0.0036	0.0182
524 Insurance carriers & related	0.0014	0.0042	0.0556	0.2783
525 Funds- trusts & other finance	0.0000	0.0001	0.0005	0.0024
531 Real estate	0.0036	0.0109	0.0065	0.0328
532 Rental & leasing services	0.0017	0.0052	0.0037	0.0187
533 Lessor of non-finance intangible assets	0.0001	0.0004	0.0015	0.0075
541 Professional- scientific & tech services	0.0920	0.2807	0.1045	0.5234
551 Management of companies	0.0011	0.0033	0.0046	0.0232
561 Administrative support	0.0040	0.0123	0.0106	0.0531
562 Waste management & remediation services	0.0003	0.0008	0.0007	0.0033
	0.1164	0.3550	0.2100	1.0523

Table 11.Expenses marginalized and allocated to their primary economic sector and other retailers involved.

All supplies (plastics, metals and textiles) were allocated based on general assumptions from Implan ® supplies involving retailers and transportation. We modified transportation to add water transportation as It is a common from the factory.

NAICS	Title	Proportion
3XX	Main Sector	0.50
420	Wholesale Trade	0.10
453	Misc. Retailers	0.30
483	Water Transportation	0.08
484	Truck Transportation	0.02
	Total	1.00

Vehicle and motor pool expenses included renting cars, oil, gas, insurances and fuel for boats, we do not have detailed expenses, and therefore we assumed 70 % of the expenses for the IMPLAN default margins and also Leonard and Watson (2011) for the petroleum refineries, 10% for insurances, and 20% miscellaneous retailers.

NAICS	Title	Proportion
211	Oil & gas extraction	0.154
324	Petroleum & coal prod	0.276
420	Wholesale Trade	0.253
482	Rail Transportation	0.005
483	Water transportation	0.004
484	Transportation (truck)	0.006
486	Pipeline transportation	0.003
524	Insurance carriers & related	0.100
453	Misc. Retailers	0.200
	Total	1.000

Mussel seed was marginalized based on general assumptions from our representative farm and allocated to livestock sector (112) or the mussel sector once it is included in the IO model.

NAICS	Title	Proportion
112	Livestock (mussel)	0.80
420	Wholesale Trade	0.10
483	Water Transportation	0.08
484	Truck Transportation	0.02
	Total	1.00

Table 12: Industry sectors (NAICS, 2012) allocated into nine groups.

#	Sectors included	#	Sectors included
1	111 Crop Farming	4	484 Truck transportation
	112 Livestock-Mussels		485 Transit & ground passengers
	112.1 Mussels		486 Pipeline transportation
	113 Forestry & Logging		487 Sightseeing transportation
	114 Fishing- Hunting & Trapping		492 Couriers & messengers
	115 Ag & Forestry services		493 Warehousing & storage
2	211 Oil & gas extraction		481 Air transportation
	212 Mining		482 Rail Transportation
	213 Mining services		483 Water transportation
	221 Utilities	5	511 Publishing industries
	230 Construction		512 Motion picture & sound recording
3	311 Food products		515 Broadcasting
	312 Beverage & Tobacco		516 Internet publishing and broadcasting
	313 Textile Mills		517 Telecommunications
	314 Textile Products		518 Internet & data process svcs
	316 Leather & Allied		519 Other information services
	321 Wood Products		521 Monetary authorities
	322 Paper Manufacturing		522 Credit inmediation & related
	323 Printing & Related		523 Securities & other financial
	324 Petroleum & coal prod		524 Insurance carriers & related
	325 Chemical Manufacturing		525 Funds- trusts & other finan
	326 Plastics & rubber prod		531 Real estate
	327 Nonmetal mineral prod		532 Rental & leasing svcs
	331 Primary metal mfg		533 Lessor of nonfinance intang assets
	332 Fabricated metal prod		541 Professional- scientific & tech svcs
	333 Machinery mfg		551 Management of companies
	334 Computer & other electron		561 Admin support svcs
	335 Electrical eqpt & appliances		562 Waste mgmt & remediation svcs
	336 Transportation eqpmt	6	611 Educational svcs
	337 Furniture & related prod		621 Ambulatory health care
	339 Miscellaneous mfg		622 Hospitals
4	42 Wholesale Trade		623 Nursing & residential care
	441 Motor veh & parts dealers		624 Social assistance
	442 Furniture & home furnishings	7	712 Performing arts & spectator sports
	443 Electronics & appliances stores		712 Museums & similar
	444 Bldg materials & garden dealers		713 Amusement- gambling & recreation
	445 food & beverage stores		721 Accommodations
	446 Health & personal care stores		722 Food services & drinking places
	447 Gasoline stations	8	811 Repair & maintenance
	448 Clothing & accessories stores		812 Personal & laundry services
	451 Sports- hobby- book & music		813 Religious- grantmaking
	452 General merch stores		814 Private households
	453 Misc retailers	9	92 Government & non NAICs
	454 Non-store retailers		

Table 13: Excerpt for the Washington-Social Account Matrix (SAM) (2012) in million dollars used for the model. Not all sectors were included, dots (…) showed the existence of additional sectors, lines (-) and empty cells recorded unknown values and (0) values <0.

2012 Washington SAM ($ Million)	111	112	113	114	Other Sectors	(C)	(I)	(F Trade)	(D Trade)	Total
111 Crop Farming	224.38	73.39	28.58	0.31	…	-	37.27	1,418	4,949	7,844
112 Livestock	20.99	163.12	3.24	0.03	….	-	8.31	13	1,052	2,309
113 Forestry & Logging			139.20		….	-	18.04	129	331	1,103
114 Fishing- Hunting & Trapping					….	-	55.27	1,300	103	1,497
115 Ag & Forestry Svcs	528.01	28.46	88.78	1.38	….	-	-	35	66	779
211 Oil & gas extraction	1.33	0.19	0.03	0.13	….	4.88	-	31	179	603
212 Mining	8.49	1.20	0.00	0.01	….	2.64	18.71	94	153	871
213 Mining services	0.00	0.00	0.00	0.00	….	73.77	0.00	0	6	115
221 Utilities	78.76	13.10	0.22	0.39	….	0.65	-	1	2	5,898
230 Construction	72.30	8.03	1.76	4.77	….	17,688	-	-	794	32,135
311 Food products	2.95	142.91	0.94	1.01	….	0.32	15.07	1,270	8,293	16,242
312 Beverage & Tobacco	0.00	0.64	0.00	0.00	….	0.00	2.60	158	805	3,415
313 Textile Mills	1.67	0.05	0.00	0.12	….	0.47	0.11	92	270	546
314 Textile Products	0.01	0.00		0.00	….	0.00	0.01	56	108	363
316-521 Sectors	…..	…..	….	….	….	…….	…..	…	….	…….
521 Monetary authorities	320.20	41.07	6.72	4.48	….	-	-	636	14	13,105
522 Credit inmediation & related	3.83	0.40	0.63	0.25	….	-	-	44	15	1,938
523 Securities & other financial	9.24	4.01	1.61	3.42	….	-	-	381	34	7,892
524 Insurance carriers & related	1.01	0.66	0.30	1.49	….	-	-	298	892	10,969
525 Funds- trusts & other finan					….	-	-	-	0	1,810
531 Real estate	517.43	40.57	1.64	1.00	….	3,492.6	-	42	4,410	57,928
532 Rental & leasing svcs	21.82	2.18	1.67	0.19	….	-	-	266	80	2,588
533 Lessor of nonfinance intang assets	0.82		0.01	0.01	….	-	-	526	4	1,025
541 Professional- scientific & tech svcs	39.63	8.64	9.86	8.24	….	3,606.4	0.9	1,118	8,402	39,886
551 Management of companies					….	-	-	1,494	61	8,345
561 Admin support svcs	7.88	1.18	1.57	0.54	….	2.4	-	68	1,274	12,817
562 Waste mgmt & remediation svcs	0.90	0.06	0.46	0.37	….	1.1	-	12	1,755	4,011
611 Educational svcs	8.78	1.31	0.53	9.05	….	-	-	13	276	3,961
621 Ambulatory health care					….	-	-	0	1,205	20,134
622 Hospitals					….	-	-	3	32	11,595
623 Nursing & residential care					….	-	-	-	7	3,954
624 Social assistance					….	-	-	-	191	3,527
712 Performing arts & spectator sports	1.08	0.19	1.86		….	-	-	8	133	1,870
712 Museums & similar					….	-	-	-	1	296
713 Amusement- gambling & recreation	0.60	0.22			….	-	-	-	153	2,655
721 Accomodations	1.62	0.13	0.01	0.00	….	10.8	-	0	2,666	2,966
722 Food svcs & drinking places	3.32	0.67	0.01	0.01	….	0.1	-	23	0	14,856
811 Repair & maintenance	5.83	0.56	8.84	0.15	….	-	-	2	346	4,690
812 Personal & laundry svcs					….	-	-	-	392	3,909
813 Religious- grantmaking- & similar orgs	8.69	0.97		0.36	….	-	-	6	130	4,600
814 Private households					….	-	-	-	29	363
92 Government & non NAICs	47.11	7.41	0.44	3.38	….	2,029.7	0.0	1,720	5,087	59,857
Employee Compensation	1,259.93	233.95	349.80	266.79	….					203,168
Proprietor Income	2,100.65	97.28	254.53	820.67	….					25,988
Other Property Type Income	131.05	512.45	(4.99)	201.27	….					127,567
Tax on Production and Imports	(92.93)	(19.69)	66.41	30.62	….					30,462
Households LT10k	0.00	0.00	0.00	0.00	….	5,119.1	-	1	15	7,350
Households 10-15k	0.00	0.00	0.00	0.00	….	1,440.4	-	0	15	4,679
Households 15-25k	0.00	0.00	0.00	0.00	….	3,663.6	-	2	89	14,783
Households 25-35k	0.00	0.00	0.00	0.00	….	3,098.9	-	2	160	17,513
Households 35-50k	0.01	0.00	0.00	0.00	….	2,478.0	-	3	360	28,458
Households 50-75k	0.01	0.00	0.00	0.01	….	651	-	5	849	52,156
Households 75-100k	0.01	0.00	0.00	0.01	….	5	-	4	851	48,871
Households 100-150k	0.01	0.00	0.00	0.01	….	7	-	6	1,253	70,601
Households 150k+	0.01	0.00	0.00	0.01	….	6	-	5	1,570	104,199
Federal Government NonDefense	0.54	0.25	1.12	0.01	….	31,062	0	13	41	96,293
Federal Government Defense					….					29,570
Federal Government Investment	0.00	0.00	0.00	0.00	….	1	-	1	3	8,157
State/Local Govt NonEducation	40.51	3.79	16.69	7.27	….	33,147	2	44	656	83,186
State/Local Govt Education					….					18,598
State/Local Govt Investment					….					9,864
Enterprises (Corporations)					….					41,810
Capital (C)	0.30	0.05	0.02	0.22	….	149.5	-	75,667	372	200,504
Inventory Additions/Deletions (I)	6.45	3.04	0.14	0.41	….	2,272	3	349	796	3,922
Foreign Trade (F Trade)	391	115	43	20	….	18,446	1,476	-		126,617
Domestic Trade (D Trade)	1,241	679	32	43	….	37,643	774			133,071
TOTAL	7,844	2,309	1,103	1,497	….	200,504	3,922	126,617	133,071	2,147,713

Table 14: Excerpt for the United States-Social Account Matrix (SAM) (2012) in million dollars used for the model. Not all sectors were included, dots (…) showed the existence of additional sectors, lines (-) and empty cells recorded unknown values and (0) values <0.

United States 2012 (Million $)	111	112	113	114	Other Sectors	(C)	(I)	(F Trade)	(D Trade)	Total
111 Crop Farming	16903	15852	707	9	….	-	3,931	66,095	0.00	241,950
112 Livestock	1807	33693	146	1	….	-	1,163	1,859	0.00	171,594
113 Forestry & Logging			1826		….	-	192	1,650	-	14,148
114 Fishing- Hunting & Trapping					….	-	540	4,772	-	9,579
115 Ag & Forestry Svcs	15257	1886	1277	22	….	-	-	989	-	20,559
211 Oil & gas extraction	712	237	7	38	….	3,688	-	16,103	-	311,827
212 Mining	568	181	0	0	….	374	2,255	23,773	-	94,196
213 Mining services	1	1	0	0	….	124,260	5	96	-	132,081
221 Utilities	4902	1870	7	13	….	72	-	57	0.01	497,069
230 Construction	2543	648	31	91	….	865,866	-	-	0.01	1,435,206
311 Food products	187	28707	41	48	….	35	3,973	65,090	-	836,648
312 Beverage & Tobacco	0	116	0	0	….	0	215	6,918	-	189,414
313 Textile Mills	310	21	0	15	….	877	47	12,532	0.00	62,744
314 Textile Products	2	0		0	….	6	27	3,265	0.00	25,049
316-516 Sectors (Values not recorded)		8			….	-	0	2,779	0.00	7,303
316-521 Sectors	…..	…..	….	….	….	….	….	….	….	….
522 Credit inmediation & related	214	51	17	8	….	-	-	3,098	0.00	137,025
523 Securities & other financial	455	453	40	91	….	-	-	27,576	0.00	571,520
524 Insurance carriers & related	52	77	8	41	….	-	-	19,057	-	682,524
525 Funds- trusts & other finan					….	-	-	-	-	165,800
531 Real estate	18259	3283	29	19	….	137,542	-	1,622	-	2,329,582
532 Rental & leasing svcs	914	209	35	4	….	-	-	13,962	-	136,802
533 Lessor of nonfinance intang assets	93		1	0	….	-	-	88,092	-	171,804
541 Professional- scientific & tech svcs	1855	928	230	208	….	187,493	26	42,487	-	1,771,766
551 Management of companies					….	-	-	83,307	0.01	465,411
561 Admin support svcs	370	127	37	14	….	139	-	3,477	-	632,864
562 Waste mgmt & remediation svcs	20	2	7	7	….	33	-	255	-	87,350
611 Educational svcs	535	183	16	298	….	-	-	1,007	-	275,912
621 Ambulatory health care					….	-	-	3	0.00	870,857
622 Hospitals					….	-	-	178	0.00	654,643
623 Nursing & residential care					….	-	-	-	0.01	198,679
624 Social assistance					….	-	-	-	0.00	152,367
712 Performing arts & spectator sports	54	22	46		….	-	-	406	-	113,941
712 Museums & similar					….	-	-	-	0.00	16,581
713 Amusement- gambling & recreation	24	20			….	-	-	-	0.00	121,150
721 Accomodations	87	19	0	0	….	572	-	7	0.00	159,940
722 Food svcs & drinking places	121	56	0	0	….	4	-	1,032	0.03	659,353
811 Repair & maintenance	223	49	168	3	….	-	-	69	-	211,073
812 Personal & laundry svcs					….	-	-	-	0.01	168,764
813 Religious- grantmaking- & similar orgs	386	99		9	….	-	-	269	0.00	242,875
814 Private households					….	-	-	-	0.00	15,041
92 Government & non NAICs	1257	450	7	63	….	91,594	0	74,132	0.00	2,063,275
Employee Compensation	17006	9974	3252	939	….					8,619,970
Proprietor Income	69332	12770	3189	3426	….					1,224,900
Other Property Type Income	3156	32078	-449	1316	….					5,334,130
Tax on Production and Imports	-2012	-1568	582	558	….					1,065,600
Households LT10k	0	0	0	0	….	268,930	-	49	-	376,243
Households 10-15k	0	0	0	0	….	94,977	-	28	-	264,488
Households 15-25k	0	0	0	0	….	216,218	-	104	-	746,968
Households 25-35k	0	0	0	0	….	176,358	-	112	-	833,472
Households 35-50k	0	0	0	0	….	151,393	-	144	-	1,292,578
Households 50-75k	0	0	0	0	….	88,658	-	233	-	2,187,413
Households 75-100k	0	0	0	0	….	235	-	187	-	1,877,698
Households 100-150k	1	0	0	0	….	334	-	265	-	2,698,575
Households 150k+	1	0	0	0	….	350	-	278	-	4,439,644
Federal Government NonDefense	58	63	20	0	….	1,361,031	18	588	-	3,981,800
Federal Government Defense					….					673,300
Federal Government Investment	0	0	0	0	….	48	-	38	-	285,011
State/Local Govt NonEducation	1607	345	312	131	….	658,723	45	1,395	-	2,990,600
State/Local Govt Education					….					803,642
State/Local Govt Investment					….					334,900
Enterprises (Corporations)					….					1,748,257
Capital (C)	14	5	1	5	….	8,944	-	783,398	-	5,706,479
Inventory Additions/Deletions (I)	1064	1226	6	15	….	74,790	936	18,584	-	166,609
Foreign Trade (F Trade)	15545	8017	1296	397	….	292,073	45,902	-		2,827,590
Domestic Trade (D Trade)	0	0	0	0	….	0	-			0
TOTAL	241950	171594	14148	9579	…..	5,706,479	166,609	2,827,590	0.11	78,970,525

CHAPTER 3: Socio-economic contributions, and environmental attributes of existing and potential marine mussel (Family *Mytilidae*) aquaculture systems

Abstract

Bivalve mollusks are an important component of marine ecosystems, and form aggregate communities that provide important ecological functions and ecosystem services within coastal communities. Their value as human foods has been recognized for centuries, and global aquaculture production of bivalves has recently surpassed wild harvests. The economic value of marine bivalve mussels has increased by 350% in less than a decade, but only a small proportion of the global production is from the US. In an effort to improve the understanding of factors affecting sustainability, and develop rationalization for valuation of natural ecosystem services, a mussel farm in a large domestic bivalve aquaculture facility in Puget Sound, Washington State was evaluated. The study estimated water, land and carbon footprints of the mussel production, processing and distribution systems, and evaluated the social-economic factors of the work force including demographics, and worker attitudes regarding job security and safety, income, educational preparation and mobility. A kg of farmed mussels needed 73-94 L of fresh water during the annual production of 550,000 kg of mussels. The carbon footprint of the farm, processing and distribution from the mussel industry resulted in 1,016,957 kg of CO_2e or 1.85 kg of CO_2e/kg of mussels distributed, or 3.7 kg of CO_2e/kg of edible mussel meat. These results highlight the potential benefits and risks of increasing domestic mussel production and consumption, and options to improve national economic and social stability. The potential future domestic expansion of this industry is discussed using a framework of harvest, socio-economic factors, and protection of natural ecosystem services.

Introduction

Increased and intensive agricultural demands, scarce freshwater resources and global climate change are some of the conflicts and challenges resulting from increasing human population (Schau and Fet, 2008; Shiklomanov and Rodda, 2003; Steinfeld, 2007; Vorosmarty et al., 2000). In 2011, FAO announced a need to find a new revolution/approach for the new millennium to develop sustainable intensification of agriculture practices. FAO promoted and published techniques to achieve sustainable agriculture by *saving to grow*, using an ecosystem approach that imitates nature and to harvest the right amount without putting excessive pressure on natural resources (Rai et al., 2011). All food systems need to be considered when stimulating sustainable agriculture (Torquebiau et al., 2016), yet sustainable agriculture cannot continue its expansion to provide additional food sources without compromising our environment (Bajzelj et al., 2014).

Measures of sustainability in human activities will determine opportunities for global growth strengthening methods that secure food supply, eradicate poverty, and conserve/protect our environment. Since 1980's sustainability is a well-known and widely used concept, however Gatto (1995) in his editorial expressed the inconsistency of the definition and concluded that sustainable concept needed to be better defined and more realistic to be evaluated (Gatto, 1995). He suggested the need to address the path of human development and its compromise between all parties (scientists-environmentalists and economic investors, developed and developing countries, and different human generations). Sustainable development has enormous complexities, and dimensions, and tools to evaluate them are further confounded by uncertainties, and resistance to integrating environmental and/or socioeconomic dimensions into decision making and performance evaluations (Stinchcombe and Gibson, 2001). Sustainable evaluations have to include environmental and socioeconomic aspects from cradle to cradle (Mauerhofer, 2008; Mori and Christodoulou, 2012) and their interactions between the potential of losing fisheries, forests and water resources (Ostrom, 2009).

Overall, aquaculture plays an important role in food provisioning through the production of high-protein source of food including aquatic animals, algae and seaweeds. According to FAO, in 2013 aquaculture contributed more food than capture fisheries, accounting for a little bit more than 50%. Aquaculture produced 97 million tons and captured fisheries 93 million tons of the total aquatic products consumed by humans (FAO, 2015).

In 2016, the US expanded the opportunity to farm in federal waters of the Gulf of Mexico (Meyhoff Fry, 2012), providing opportunities for increased mussel aquaculture. If well managed and regulated, marine aquaculture poses an opportunity to strengthen local and national economies while maintaining vital ecosystems (Ferreira et al., 2009; Stadmark and Conley, 2011; Whitmarsh et al., 2006). Production of low trophic species or integration of different trophic level species in operations is thought to be environmentally and economically beneficial, and more sustainable (Guggisberg, 2016; Pullin et al., 2007). Integrated Multi-Trophic Aquaculture systems (IMTA) combines species with different attributes that benefit from and utilize wastes from other aquacultural production. Practical examples of IMTA include mussels and seaweeds included with finfish in several successful evaluations (Chopin et al., 2001; Reitan et al., 2008; Sarà et al., 2009; Soto and Jara, 2007; Soto and Mena, 1999).

Marine bivalves have been utilized as food resources for millennia (Cortés-Sánchez et al., 2011) and have great economic value as commodities (Neori et al., 2004). Aquaculture production of bivalves has increased globally in many regions. Some of this expansion is related to the advantage of developing infrastructure for aquaculture with species that are unfed, capitalizing on the natural productivity of marine and brackish ecosystems. The role of bivalves in natural ecosystems systems has been highlighted by many scientists. Bivalve shellfish form aggregate communities, and these systems support many ecological functions in the coastal environment (Carranza et al. 2009; Gutierrez et al., 2003; Barrell and Grant 2015). Their reefs and sea grass communities help create substrates and maintain coastal shorelines, utilize local productivity that can reduce eutrophic conditions (Baggett et al 2015; Bergström et al. 2015).

Production and consumption of marine bivalve mussels in brackish and marine systems can increase human well-being, the national economy, and provide a direct measure of ecosystems services. Marine mussels offer a high-protein food source for humans and animals, have potential medical uses, stimulate jobs growth and increase income. Mussels within the family *Mytilidae* are wild harvested and grown in controlled environments by aquaculture. Mussel aquaculture production is marginal as majority of aquaculture is dominated by finfish (FAO, 2014). However, since the 1950's wild harvest and aquaculture of mussels have provided more than 100,000 t of live mussels for human consumption per year. FAO started to record statistics from mussels in 1950 reporting about 100,000 t for the year, about 95,600 t from the wild (about 50% harvested in Korea) and around 1,000 t from aquaculture (Table 1). Noteworthy, earlier data for mussel aquaculture in many countries was not recorded. In 2000, aquaculture production surpassed wild harvested products by producing 1.3 million t compared to 0.2 million t from the wild. In 2013, aquaculture produced 95% of the total mussel products worldwide, with approximately 40% being produced in China followed by Chile with 13% (Table 2).

Out of 12 species harvested from aquaculture, four mussel species are the most common worldwide: blue mussel species (*Mytilus edulis*), Mediterranean mussels (*Mytilus galloprovincialis*), Asian green mussel (*Perna viridis*) also known as *Mytilus smaragdinus*, and the Chilean mussel *(Mytilus chilensis)* (Table 3).

Early in 1990's all mussels from Europe were considered to be *Mytilus edulis* and some authors and organizations still combine their information and call different species blue mussels or mixed species. FAO reports mussels by the species or group them into the *Mytilidae* family and define them as Mussels "nei", which means not elsewhere identified (FAO, 2015). As in case of *Mytilus ssp.*, there have been similar confusion with *Perna* species as there are also numerous synonyms including *Mytilus perna* (Linnaeus, 1758) (FAO 2014). Since several *Mytilus* species are known to hybridize (Borsa *et al*., 2012), therefore mussels in general are referred to *Mytilus spp*. Data was collected from all species of marine mussels utilized, produced, and consumed, worldwide.

In 2004, global mussel aquaculture production of about 1.67 million t was valued at $ 907 million (about $0.54 per kg) while in 2013, 1.58 million t produced were valued at $3 billion ($1.89 per kg). The economic value of mussel products has increased by 350% in less than a decade and prices are continuing to rise. In the US, mussels and mollusks in general are not among the most popular aquaculture production nor are a growing industry. However, for Washington State, the largest aquaculture producer of bivalves in the US, mollusks generated more than $150 million in sales in a year. In the US, Washington is the leading producer of shellfish aquaculture (oysters, clams, mussels and geoducks) contributing about $184 million to the state's economy and supported about 2,700 jobs in 2010 (1,900 direct and 810 indirect jobs) (Northern Economics, 2013). This same study reported that shellfish (oysters, clams, and mussels) in California generated $23.3 million for the State's economy and provided 200 direct jobs and 90 jobs generated in supporting industries. In 2013, the US produced about 2.23 million kg of food or market size live mussels (average of 44 live mussels per kg), and in value, it accounted for about $12.2 million dollars ($5.50 per kg) (USDA, 2014). A case study showed that an input-output model for a blue mussel industry with an annual gross revenue of $1.2 million (with a product price of $1.32 per kg of mussels) would contribute $6.49 million in total sales or output, $3.33 million in income and 92 full and part-time jobs for the US economy. In the previous case study, input-output from mussel farm-gate operations were evaluated to show the mussel production output of $5 million generated about $7.9 million within the inter-industry economic contributions (Chapter II this dissertation).

Objectives

The objectives of this paper were to collect data from a case study in the State of Washington, highlighting the sociological, economic and ecological aspects of the suspended bivalve mussel culture systems within the framework of sustainability, and then to examine data from the literature to indicating the potential opportunities and rationale for increasing domestic growth of mussel aquaculture within the new framework for aquaculture leases by NOAA fisheries (NOAA., 2016). Through this analysis environmental and socioeconomic costs and benefits of mussel production and consumption were collected, and additional socioeconomic contributions from mussel production systems were estimated.

Methods

Case study in Washington State

Evaluations were made at a large, integrated marine bivalve aquaculture facility in Washington State within Puget Sound considered the largest shellfish producer in the US. Interviews and site visits were used to collect data from the vertically integrated farm that has been growing shellfish for more than 100 years and Mediterranean mussels (*Mytilus galloprovincialis*) in floating rafts for more than 25 years in Washington State. The life cycle of the mussel production system was evaluated including attributes of human labor and the ecological footprints allocated to the farm, and combined different methodologies to utilize relevant information to understand the sustainability of the facility. The assessment included the farm, the processing plant, marketing, packaging and distribution of the mussel product (Figure 1). The harvesting stage within animal production was included because the people and equipment involved in harvesting were the same as those in the farm.

Interviews and collected data from farm records were used to estimate water and carbon footprints, obtain personal attributes of the work force and management structure. The mussel farm purchases the mussel seed from their hatchery located in Washington and occasionally from a hatchery in Oregon. Mussels are cultured on floating rafts with ropes, and reach a marketing size from 12 to 16 months. On average, they use 56 floating rafts using about 1,000 ropes, in water approximately 4.5 m deep. The farmed mussels yield on average 50% meat by weight. As gametogenesis progresses, mussels enlarge but become somewhat grainier in texture. In late March after spawning occurs, mussels' meats are somewhat emaciated, and the additional individuals are needed in presentations to compensate for meat yields and water content. Mussels are weighed, packed live in their shells in mesh bags for distribution through various transportation networks within the US (90%) and Canada (5%). A small portion of <5% is imported to China vacuum-packed. Fresh mussels have about 10-d shelf-life, if refrigerated. Other presentations include pasteurized and vacuum packed, with shelf-life about 20 days or if frozen one year.

Collection of environmental and socioeconomic data

The interview methodology was approved by the Institutional Review Board (IRB) at the University of Idaho (Appendix A). Personal interviews were used to obtain general information on the system and the staff (Appendix B). Information from managers provided details on the production system, processing, marketing facilities, costs and market prices, annual production. Information related to the use of water, land/area, and energy (as electricity and fuel) consumed in production and processing stages were collected to estimate the ecological footprints. Materials used for packing, weight of the marketing presentation, and destinations for the final product were used to calculate the fuel required from the transportation to markets. Additionally, an overview of the marketing and origin from the imported mussels was provided and included in the consumption of the US population.

Specific data about workers and their workplace was collected in person with each employee in confidential conversations, blinding the outcomes. This interview (Appendix C), also translated in Spanish (Appendix D). Questions focused on demographics, job stability, job safety and job security. Job safety and job security were open-ended questions as well as multiple choice and questions where they could rate on a five-point scale, from 1 “very unsafe or unsecure” to 5 “very safe or secure” or from 1 “never” to 5 “always”. The workers were classified as into three ranks I) Executives (5 people; 1 responded in Spanish) II) manager assistants and supervisors (4: 1 responded in Spanish) and III) farm and processing plant operators (10: 9 responded in Spanish).

Ecological footprints

The ecological footprint principle (Hoekstra et al., 2016; Hoekstra and Wiedmann, 2014; Wackernagel et al., 2002; Wackernagel et al., 1999) was used to estimate freshwater, land, and energy required during different stages of the production system and also included the origin of the mussel products consumed in the US and the local production distribution. In cases when data were not all available estimations and assumptions for carbon footprints were made regarding transportation. Commercial and public maps were used to provide estimates of automobile efficiency (e.g. Washington post https://www.washingtonpost.com/news/wonk/wp/2013/12/13/cars-in-the-u-s-are-more-fuel-efficient-than-ever-heres-how-it-happened/). These resources provided estimates of fuel required for the commute, convert minutes of driving, from worker commuting, and estimates of energy kWh by the price of electricity was provided. Many emissions were estimated in CO2e, or carbon dioxide equivalents, to enable analytical comparisons. International footprint standards recommend the inclusion of fuel used by the company vehicles and by the employees that commute to work as they are part of the resulting carbon footprint for the industries. Additionally, data from other natural resources used during the process were collected to highlight environmental practices that the farm included in their production as a measures to protect their own environment and decrease their ecological footprint.

Socioeconomic indicators

The estimated socioeconomic indicators were based on suggestions from Kruse et al. (2009) and the potential of evaluation screened by Iribarren et al. (2016). Additional components were included such as the level of job security, safety, and some of the reasons why workers prefer to work in mussel production systems instead of in other places. Many results were reduced to allocations per kg of fresh mussels in the shell to allow for comparisons.

Literature review of global mussel production, use and sustainability

The published literature and national and international on-line data bases were reviewed to summarize ecological footprints and socioeconomic indicators from mussel production at the global scale. Data collected included uses of product, and management practices and attributes of the global production and summarized the systems used, total production, and social context. Using these data, the opportunity and challenges of increased domestic production were addressed to increase sustainability of the industry and our food resources from seafood, and enhance understanding of the value of natural ecological services and domestic regulatory environment assuring safe water quality.

Results

Case study environmental outputs

All water used in the farm and processing plant was groundwater. A total of 120,000 L was used in farm operations for the annual production (550,000 kg of mussels with shell) resulting in 0.22 L of water per kg of mussels in their shells. This water was used to treat or avoid potential parasites sensitive to salinity changes: about 10,000 L of fresh water and repeated about 12 times per year. Additionally, the farm processing plant used 530,000-570,000 L per day of operation for all species harvested and processed and we estimated a total for the proportion of fresh mussels processed at the plant (approximately a 25 - 30%). From these calculations, based on proportion of harvest, and days of operation we estimated a range from 40 - 51 million L for the total mussel processed, resulting in 73 - 94 L/kg mussel in shell. The waste water from processing passes through a water treatment to decrease sediments and remaining effluent is diverted to a forest that the farm implemented to increase their carbon sequestration and reused their effluents. Total fresh water footprints were estimated to be 40.12 – 51.12 million L of freshwater/total processed product, resulting in 73 - 94 L of freshwater/kg of mussels with shell or double for a kg of edible mussel, considering a 50% yield on average form mussels in their shell, resulting on 146 - 188 L/kg of meat. We did not estimate the seawater used in production, but laboratory estimation by farm staff reported filtration rates by mussels to range from 2-2.5 L/h, depending on the amount of productivity in the water, and the density of the culture system. The farm estimated chlorophyll content of plankton from averages of different seasons to be from 3.22 to 8.35 μg/L. The annual water temperature ranged from 7 – 20°C, and averaged 15°C, salinity averaged 27 ppt, ranging from 27.79 to 28.2 ppt, and pH averaged 8.12 ranging from 7.27 - 8.9.

The land used to produce mussels in the farm was estimated but did not include land used for the buildings, offices, processing plant, farm material storage and parking of vehicles. The area used within the mussel farm covers about 46,080 m^2 used to produce an average of 550,000 kg of mussels, resulting in about 0.08 m^2 per kg of mussel produced, or 0.16 m^2 per kg of edible meat.

The carbon footprint was estimated from the farming stage and processing plant (Table 4). For the infrastructure we did a comparable estimation resulted from Tracking (2008) that showed similar infrastructure used and production system. The production results were extrapolated using estimates of Tracking and considered 5,473 kg of CO_2e per year. Additionally, use of boats to reach the mussel site from the shore, the automobiles used within the farm operations used about 13,310 L/diesel/yr, and fuel used by the workers who commute to work (15 min to commute in personal cars for 10 workers) was estimated at 4,680 L/yr for about 10 workers involved in the farming stage. The total estimate from the farm operations resulted in 51,466 kg CO_2e or 0.09 for harvested kg of mussel with shell. The electricity used in the processing plant for mussels resulted in 20% of the total usage in the farm and the data obtained was from their monthly utility costs ($300), and converted to kWh (Table 4). The total estimation from the processing plant resulted on 6,500 kg CO_2e or 0.08 per kg of mussel with shell processed. When included the distributing stage of the industry (Figure 3), the carbon footprint from the distribution of live mussels in their shell nationally and vacuum-packed internationally ranged from 0.009 - 5.48 kg of CO2e. The total carbon footprint estimated for the distribution from all the production per year was 959,249 kg of CO_2e. Including farm, process and distribution from the mussel industry, the resulting carbon footprint was 1,016,957 kg of CO2e, or 1.85 kg of CO2e/kg of fresh mussels with shell distributed, or potentially 3.7 kg of CO_2e/kg of edible mussel meat.

Case study socioeconomic and food provisions

The farm provided four market sizes: small (4.5 cm = 20 g per mussel, 48 mussels in their shell per kg); medium (5-7.6 cm = 25 g per mussel, 40 mussels in their shell per kg); large (7.6-10 cm = 28 g per mussel, 35 mussels in their shell per kg); and jumbo (12-15 cm = 75 g per mussel, 13 mussels in their shell per kg). A serving size (85 g) of Mediterranean mussels from the farm was reported to contain 20 g of protein, 147 calories and various minerals and vitamins (Table 5). Processing 550,000 kg of live mussels and using the average of yields per mussel (50%), our farm would provide 275,000 kg of edible meat per year or more than three million serving sizes. Additional information was provided by the managers of the farm regarding food provision and marketing presentations, data included in Appendix E.

Worker indicators

An observational analysis was used to summarize interviews and data collected from all workers at the mussel farm. Executives worked as general operational managers with the major business responsibilities, including purchase of raw materials and seed, public relations and communications, farm manager, processing plant manager and chief salesperson. The manager assistants supported the executives within the farm and the processing plant and the supervisors and operators were part of the farm and the processing plant. The employees were from multicultural backgrounds with the majority being foreign labor, and with a range of income from $20,000 to more than $70,000. The majority of workers were located in the range of income from $20,000-40,000. Additionally, the majority of workers did not have a high school diploma, especially those working at the processing plant. Four of the workers (3 in the executive level and 1 in the farm) obtained their Bachelor’s or Master’s degree, including degrees within the national and international education system (Table 6). The operations involved 19 positions, 14 of which were full-time and 5 were considered part time from the producing sector to the distribution stage, part-time allocations for employees also occurred in the executive branch that oversees all the species production in farms within the company that also produce oysters, clams, and geoduck (Figure 3). Workers involved in the transportation sector were not interviewed.

The wages earned by employees contributed to >75% of the household income for the majority of workers. Additional, parameters were estimated to show workers per production stage, hours spent at their job salaries, used to estimate the total labor cost and working hours required per total production per year as well as per kg of mussel processed (Table 7). Employees spent 34,650 hr/yr, and divided by total production, these resulted in 0.063 h/kg mussels packed. Labor costs including compensation, benefits and taxes were about $500,000/yr or $0.90/kg of mussel sold. Total income for labor within the production, harvesting, processing, packaging, and sales stages was estimated as $1.32 million/yr or $2.4/kg mussels. Two employees reported working from 50 to 60 h per week. The educational level of employees was related to their position, with the executives with some college.

Job stability was assessed using duration of employment, interviewing the workers and followed up with information related to hiring obtained from the manager of the company. The average time workers had spent in the company was 10 yrs with a range of a few days to 18 yrs. The workers in operations valued benefits (scale 1 = low; 4 = high) ranging from 3 to 4, and higher ranking workers (executive and assistant managers, and supervisors) ranked benefits from 2 to 3.5. The overall average value from all the workers in the company was 3.22. Workers expressed the best part of the work and its benefits were the flexibility of the schedule, working outdoors, and in a family-supportive environment. The benefit assigned with the lowest score was health insurance; workers obtain this benefit by paying a small fee per insured and per family member ($50 per month/person). Many of the higher-position workers commented on the quality of the insurance being between 2 to 3 but considered it as a better insurance compared to that offered from other companies. Two workers (~10%) from the company considered a good benefit as having a “401 (k)” and 25% of the workers suggested the need to have economic incentives in the forms of bonuses, as they always provide or increase the happiness of the workers (Appendix F).

All of the executive managers felt their positions were very secure (5); most of them had been working in the farm > 10 yr. Males older than 30 and managers in lower ranks felt their positions in the company to be either very secure (5) (50%) or somewhat secure (4) (50%). At least half the workers in the farm and in the processing plant felt their positions were very secure (5), and these were men, older than 35 and either working for more than 10 years, off-shore, or were new in the company. Only one female was working in the mussel production system and was in the processing plant (Table 6). One group considered their jobs somewhat insecure, and they expressed this ranking because they had communication problems with management.

The aspects of job safety were of importance to all interviewed. The average response from all was that their jobs were somewhat safe. Evidence showed higher feeling of job safety among the workers in the processing plant. Some workers in the farm expressed difficulties with weather conditions, outdoors, as well as working in aquatic environments. To evaluate job safety, workers were asked how frequently they worked to their full potential, a question that brought smiles within the interviews. The overall average rank was 3.8, and comments were made regarding the trade-off of job safety with working at full potential during winter conditions. One worker commented that they worked more efficiently (score 4) when on a contract than by the hour. When asked what was more important if job security or safety in their work 20 % answered *both* are equally important, 30% *security* is more important and 50% *safety*. Those that answered *both* had completed high school or higher education, and were among the ages of 30 to 40 years old. From those that answered *security,* 80% were among people between 40 to 60 years and the rest were newly hired and both expressed gratitude to have a job. From those that answered safety as being more important, 80% were either in the working section of the farm or in the processing plant, and they were among people between 23 and 44 years old.

The executive managers and supervisors felt they provided their opinions freely either verbally, in writing or both. Within the workers in the farm the answer varied from often to never, mostly verbally with an average score of occasionally. In the processing plant only the female worker provided her opinion occasionally and the rest seldom or never provided input. The processing plant manager commented that they had made efforts to enlist more feedback, knowing this was needed. All the workers interviewed indicated they could give feedback, but not all used the option.

Appendix G shows the codebook that we used to provide a number to workers' responses in order to provide numerical data that can serve to quantify their involvement in the farm and a level of an overall indicator of the socioeconomic parameters evaluated.

Literature review of global mussel aquaculture

Farming systems, species, and presentations

The US imports most of mussel products, with the majority coming from Canada as live, fresh farmed or wild, followed by New Zealand and Chile. New Zealand and Chile provide the most frozen, dried, and salted mussels for the US. In volume almost 50% of the product come as frozen and 49% live mussels (farmed), 1.7 % is live, fresh mussel from the wild (Table 8).

Different systems, type of production including wild capture and aquaculture as well as different species are involved in those countries where US imports are originated. Table 9 provides with an overview of the mussel system in those countries as well as the marketing presentation, volume and value represented from their total exports.

Various methods of mussel farming are used worldwide that range from on-bottom culture and bouchot type, subtidal and on bottom raft and long-line. Depending on farm locations and environmental factors, the yields vary. Marketable sizes in most global farms are reached in < 2-3 years, depending on the stocking densities, the environment, water quality, system, and rich-nutrient water.

In 2013, *Mytilus chilensis* was the dominating species in aquaculture production (241,821 t), mainly harvested from bottom and suspended systems (longlines). *Mytilus edulis* or blue mussel a native species from the North Atlantic Ocean and also considered native to North Pacific (197,832 t), *Perna viridis* or Green mussel (162,933 t), *Mytilus galloprovincialis* (115,664 t), and *Perna canaliculus* or New Zealand mussel (83,561 t) (Table 1). These four species are produced mainly from suspended cultures (longlines and rafts) but harvest from bottom or intertidal systems are not uncommon. However, reporting and statistics of many countries do not provide exact species that are farmed making the exact estimation troublesome. Additionally, *Mytilus ssp.* hybridization and evolutionary affinities further confound precise assessments (Borsa et al., 2012; Toro et al., 2005).

In Spain the dominant form of mussel production is the use of rafts (Iribarren et. al 2010). One of the popular methods in Sweden is the long-line approach, where mussels are grown on 6 m-long suspenders attached to horizontal lines. On the west coast of Sweden one long-line unit (8-10 lines) was estimated to produce 140-180 t of mussels in about 18 months with optimal sites producing up to 40 kg of fresh mussels per m^2 per year (Lindahl et al., 2005).

In Denmark, long-lined mussels culture are popular for marketing their mussels as live while wild mussels are commonly canned (boiled and canned). Majority of mussels harvested in Chile and New Zealand are sold fresh, with a portion of production being frozen. There are also a number of factories that process mussels to be vacuum packed, smoked, crumbed, stuffed, prepared in mussel chowder or marinated (FAO, 2016).

According to the Island Institute's guide to mussel aquaculture, the farmers in Maine use 300 to 500 seed mussels per meter of rope to harvest marketable mussels in 15 to 18 months. Mussels grown on ropes also have a higher meat to shell ratio and potential higher market value (http://www.islandinstitute.org/resource/maine-guide-mussel-raft-aquaculture-0).

Environmental outputs

Figure 4 shows a diagram of the distribution of the mussel products throughout the different countries that come into the US and we estimated the carbon footprint of the total consumption of mussels. The transportation of the product from outside the US into domestic consumption resulted to be about 100 M kg of CO_2e.

Measurement of water during the processing of mussels was included in the evaluation of farms in Spain by Iribarren et al. (2010c), they accounted for fresh and marine water used per kg of dry meat and used different presentations. In total a kg of mussels in the process of cleaning them took about 7 L of seawater and 14.4 L/kg of live mussels, once processed in different market preparations freeze mussels required and additional of 2.75 L/kg of dry meat, boiled 5.69 L and canned 8.7. If depuration is needed in the Spanish farms it is provided in the dispatch centers (on- or off-shore) and involves keeping mussels for 24-48 h in pathogen-free water so the mollusks can filter the water and get depurated. Used water is then treated and drained to the ocean or sewage. (Iribarren et al., 2010c). Land requirements for production were estimated in Greece, by (Theodorou et al., 2014) who reported ranges of 0.094 - 0.10 m^2 per kg of edible mussel were used in assessed locations. In Spain, Iribarren et al., (2010b) estimated about 0.025 - 0.03 m^2 was needed for processing a 1 kg of mussel flesh.

Most environmental evaluations of mussel systems have focused on carbon footprints or environmental emissions from different stages within the life cycle of the mussel production. A report on carbon footprints from a small shellfish farm in Ireland estimated 0.61 kg of CO_2 e, including natural water content of the mussels or excluding the water a footprint of 1.7 kg of CO_2 e/kg of edible product (Meyhoff Fry, 2012). Their carbon footprint was estimated based on the use of energy, fuel for their boats (40%), cars (44%), office/storage (7%) and travel from marketing sales (9%). They show possible mitigation strategies – energy efficiency (electricity/heating) of their office/storage space and use bio-diesel for their fleet instead of regular diesel. Another report unpublished from Scotland. (http://www.carbontracking.com/reports/Kush_Footprint_Rev4.pdf), reported that rope-grown mussels had a carbon footprint of 0.25 kg of CO_2 e/kg of mussel harvested. Iribarren et al. (2010c) estimated environmental effects from fresh, canned, and frozen mussels and highlighted higher negative environmental effects produced from the life cycle of mussels linked to mussel depuration not to cultivation or consumption. A LCA assessment of mussel production from a sub-sector perspective (culture, dispatch centers, canning factory and cooking plant) by Iribarren et al. (2010b), showed the largest contributions to potential environmental impacts resulted from logistics (dispatch centers), especially from the use of electricity and chlorine gas production in processing of mussels. They suggested that some of the mitigation methods could be an efficient energy use (electricity) with frequency inverters applied. A critical step for fresh mussels was processing in dispatch centers and mussel culturing was vital for canned mussels (Iribarren et al., 2010a; Iribarren et al., 2010c, d). This is because 1 kg of edible meat of canned mussels represents ~20% of 1 kg of mussels produced while fresh live mussels from our farm accounted for 30-70% of edible meat. In general, blue mussels yield 20-35%, Greenshells 35-45% and Mediterranean 35-50% of edible meat per 1 kg of mussels (Pacific Seafoods, 2016).

An analysis of LCA (DEA and ISO standards) by Lozano et al. (2010) for mussel cultivation on rafts in Galicia, Spain, showed potential for reduction of environmental impacts from 11% terrestrial ecotoxicology and 67% ozone layer depletion from studying inefficiencies. This study used data gathered through surveys to explore production optimization from small family-farms to large commercial operations (Lozano et al., 2010). Other studies have focused on additional environmental contributions from mussels.

Filgueira et al. (2015) urged the need to provide with reliable research that provides with an overview and realistic estimations of the mussel potential to provide food from the flesh of the animal but also to use the shells as a by-product to estimate potential CO_2 sequestration from mussels. Carbon offsets have been estimated at about 0.18 kg of kg CO_2 equivalent per kg of mussel harvested. Every shell contains 12% carbon which is equivalent to 44% CO_2. Mussel filtration services have N and P removal comparable than those of wetlands and waste treatment plants and carbon/nutrient trade benefits (credits) could be given to mussel farms from polluters e.g. factories or agriculture as mussels currently provide nutrient cleaning service for “free” so mussel farms should be economically rewarded for their service (Lindahl et al., 2005). Agro-Aqua recycling e.g. shells and mussel meat from shellfish not for human consumption (e.g. dear or damaged) can be used for chicken feed or organic fertilizer in agriculture. In Sweden, by-products from mussel production may benefit other food production systems. Mussel shells and other mussel debris might be used as a $CaCO_3$ source and an additive to animal fodder (e.g. for chickens), and organic remains from canning and cooking plants or dispatch centers could be sent off to factories that produce fish meal or used as fertilizers (Iribarren et al., 2010b). Under these scenarios, 100 t of mussels could yield 65 t of CaCO3 or 21.5 t of fish meal (Nielsen et al. 2003). Production of mussel paté was explored by Iribarren et al. (2010b). In the case of mussel remains disposal, landfill may be better than incineration (and ash) but area requirements and social issues from landfills may arise.

Socio-economic components worldwide

In 2013, marine mussel aquaculture produced 1,754,783 t from marine environments valued at $3,322,756,000 and 911 t from brackish water dominated by Mediterranean mussel (*Mytilus galloprovincialis*) valued at $819,000 (FAO, 2015). FAO also reported that world aquaculture production from mussels has tripled in value from 2004 to 2013, while production only increased by about 5%. In 2010 Galicia was estimated to produce 215, 681 t of bivalves worth about $140 million in primary sales, which corresponded to about 64% of total value of aquaculture of Spain (FAO 2014). Based on the data from Sweden, a local mussel farm that produces about 2,800 t of mussels annually would need 5-10 employees depending on its mussel processing scheme. With average salary of one worker as $36,600 approximately $23,800 would come back to local and state government in form of taxes

(Lindahl et al., 2005). In Spain data from 2006-07 showed that mussel processing provided $85.8 million and 900 jobs (Franco, 2006); with $10.4 million and 530 jobs in Galicia and in dispatch centers $113.1 million and 500 jobs. In rural communities from Brazil for example families make their income by harvesting mussels from mangroves and this activity is considered of a high socio-economic interest and value for the local people (Grasso, 2000). Indirectly, mussel farming contributes to household income and national income as well as to the agricultural food production and medical sources for humans and animals.

It is important to remember that profitability of mussel production has been affected by various risk factors. Some of these factors are related to local laws and regulations, fees and land prices, type of production, fluctuations in mussel prices, disease outbreaks and climate change. In general, examples from the literature indicate that mussel farming is more profitable for larger producers (> 1-3 ha), however financial sustainability of the mussel sector may be improved by business structuring, diversification across two or more aquaculture crops (e.g. combining mussel and scallop operation), and establishment of producer organizations or cooperatives (Kite-Powell et al., 2003, Mongruel and Perez Agundez, 2012, Theodorou et al., 2014).

Global food production

From 1960 to 2011, mollusk aquaculture (including cephalopods) consumption increased from 0.6 to 2.5 kg of food per capita per year providing with about from which 73 g of protein per person per year (FAO, 2014). A large part production (40%) is sold fresh, 35% are processed in local canning facilities, 20% is boiled and frozen and 5% is boiled and then canned (FAO, 2014). However, different edible yield values were provided in the literature, according to Winther et al. (2009) a kg of edible mussels in Paris results from 4.2 kg of live mussels harvested, washed and sorted from Norway. In Spain, one kg of fresh mussel flesh is about 4 kg of mussels, while 1 kg of canned or frozen involves farming about 13 kg of mussels (Iribarren et al, 2010a). Also, mussel species yield to different values and different seasons.

Discussion

Environmental outputs

Different methodologies have been used to measure socioeconomic and environmental dimension such as the Human Sustainable Development Index (HSDI) that have proven the relationship between socioeconomic aspects and environmental degradation and positive correlation to CO_2 emission and income (Bravo, 2014) and the Sustainable Livelihood Security Index (SLSI) that focuses more to the social aspects of different human activities, forestry, tourism and measurements from the social perspective (Chen et al., 2013; Singh and Hiremath, 2010; Tao and Wall, 2009; Wang et al., 2016). However, EF it is the only tool that measures sustainability from human demands and pressures over the Earth and it focuses on human burdens on natural resources (especially on freshwater, land and carbon). It also assesses the capacity of the Earth to renew and assimilate wastes resulting from human activities at a global scale. Since 1980, humanity have over-passed the capacity of the Earth to assimilate our consumption patterns and generated wastes (Wackernagel et al., 2002). The LCA provides with an overview of all stages involved in the production of our goods and helps understand sustainability by measures of the input-output from environmental indicators.

Water footprint

Mussels are filter feeders obtaining all their nutrients from the water column thus mussel aquaculture does not require water embedded in animal feed production, unlike in other animal production systems (e.g. finfish, beef etc.). Globally, it takes an average of 15,000 L to produce a kg of edible beef, however, most of the water footprint about 80-90% in the water footprint accounted for food sources (Cajas-Cano and Moffitt, 2009; Mekonnen and Hoekstra 2010). A range of water footprint was estimated from 500 L per kg of edible fish meat (relaying on fish mean and fish oil) to 2,862 L per kg of fish species relaying on soybean meal and groundnut oilcake (Pahlow et al., 2015). Freshwater used during the production system in our mussel farm accounted for less than 1 L per kg of edible mussel meat, mussels rely more on their environment accessible water and their estimation may result from the filtrated marine or brackish water needed for their survival and the zooplankton, phytoplankton and other nutrients available.

During the processing stage, Iribarren (2010a) estimated an input of 14.4 L of freshwater and 6.99 L of seawater needed for processing one kg of canned mussels and 7.8 seawater for processing and depurating 1 kg of fresh mussels. This water is treated and drained to the ocean. Additional to the water used in the consumption of fresh mussels in household which was estimated an average of 1.72 L/kg of fresh live mussels clean in households. From our results we estimated about 84-94 L of water used per kg of fresh mussel with their shell processed or 168-188 L per kg of edible mussel meat. Importantly, the case study farm does not depurate mussels as Washington Dept. of Health monitors levels of contamination and presence of toxins in water and mussels ensuring safety of seafood for human consumption.

In case of waste water from mussel cleaning and processing, the farm discharges the water into their artificial forest or water is treated before being discharged (municipal wastewater treatment plant). However, there is evidence for successful use of wastewater from mussel processing as a source of organic fertilizer (Winther et al., 2009).

In case of processed (not fresh or frozen), boiled or canned mussels will have higher water footprint. As smoked/canned mussels require oils and other ingredients, there will be a higher water footprint associated with embedded water from e.g. oil production (such as sunflower, olive, soy, and the production of cans and packaging). However, a complete assessment of the fresh or marine volume of water is not yet included in life cycle assessment analysis, other than the volume withdrawn for processing and depuration of the mussels.

Land footprint

Requirement for land may be mitigated by ecosystem services provided by mussels – shore stability and prevention of erosion in case of wild mussel beds, or providing a suitable habitat for other organisms in the seabed like sea grasses. Also removal of excess nutrients / filtration could be beneficial for stability of the bottom or shoreline. Land used in our case farm resulted in about 0.08 m^2 per kg of mussel produced or 0.16 m^2 per kg of edible mussel. In Greece, Theodorou et al. (2014) calculated about 0.094-0.10 m^2 per kg of edible mussel. Mussel farm sizes, area for processing plants and land required for storage materials and parking vehicles as well as additional land area used for mussel production related activities should be estimated but we did not have data available and it may be comparable to the area required for storage and processing of other types of animal production systems. Additionally, Iribarren et al., (2010b) estimated about 0.025-0.03 m^2 was needed for processing a 1 kg of mussel flesh.

Carbon footprint

Most environmental evaluations of mussel systems have focused on carbon footprints or environmental emissions from different stages within the life cycle of the mussel production. Values varied significantly according to the life cycle stages included as well as the assumptions taken and the functional unit. Among the life cycle stages other factors may be included such as infrastructure, buildings, and worker input (e.g. fuel used for commuting to work). Meyhoff (2012) estimated a total of 251.56 kg of CO_2e/t of mussels farmed, harvested and processed, resulting on 0.25 kg of CO_2e/kg of products ready for distribution. Other authors (Iribarren et al., 2010a; Iribarren et al., 2010b; Iribarren et al., 2010c, d) reported the life cycle assessment of mussels by different stages, production, processing and use of by-products. In their results they used a functional unit to supply 1 kg of proteins from fresh, canned and frozen mussel, their results were 133, 50, 56 Kg of CO_2e, respectively. Fresh mussels showed a higher number because they are presented in their shell therefore, more weight is needed to provide with a kg of protein while canned and frozen required higher yields for the processing stage. A kg of canned mussels requires about 10 kg of produced mussels. Therefore, it is important to understand the functional unit used in the LCA's as well as to provide a holistic picture from all the stages.

<u>Socio-economic components</u>

Food source for humans

Mussels have been used as food for humans for centuries and still have large production volumes worldwide (FAO). They are also important food sources for other animals. Additionally, mussels unsuitable for human consumption (e.g. damaged, dead etc.) could be used for animal feed (chickens), for fish meal or as a fertilizer. Even though mussels are not a top species produced by aquaculture, they provide with more than 24 g of protein and micronutrients. Generally, a 100 g of cooked mussels were considered a good source of vitamins such as niacin and folate as well as sodium and zinc. Mussels are also an excellent source of vitamin C, vitamin B12, thiamin, riboflavin, iron, phosphorus, manganese and it may supply with about 40% of the protein RDV. The sources and benefits of polyunsaturated fatty acids (PUFAs) omega-3 fatty acids, have been studied for decades (Budowski, 1981; Domingo et al., 2007; Dyerberg and Jørgensen, 1982).

Mussel extracts are rich in fatty acids, with a ratio of about eight-to-one of omega-3 to omega-6 oils, additional amino-acids, proteins, chelated minerals and glycosaminoglycans (such as Chondroitin-4- and -6- Sulfates). Extracts of mussels (1,000 mg) are marketed as an alternative to Chondroitin based products ($15/90 capsules-serving size 2 capsules a day). Provided by popular brands from US and Canada, (Swanson Vitamins and Food Science of Vermont), as a dietary supplements New Zealand Green Mussel is being sold as freeze dried capsules ($5/60 caps including 500 mg of mussel content) or oil ($10/30 soft gels including 50 mg of mussel oil) from Swanson Vitamins or oil ($45/60 soft gels including 500 mg of mussel oil) from Bio-Mer, Ltd. They can be found with other ingredients added such as Gelatins, Glucosamine Sulfates as well (600 mg from shrimp and crab), and 200 mg of alfalfa leaf, magnesium, and olive oil or cinnamon oil. Positive results from understanding and accounting for mussels' components and their contributions may increase mussel consumption and allow the expansion of this production.

Social-benefits

The LCA main social indicator is based on the provision of jobs within the industry evaluated and also the other industries related. Additional research has provided the need to include other socio indicators such as employment practices (e.g. employment opportunities, fair wage or discrimination), health and safety, job satisfaction (Iribarren et al. 2016; Kruse et al. 2009). Kruse et al. (2009) determine different type of indicators and provided examples of measurement units, however, suggested the need to collect primary data directly in the industries, and potentially using the native language of the workers. Iribarren et al. (2016) evaluated and screened the possibility of measuring and comparing in a life cycle assessment the different components suggested by other authors including Kruse et al.

Job stability can also have as indicator age and years worked in the company. The average age of workers in mussel production system was 40 years, ranking from 23 to 59 and the average of years worked showed to be almost 10 years ranking from 1 week to 19 years. Job Security depended on rank, positions, and time worked at the company. Additionally, freedom of communication depends on rank and position within the company.

Potential expansion and benefits of supporting domestic production

Different factors determine potential for mussel industry expansion, especially the relationship between level of activity/intensity and mussels' environmental inputs and outputs. It is critical for the mussel industry as it depends on water quality and nutrients. Number and size of farms are limited by physical constrains, water quality and availability of food (Zeldis et al., 2004; Davenport et al., 2000). Even though mussels are feeding on plankton, their production and release of nitrogen enhances primary production (phytoplankton), which in turn increases zooplankton populations (Asmus and Asmus, 1991; Lehane and Davenport, 2006; Ogilnie et al., 2003), and that takes place in oligotrophic areas. Blue mussels showed filtration rates between 1.2-5.2 L per hour depending on water temperature, salinity and nutrient load (Strohmeier et al., 2015). In laboratory setting, Mediterranean mussels may filter up to 2.42 L per hour depending on water temperature, velocity, food quality and quantity (Denis et al., 1999). Additionally, use of controlled upwelling can further enhance mussel growth (Stronmeier et al., 2015). In recent years GIS and modeling data have been used for predicting the growth of blue mussels and planning of farm placement or sites for eutrophication mitigation through mussels (Bergström et al., 2015). Finally, opening of Gulf of Mexico for aquaculture may offer a great opportunity for expansion of mussel production.

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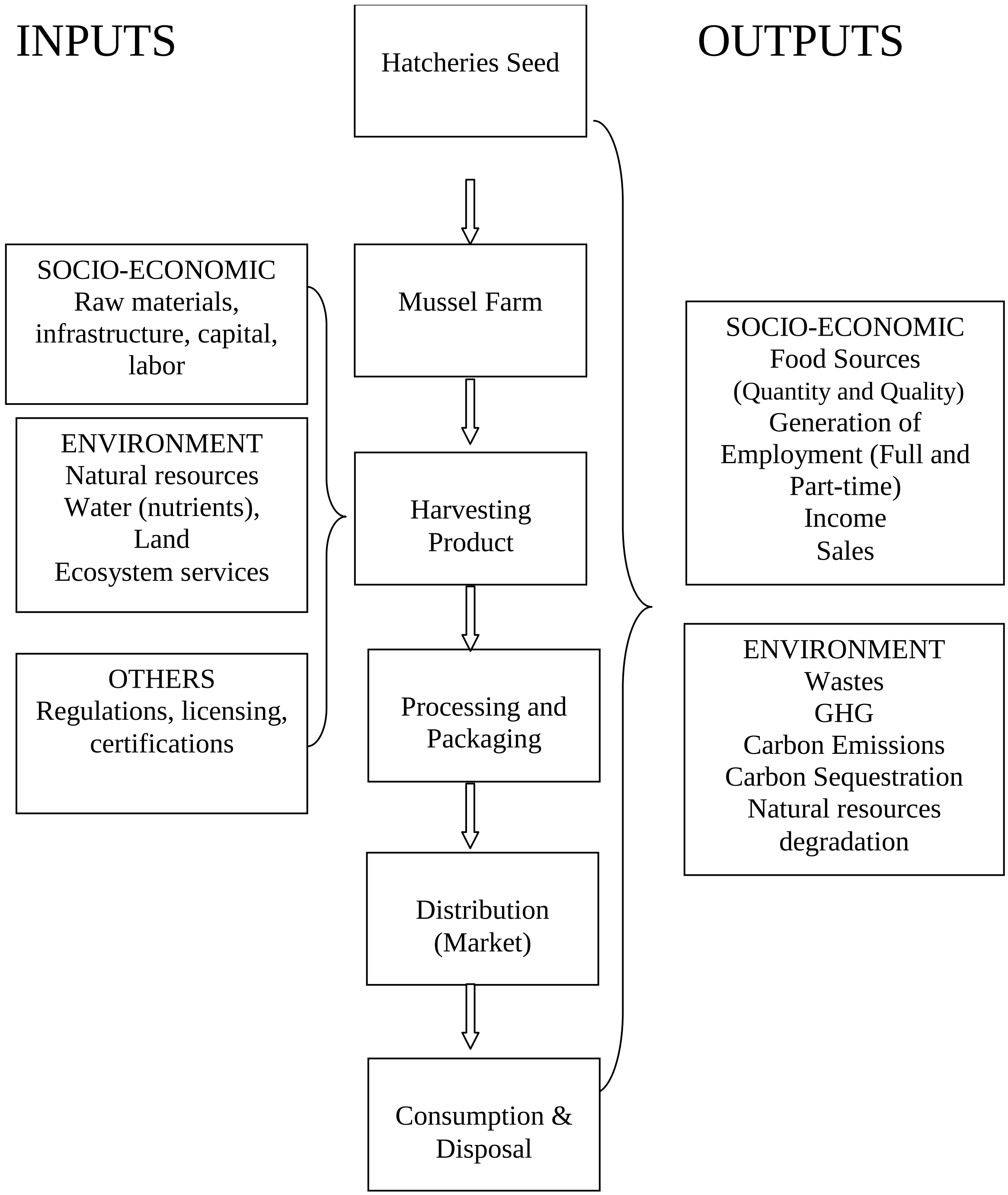

Figure 4. Conceptual life-cycle model, including minimum input-outputs of a general mussel production system

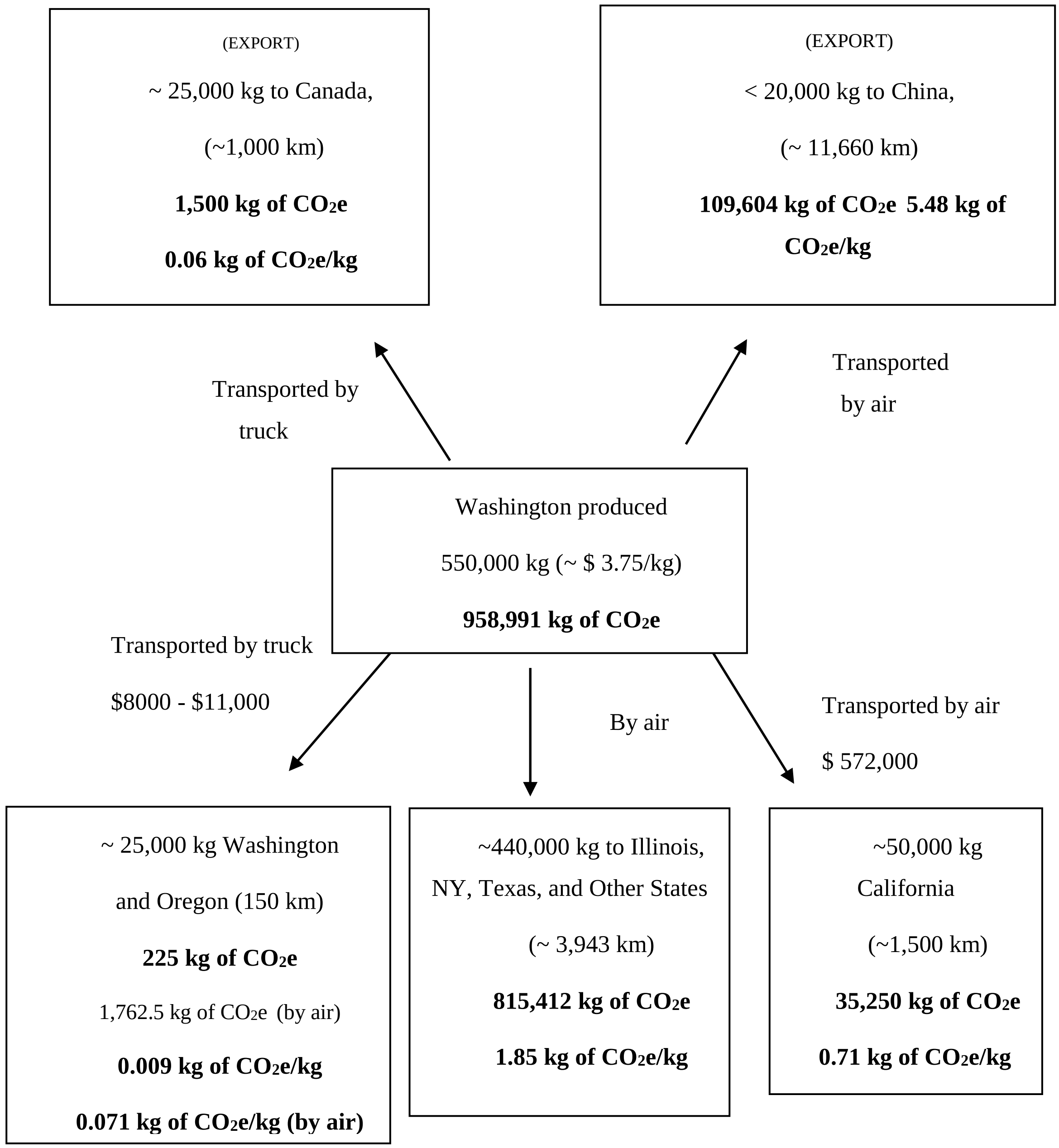

Figure 5. Conceptual model to estimate carbon footprints from the distance needed to distribute live mussels in their shell (except when imported to China- that are vacuum packed). The diagram includes cost, transportation, km travelled for final destination of the product. Total cost estimated from data provided at the farm: by truck \$0.30 to \$0.45/kg and by plane to National locations \$1.30/kg, Inter- national data was not available. The carbon footprints were based on $CO2e$ for truck (60 g of $CO2e$ / t of product / km) and air cargo (470 g of $CO2e$ / t of product / km) (Council, 2016).

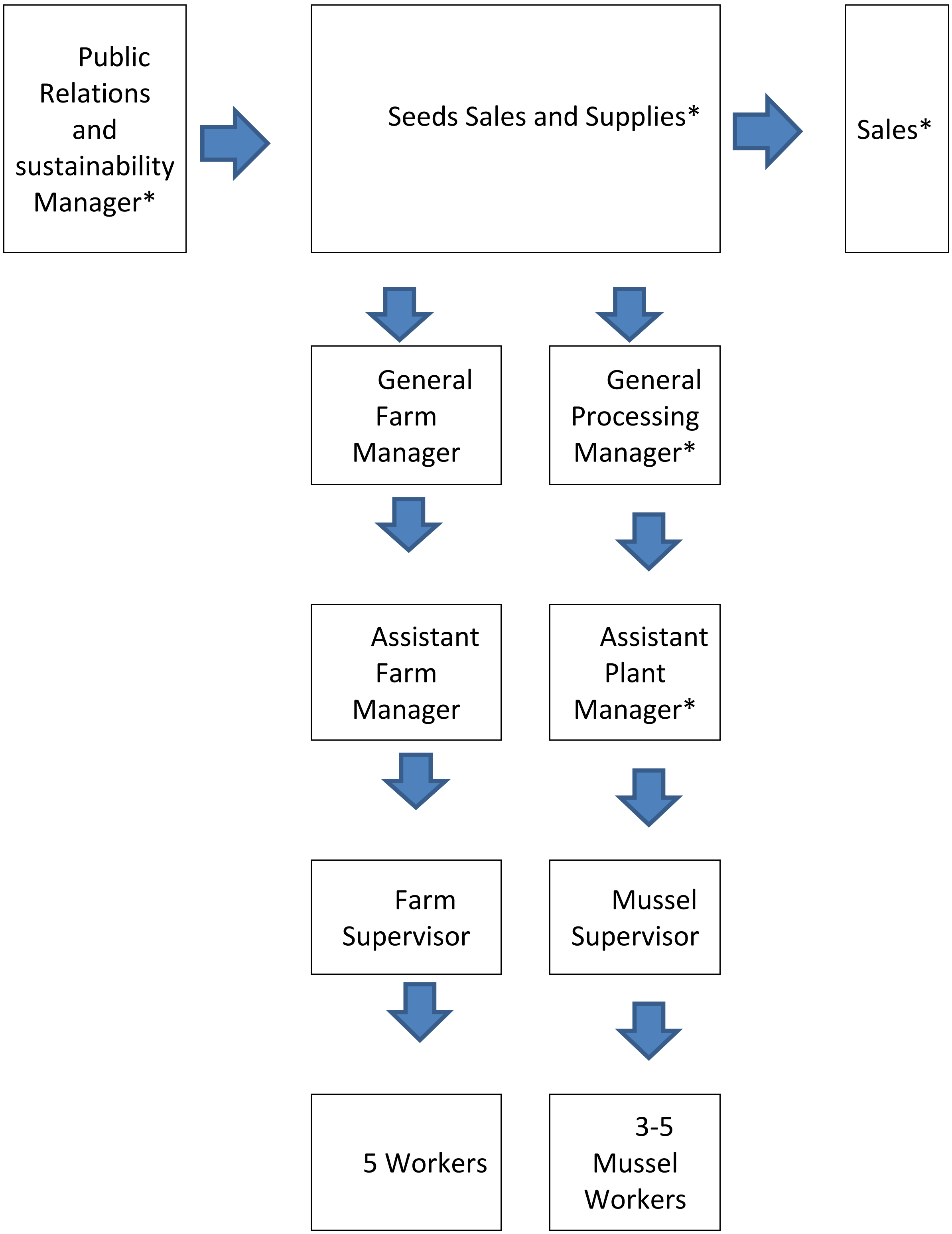

Figure 6. Flow chart of the workers involved in mussel farming. * Part time workers for the mussel sector but full-time workers working for other species grown within the company.

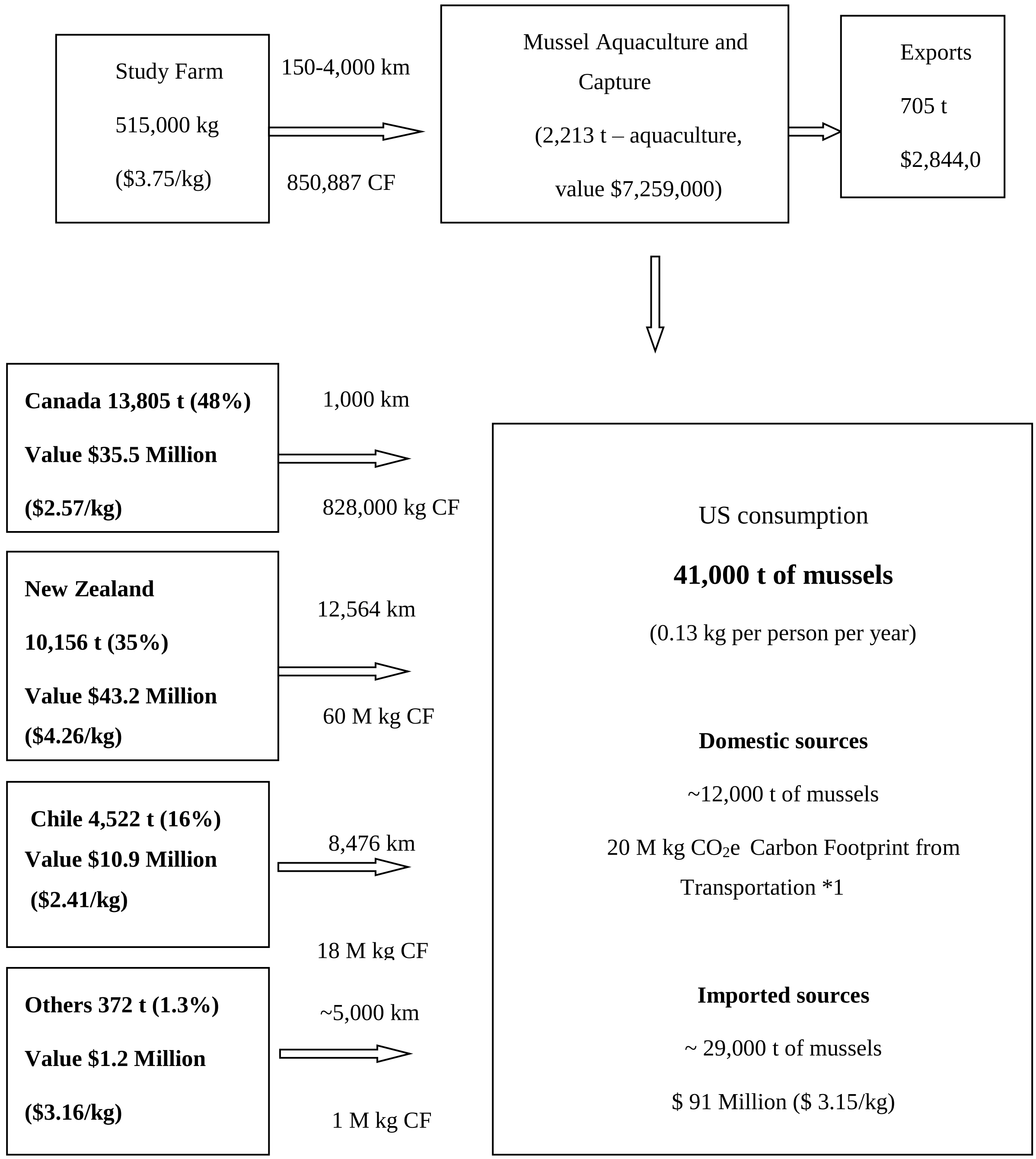

Figure 7. Conceptual model of the US consumption and sources.

[1] Calculations for carbon footprint (CF) for domestic sources were extrapolated by the resulting CF from the farm reflected to the total domestic sources.The carbon footprints were based on CO_2e values provided by (Council, 2016) for truck (60 g of CO_2e / t of product / km) and air cargo (470 g of CO_2e / t of product / km). Source: (NOAA., 2015; FAO, 2016).

Table 1. Worldwide wild harvest (t) in marine areas by continent, major producers, species, all countries included also the separated countries, therefore total per continent is the total of all countries without the separated ones. Empty cells represent unreported data and bolded values are estimates from FAO.

			YEARS			
Area	**Mussel Species**	**Scientific name**	**1950**	**2000**	**2010**	**2013**
		AFRICA				
Tunisia	Mediterranean	*Mytilus galloprovincialis*		0	0	63
		AMERICAS				
Brazil	Sea nei	*Mytilidae*		802	2,116	5,281
Chile	Chilean	*Mytilus chilensis*	3,490	5,236	354	355
	Cholga	*Aulacomya ater*	7,400	5,563	3,638	4,779
	Choro	*Choromytilus chorus*		217	559	640
Total Chile			10,890	11,016	4,551	5,774
Peru	Cholga	*Aulacomya ater*		13,370	9,022	6,954
United States	Blue	*Mytilus edulis*	607	6,009	14,981	9,132
	Sea nei	*Mytilidae*	0	771	1,088	1,056
Total United States of America			607	6,780	16,069	10,188
All countries	Blue	*Mytilus edulis*	607	6,457	15,031	9,158
	Chilean	*Mytilus chilensis*	3,490	5,237	354	355
	Cholga	*Aulacomya ater*	7,400	18,933	12,664	11,733
	Choro	*Choromytilus chorus*		217	559	640
	River Plata	*Mytilus platensis*	3,600	412	81	112
	Sea nei	*Mytilidae*	0	2,125	6,715	9,185
	South American rock	*Perna perna*		316	**1,000**	**1,400**
Total Americas			15,097	3,697	36,404	32,583
		ASIA				
All countries	Green	*Perna viridis*	42,000	41,173	476	8,093
	Horse nei	*Modiolus spp*		94	0	0
	Korean	*Mytilus coruscus*	1,400	1,133	3,271	1,967
	Mediterranean	*Mytilus galloprovincialis*		1,200	989	887
	Sea nei	*Mytilidae*		5,795	10,224	5,060
Total Asia			43,400	49,395	14,960	16,007
		EUROPE				
Denmark	Blue	*Mytilus edulis*	21,800	110 618	27 872	37 491
All countries	Blue	*Mytilus edulis*	26,600	126 874	35 134	47 090
	Horse nei	*Modiolus spp*		2	0	0
	Mediterranean	*Mytilus galloprovincialis*	10,500	**44,883**	1,023	627
	Sea nei	*Mytilidae*		1,855	60	50
Total Europe			37,100	173,614	36,217	47,767
		OCEANIA				
New Zealand	Sea nei	*Mytilidae*	0	4,467	153	201
Oceania	Australian	*Mytilus planulatus*		1	0	0
	Sea nei	*Mytilidae*	0	4,467	153	201
All countries			0	4,468	153	201
Total Oceania			0	4,468	153	201
GRAND TOTAL			95,597	261,174	87,734	96,621

Table 2. Worldwide aquaculture production by continents, major countries, and value for 1950, 2010 and 2013. Total per continent is the total of all countries without the separated ones. Empty cells in showed unreported data and bolded values are estimates from FAO.

Region	Species	Scientific name	YEARS						
			1950	2000		2010		2013	
			Quantity (t)	Quantity (t)	Value ($1000)	Quantity (t)	Value ($1000)	Quantity (t)	Value ($1000)
			AFRICA						
Africa	Blue	Mytilus edulis		**10**	**10**	**5**	**14**	29	13
	Mediterranean	Mytilus galloprovincialis		504	513	717	1,199	**860**	**1,966**
	Total Africa			514	523	722	1,213	**889**	**1,979**
AMERICAS									
Canada	Blue	Mytilus edulis	0	21,287	18,641	25,675	36,654	29,079	48,051
Chile	Chilean	Mytilus chilensis	**10**	23,477	16,434	221,522	460,766	241,841	2,072,577
	Cholga	Aulacomya ater		295	148	1,736	6,232	3,775	1,223
	Choro	Choromytilus chorus	0	224	134	757	1,817	550	1,320
	Total chile		**10**	23,996	16,716	224,015	468,815	246,166	2,075,120
US	Blue	Mytilus edulis	773	2 248	4 878	2 207	6 621	2 228	7 798
All countries	Blue	Mytilus edulis	773	2,248	4,878	2,207	6,621	2,228	7,798
	Blue	Mytilus edulis	773	23,535	23,519	27,982	43,663	31,313	55,870
	Chilean	Mytilus chilensis	10	23,477	16,434	221,522	460,766	241,841	2,072,577
	Cholga	Aulacomya ater		295	148	1,736	6,232	3,775	1,223
	Choro	Choromytilus chorus	0	224	134	757	1,817	550	1,320
	River Plata	Mytilus platensis		20	40	**103**	**400**	9	33
	Sea nei	Mytilidae		88	101	218	386	254	487
	Rock	Perna perna		11,770	5,890	13,723	20,584		
	Total Americas		783	59,409	46,266	266,041	533,848	277,741	2,131,510
			ASIA						
All countries	Green	Perna viridis	**14,000**	120,483	15,173	214,415	53,017	162,933	57,458
	Korean	Mytilus coruscus	**100**	11,713	4,250	54,440	24,833	34,429	13,561
	Mediterranean	Mytilus galloprovincialis		321	411	340	215		
	Sea nei	Mytilidae	**2,895**	**471,598**	**94,320**	702,157	182,561	747,077	194,240
	Total Asia		**16,995**	**604,115**	**114,153**	971,352	260,626	944,439	265,260

Table 2, continued

Region	Species	Scientific name	1950 Quantity (t)	2000 Quantity (t)	2010 Value ($1000)	2010 Quantity (t)	2010 Value ($1000)	2013 Quantity (t)	2013 Value ($1000)
					EUROPE				
France	Blue	*Mytilus edulis*	8,300	60,819	73,058	**61,800**	**154,469**	**61,000**	**153,535**
	Mediterranean	*Mytilus galloprovincialis*	2,200	7,181	8,626	**15,000**	**30,728**	**13,900**	**32,141**
	Total France		10,500	68,000	81,684	**76,800**	**185,197**	**74,900**	**185,676**
Netherlands	Blue	*Mytilus edulis*	31,900	66,800	66,800	56,227	91,767	54,300	141,569
Spain	Sea nei	*Mytilidae*				1,113	1,587	-	**79,533**
	Sea nei	Mytilidae	2,100	247,730	86,706	187,976	124,457	162,012	
	Total Spain		*2,100*	247,730	86,706	189,090	126,044	162,012	106,154
All countries	Mediterranean	*Mytilus galloprovincialis*	0	47,200	29,034	1,410	1,087	**800**	-
	Sea nei	*Mytilidae*				1,113	1,587	-	106,154
	Blue	*Mytilus edulis*	48,200	189,890	189,911	179,592	**307,913**	**166,490**	**378,422**
	Mediterranean	*Mytilus galloprovincialis*	2,200	79,871	45,178	99,375	99,859	**114,804**	**606**
	Sea nei	*Mytilidae*	2,100	248,101	87,160	188,158	124,548	163,275	-
	Total Europe		*52,500*	517,862	322,250	467,125	532,320	444,569	**612,453**
					OCEANIA				
Australia	Australian	*Mytilus planulatus*		2,017	3,066	3,465	9,294	3,584	9,872
New Zealand	New Zealand	*Perna canaliculus*	600	76,000	77,168	95,168	240,941	83,561	301,683
All countries)	Australian	*Mytilus planulatus*		2,017	3,066	3,465	9,294	3,584	9,872
	New Zealand	*Perna canaliculus*	600	76,000	77,168	95,168	240,941	83,561	301,683
	Total Oceania		600	78,017	80,233	98,633	250,236	87,145	311,555
GRAND TOTAL			70,878	1,259,403	562,902	1,803,151	1,577,030	1,753,894	3,320,778

Table 3. Worldwide aquaculture production by species, major countries and value for 2013. Empty cells represent unreported data and bolded values are estimates from FAO, based on comparisons from previous years.

Species (common name)	Area by Continent and (country or countries)	Quantity (t)	Value ($1000)
	MARINE ENVIRONMENT		
Mytilus edulis (Blue)	Africa	29	13
	Americas (Canada)	29,079	48,051
	Americas (others)	2,228	7,798
	Europe (France)	**61,000**	**153,535**
	Europe (Netherlands)	54,300	141,569
	Europe (others)	51,190	83,318
Sub-total *Mytilus edulis*		197,826	434,284
Mytilus galloprovincialis (Mediterranean)	Africa (South Africa)	**860**	**1,966**
	Europe (France)	**13,900**	**32,141**
	Europe (Italy)	**79,000**	**79,533**
	Europe (others)	**21,904**	**14,719**
Sub-total *Mytilus galloprovincialis*		115,664	128,359
Aulacomya ater (Cholga)	Americas (Chile)	3,775	1,223
Choromytilus chorus (Choro)	Americas (Chile)	550	1,320
Mytilus (Chilean)	Americas (Chile)	241,841	2,072,577
Mytilus coruscus (Korean)	Asia (Korea, Republic of)	34,429	13,561
Mytilus planulatus(Australian or River Plata)	Oceania (Australia)	3,584	9,872
	Americas	9	33
Sub-total *Mytilus planulatus*		3,593	9,905
Perna canaliculus (New Zealand)	New Zealand	83,561	301,683
Perna viridis (Green)	Asia	162,933	57,458
	Thailand	127,824	25,435
Sub-total *Perna viridis*		290,757	82,893
Mytilidae (Mussels sea “nei”, not elsewhere identified)	Americas	254	487
	Asia (China)	747,077	194,240
	Europe (Spain)	162,012	106,154
	Europe (others)	1,263	1,483
Sub-total *Mytilidae*		910,606	302,364
Grand total for marine environment		1,882,602	3,348,169
	BRACKISH-WATER ENVIRONMENT		
Mytilus galloprovincialis (Mediterranean)	Africa	111	213
	Europe	**800**	**606**
Grand- total for brackish-water environment		911	819

Table 4. Direct carbon footprints estimation for the mussel farm and processing plant in a year using information provided by the farm (appendix D-estimations of energy in the farm and processing plant) and also other references to complete additional sectors from the farming stage.

Mussel system	Value	Emission Factor	Total kg of CO_2e year	kg
Farming Stage				
Infrastructure [1] (per year)			5,473	
Boats and trucks (Diesel) (L/yr)	13,310	2.63	35,005	
Working commute [3] (Gasoline)(L/yr)	4,680	2.348	10,988	
Processing plant				
Electricity ($300)/m (kWh)[4]	9,375	0.69	6,500	
Distributing[5]	Distances in Fig. 2		958,991	
Grand Total			1,016,957	1.85/kg

[1] Source: equivalent value for study farm (Tracking, 2008)
[2] EPA, 2015. http://www.epa.gov/energy/ghg-equivalencies-calculator-calculations-and-references
[3] Information provided in the farm: 10 workers commute about 15 min to go to work every day. 15 min driving in the area equals to 13 km/d (300 d of work/year), Washington post announced that in the US average cars require 12 L of gasoline/100 km.
[4] Price of energy used for processing mussels, 20% of the total price of electricity ($60) and obtained the use of kWh ($0.0768 / kWh), electricity rates in Washington (2016) http://www.electricitylocal.com/states/washington/

[5] Distributing stage detailed in figure 2.

Table 5. Nutritional value for a serving size of 100 g of blue and green mussel meat, cooked, moist heat, including the intake recommended daily value (RDV) and the percentage of this provided by each of the species.

Nutritional Facts	Blue	Green	RDV	% provided[1]	
Protein (g)	24	19	50	48	38
Cholesterol (mg)	56	30	300	19	10
Total Fat (g)	4.5	3.1	65	7	5
Saturated fat (g)	0.85	0.91	20	4	5
Monounsaturated fat (g)	1.01	0.61			
Polyunsaturated fat (g)	1.21	0.94	1.6	76	59
Total Omega-3 (g)	0.87				
Total Omega-6 (g)	0.04				
Minerals					
Calcium, Ca (mg)	33	173	1000	3	17
Phosphorus, P (mg)	285	330	1000	29	33
Iron, Fe(mg)	6.7	10.9	18	37	61
Magnesium, Mg (mg)	37	82.5	400	9	21
Potassium, K (mg)	268	399	3500	8	11
Copper, Cu (mg)	0.15	0.19	20	1	1
Sodium, Na (mg)	369	226	240	154	94
Manganese, Mn (mg)	6.8	8.98	2	340	449
Selenium, Se (µg)	89.6	75.6	70	128	108
Vitamins					
Vitamin C, total ascorbic acid (mg)	13.6	5	60	23	8
Folate, total (µg)	76		400	19	-
Vitamin B-12 (µg)	24	20	6	400	333
Vitamin A, (IU)	304		900	34	-
Other Factors					
Energy (kJ)	172	440	8400	2	5
Fullness Factor	2.9				
Nutrient Balance	62				

Source for blue mussel data (USDA, 2016) and for green mussels (Aquaculture New Zealand Office-(http://www.nurturedseafood.com/nz-greenshell-mussels/attributes/nutritious/).

[1] The RDV varies depending on life stage group (Infants, children, pregnancy) and gender. An average diet is about 2,000 calories a day (USDA, 2016). USDA consider sources that provide more than 20% of its RDV an excellent source, values from 10-19% a good source.

Table 6. Socio-demographic characteristics of the workers in the mussel production system

Parameter	Exec.	Assistant Supervisors	In Farm	In Plant	Total
Gender					
Male	5	4	5	4	18
Female	0	0	0	1	1
Age in years					
20-40	1	2	3	3	9
41-50	2	2	1	2	7
51-60	2	0	1	0	3
Origin					
US	3	2			5
Foreign labor	2	2	5	5	14
Years worked in the company					
0-5	1			4	5
6-10		1	4		5
11-15	1	2	1	1	5
16-more	3	1			4
Average hours worked per week					
30-39	2	1	1	2	6
40-50	3	2	4	2	11
40-60		1		1	2
Freedom of communication					
Verbal	2	2	3	1	8
Verbal and written	3	2	1		6
None			1	4	5
Annual Income					
$ 20,000 - $ 39,000			3	3	6
$ 40,000 - $ 59,000		3	2		5
$ 60,000 - $ 69,000	2	1			3
>$ 70,000	2				2
Education level					
Less than high school graduate			1	5	6
High school graduate		2	2		4
Some college, no degree	1	1	1		3
Associate's degree		1			1
Bachelor's degree	2		1		3
Master's degree	1				1
Household members including worker					
1 adult (self)			2	1	3
2 adults and 1-2 children	2	2		3	7
2 adults and 3 or more children	3	2	3	1	9
% of family income from this salary					
<50 %	1			1	2
50-75 %	3	2	1	1	7
>75%	1	2	4	3	10

Table 7. Social indicators per kg of mussel with shell produced in different stages of the life cycle of the system and estimated breakdown of product using an average of 550,000 kg of line mussels per year.

	No. of Workers	Hours		Income		Labor cost /kg of mussels	
		h/week	h/year	$/hr	$/year	h/kg	$/kg
Raw Materials & Seed	1	2	104	40	4,160	0.0002	0.02
Off-site Farm	1	40	2,080	20	41,600	0.004	0.17
Mussel Farm & Env. Quality							-
Executives	2	53	2,730	27	73,710	0.005	0.29
Managers & Assistant	2	85	4,420	20	88,400	0.008	0.35
Workers	4	180	9,360	15	140,400	0.017	0.56
Processing and Packing							-
Executives	1	13	650	Data not available		0.001	-
Managers & Assistant	2	58	3,016	23	69,368	0.005	0.28
Workers	5	220	11,440	14	160,160	0.021	0.64
Distribution/sales	1	8	390	38	14,820	0.001	0.06
Totals	19					0.062	2.37

Table 8. Detailed information from the mussel marketing presentations, volumes, values, price, and overall percentage of products imported to the US.

Country	**Marketing presentation**	**Volume (t)**	**Value ($1,000)**	**Price $/kg**
Canada	Live/fresh farmed	13,805	35,538	2.57
	Live/fresh wild	65	151	2.31
	Frozen/Dried/Salted	90	317	3.54
	Sub-total Import to US	13,895	35,855	2.58
Chile	Frozen/Dried/Salted	4,172	10,159	2.44
	Live/fresh farmed	104	285	2.74
	Live/Fresh Wild	246	446	1.81
	Sub-total Import to US	4,522	10,890	2.41
New Zealand	Frozen/Dried/Salted	9,973	42,485	4.26
	Live/fresh farmed	56	247	4.40
	Live/Fresh Wild	127	546	4.29
	Sub-total Import to US	10,156	43,277	4.26
Mexico	Live/fresh farmed	245	774	3.16
Other (Norway)	Live/fresh farmed	0	3	99.00
Other Countries	Live/Fresh Wild	61	213	3.50
	Frozen/Dried/Salted	66	185	2.79
	Sub-total Import to US	372	1,174	3.16
Sub-total	Frozen/Dried/Salted	14,300 (49.4 %)	53,145 (58.3 %)	3.72
Sub-total	Live/fresh farmed	14,145 (48.9 %)	36,697 (40 %)	2.59
Sub-total	Live/Fresh Wild	500 (1.7 %)	1,355 (1.5 %)	2.71
	Total	28,945 (100 %)	91,197 (100 %)	3.15

Table 9. Detailed mussel system (aquaculture or capture), species, total values exported and volumes imported to the US.

Type	Scientific name	2011 (t)	2011 ($ 1,000)	Exported [1] Presentation	2011 (t)	2011 ($ 1,000)
			CANADA			
Aquaculture	*Mytilus edulis*	25,509	38,298	Live, fresh	13,879	36,449
				Other presentations	753	3,129
Capture	*Mytilus edulis*	41				
	Total Canada	25,550			14,632	39,578
			CHILE			
Aquaculture	*Mytilus chilensis*	288,583	1,148,560	Live, fresh	1	1
	Other species	4,463	13,658	Frozen, dried, salted	320	743
Capture	*Mytilus chilensis*	408				
	Other species	2,096				
	Total Chile	295,550	1,162,218		321	744
			NEW ZEALAND			
Aquaculture	*Perna canaliculus*	101,311	174,736	Live, fresh	27	174
				Frozen, dried, salted	37,396	166,824
				Other presentations	616	5,930
Capture	*Mytilidae*	112				
	Total New Zealand	101,423	174,736		38,360	173,672
			MEXICO			
Aquaculture	*Mytilidae*	465	788	Live, fresh	2,092	15,738
				Other presentations	673	5,550
Capture	*Mytilidae*	3,463				
	Total Mexico	3,928	788		2,765	21,288

[1]FAO, 2015; [2] NOAA, 2015

Other species from Chile are: *Aulacomya ater* (Cholga) and *Choromytilus chorus* (Choro), Other presentations include preserved or prepared mussels

Appendix A. Approval of protocol from the Institutional Review Board of the University.

University of Idaho

Office of Research Assurances
Institutional Review Board
PO Box 443010
Moscow ID 83844-3010
Phone: 208-885-6162
Fax: 208-885-5752
irb@uidaho.edu

To:Christine Moffitt

Cc:Lubia Nohemi Cajas Cano (Student Investigator)

J.D. Wulfhorst

From:Traci Craig, PhD

Chair, University of Idaho Institutional Review Board University Research Office

Moscow, ID 83844-3010 IRB No.: IRB00000843

FWA:FWA00005639

Date:Approved August 3, 2010

Project: **LIFE CYCLE ASSESSMENT AND ECOSYSTEM SERVICES FRAMEWORK FOR SUSTAINABLE AQUACULTURE PRODUCTION** (10-016)

On behalf of the Institutional Review Board at the University of Idaho, I am pleased to inform you that the above-named project is approved as exempt from review by the Committee. Please note, however, that you should make every effort to ensure that your project is conducted in a manner consistent with the three fundamental principles identified in the Belmont Report: respect for persons; beneficence; and justice.

Should there be significant changes in the protocol for this project, it will be necessary for you to resubmit the protocol for review by the Committee.

Appendix B. Survey I provided to the farm manager.

Interview for Manager of the Mussel Farm

Lubia Cajas Cano

PhD. Candidate

Environmental Science

Production system:

1. Are the individual farms diversified or specialized?
2. How many kg of mussels are produced per year or per cycle?
3. How many months are considered to complete a cycle?
4. What is the average product marketing size and weight?
5. What is the % of edible meat considered in a kg of live animal?
6. What is the human nutrition value of a kg of edible meat of the product?
7. Are there any of the additives below included in the production system? If yes, how are they applied and when and how much?
    a. Antibiotics
    b. Pesticides
    c. Fertilizers
    d. Hormones
    e. Other

Production and processing

8. How much water is needed to process a kg of mussels?
9. How much energy (fossil fuel and electricity) is required to produce a kg of mussels?
10. How much energy (fossil fuel and electricity) is required to processes a kg of mussels?

Marketing

11. What are the presentations for this product to be sold (e.g. whole)?
12. What is the average cost of producing 1 kg of product (live)?

13. What is the retail price/wholesale?

Production Seed Maintenance Harvest Processing Marketing Distributing Other			

14. How is the product distributed (e.g. directly, indirectly)?

15. What is the geographic scope for the sales?

16. How many employees are working at the farms?

Budget

17. What is the total revenue of the company?

18. What proportion of production are mussels in the farms?

19. What is the proportion of total sales from mussels?

20. What are the main categories of expenditures for the farm ($ or %)?

Overall worker information

21. How many employees are specifically working with mussel production system _____ processing________ distributing_________

22. Does the company honor the employees with awards or promotions for its workers? (Y or N) If so, how frequently? ______________ (monthly, annually, other)

23. Do the workers receive any training for the position? (Y or N) If so, how frequently? _______________ (monthly, annually, other)

24. How often does the company hire workers?

25. How many workers are on average required per stage and what is the female–male ratio and hours required to produce mussels in the company:

Appendix C. Survey II for workers at the mussel farm.

Employee Interview

Aquaculture Farms

Lubia Cajas

PhD. Candidate

Environmental Science

Itvw#____________ Position _______________ Gender M or F Year Born 19___

Worker Stability

1.Year worked in this company? _______

2. 1st Position: ___________________________ Same as now? (Y or N)

1. If not, # of *other* positions you held in this company? ____________

Job Security

		Very insecure	Somewhat insecure	Neither	Somewhat secure	Very secure
3. How secure do you feel your position is in the company?		1	2	3	4	5
		Never	Seldom	Occasionally	Regularly	Often
4. How frequently can you give input or suggestions to the company?		1	2	3	4	5

If more than seldom, how?

Written communication (Y or N)

Verbal communication (Y or N)

Other (Y or N) List:

6. Using a scale of '1' (low) to '4' (high), rank the the company benefits to you:

Competitive salary_______ Vacation / leave time_______

Incentives _______ (Example:_________) Others_______ (List: _______)

7. What do you like the *most* about the company? The *least*?

	Very unsafe	Somewhat unsafe	Neither safe nor unsafe	Somewhat safe	Very safe
8. How would you rate the safety of your job?	1	2	3	4	5
	Never	Seldom	Occasionally	Regularly	Often
9. How frequently do you work to your full potential on the job?	1	2	3	4	5

Job Safety

10. What is more important to you in your job: security or safety?

Demographics

11. Do you work full-time, part-time, or seasonal?

12. How many average hours do you work per week? (month or season)

_________ h / weekly (monthly, seasonally)

13. What is the highest level of education you've completed?

____ Some high school, no degree

____ High school graduate

____ Some college, no degree

____ Associate's degree

____ Bachelor's degree

____ Graduate or professional degree

14. Please stop me when I reach the category that best describes your income.

Less than $10,000 $10,000 - $19,999 $20,000 - $29,999

$30,000 - $39,999 $40,000 - $49,999 $50,000 - $74,999

$75,000 - $99,999 $100,000 or more

How many people depend upon your income from this company? _____________

Appendix D. Survey II for workers in Spanish.

Entrevista de Trabajadores

Granjas Acuícolas

Lubia Cajas

Estudiante de Doctorado

Ciencias Ambientales

Itvw#___ Posición ____________ Genero M or F Fecha de Nacimiento __________

Estabilidad Laboral

1. Año que inicio en esta empresa? ________

2. Primera posición: ___________________________ La mismo que ahora? (Si o No)

1. Si no, # de otras posiciones que ha tenido dentro de esta empresa? ____________

3. Por favor, describa los factores que afectan la estabilidad de los trabajadores en la empresa:

		Muy Inseguro	Algo Inseguro	Inseguro	Algo Seguro	Muy seguro
4. Como calficiaría la seguridad de mantener su empleo?		1	2	3	4	5
		Nunca	Rara vez	Ocasionalmente	Regularmente	Seguido
5. Qué tan seguido da su opiníon o sugerencias a la empresa?		1	2	3	4	5

6. Si la respuesta es más que ocasionalmente, como dá su opiníon o sugerencias?

Comunicación escrita (Si o No)

Comunicación verbal (Si o No)

Otra forma (Si o No) cuál?:

7. Usando una escala de 1 (bajo) a 4 (alto) liste en orden de importancia los siguientes beneficios que la empresa le ofrece: Salario competitivo________ Vacaciones / Tiempo libre ________ Incentivos ________ (Ejemplos:___________________,_________________________)

Otros________ (Ejemplos: _____________________, _______________________)

8. Qué es lo que más le gusta de la compañia, y lo que menos?

	Muy inseguro	Algo Inseguro	Inseguro	Algo seguro	Muy seguro
10¿Cómo calificaría usted la seguridad en su trabajo?	1	2	3	4	5
	Nunca	Rara vez	A veces	Regular	Seguido
11¿Con qué frecuencia usted trabaja a su máximo potencial en el trabajo?	1	2	3	4	5

9. A recibido o recibe algún tipo de entrenamiento para la posición que ocupa? (Si o No)

Si si, que tan frecuente? ________________ (mensual, anual, otro)

Seguridad Laboral

12. ¿Qué es más importante para usted en su trabajo: la estabilidad o la seguridad laboral?

Demografía

13. ¿Trabaja tiempo completo, parcial o por temporada?

14. ¿Cuántas horas promedio trabaja por semana? (Mes o temporada)

__________ horas semanales –mensuales- estacionales

15. ¿Cuál es el nivel de educación que usted ha completado?

____ Educación secundaria incompleta, sin título

____ Graduado de la secundaria

____ Algo de universidad, sin título

____ Grado técnico

____ Grado de licenciatura

____ Post-grado

16. Por favor, Indique la categoría que mejor describa sus ingresos.

Menos de $ 10.000	$ 10.000 - $ 19.999	$ 20.000 - $ 29.999
$ 30.000 - 39.999	$ 40.000 - $ 49.999	$ 50.000 - $ 74.999
$ 75.000 - $ 99.999	$ 100.000 o más	

17. ¿Cuántas personas dependen de sus ingresos de esta compañía?

Appendix E. Responses to survey I.

1. Public relations and sustainable management, seed and supplies purchases, and sales diversified, for oysters, clams, mussels and geo-ducks.
   Farm specialized on mussels
   Processing plant, distribution and marketing diversified
   Transportation diversified and mostly dine by other supplier.
2. 550,000 kg of mussels clean in their shell on average per year
   (About 39-57 rafts harvested per year with an average gross of 20,366 kg resulting in a total of about 1 million kg ready to clean and processed. Once the product is cleaned and processed it yields to about 550,000 kg of final product, mostly to be sold as live fresh mussels in their shell.
3. From 12 to 16 months, however small sizes in summer could be reached in 6 months.
4. Market sizes:
   a. Small (4.5 cm = 20 g per mussel; 48 mussels in their shell per kg),
   b. Medium (5-7.6 cm = 25 g per mussel; 40 mussels in their shell per kg),
   c. Large (7.6-10 cm = 28 g per mussel; 35 mussels in their shell per kg)
   d. Jumbo (12-15 cm = 75 g per mussel; 13 mussels in their shell per kg).
5. Edible meat from 30-70% depending on the season. Average about 50%
6. Based on general nutrition values
   a. ~ 85g of mussels per portion
   b. ~ 20 g of protein,
   c. 147 calories
   d. High content of iron, manganese, P, selenium, zinc, vitamins C and B-12.
7. None

Production and processing stage

8. Freshwater and land usage
   a. *Farming stage*: 10,000 l of fresh water (wells) 12 times a year to avoid or remove parasites, susceptible to salinity changes. The farm covers 11.4 acres or a total of 496,000 sq ft.

b. *Processing plant*: 530,000-570,000 l per day for all species processed in the plant. The processing plant processes about 25-30% of mussels in volume, equivalent to 1,818 kg of fresh mussels a day. The water comes from wells and it gets into the processing plant, is used and then it passes through a water treatment and settling pond to be re-used as a water fertilized for an artificial forest that the farm created to decrease their ecological footprint by increasing carbon sequestration.

9. *Energy in farming stage:*
10. *Energy in processing plant:*
    a. $ 300 / month for electricity, mussels do not use refrigeration, but equipment
    b. Mussel volume uses 20%

Marketing

11. Whole mussels with shell alive. < 5% vacuum-pasteurized
        i. Fresh mussels: 10-day shelf-life
        ii. Pasteurized and vacuum packed: 20 days
        iii. Frozen up to a year
    b. The processing plant over-pack to ensure quality and compensate for water and small yields: summer over-packed 5% more product; winter up to 25%
12. Cost $0.90-$1.10/kg
13. Price $4.29-6.27 (average $4.4)
14. Distribution
    a. Seattle- Portland and Canada 5-10%
    b. Chicago, New York, Texas, Others 80%
    c. California 5-10%
    d. China < 5%
15. Domestic 90% and Canada and China 10%
16. About 20 workers involved in the mussel production system (farm, distributions, sales, purchasing, marketing)
17. Fulltime (14) and 5 part-time for the mussel farm but full time with the company involved in other species (oysters, clams and geoducks)

18. The company tries to award employees but the economy and sales have decreased and it

	# of employees	Women	# of working hours
Production			
Seed	1	0	4 h/week
Farm & Harvest	8	0	40-50 h/week
Processing			
Marketing	3-5	1	/week
Distributing	1	0	
Other	1	0	

has been something that is not that common anymore.

19. Yes, workers receive training specially at the beginning
20. The company hire workers when needs, especially for the processing plant rarely for the farm.

    Workers per stage

21. 14 full-time and 5 part-time for the mussel farm but full time with the company involved in other species (oysters, clams and geoducks)
22. The company tries to award employees but the economy and sales have decreased and it has been something that is not that common anymore.
23. Yes, workers receive training specially at the beginning
24. The company hire workers when needs, especially for the processing plant rarely for the farm.
25. Workers per stage

	# of employees	Women	# of working hours
Production			
Seed	1	0	4 h/week
Farm & Harvest	8	0	40-50 h/week
Processing			
Marketing	3-5	1	40-50 h/week
Distributing	1	0	
Other	1	0	

Appendix F. Codebook for the interviews used in the mussel farm to evaluate workers position at the industry from survey II.

Code	Description	Response Code
ID	From 1 to 19	(only answer with two digits)
Nationality		1 US 2 International
Language		1 English 2 Spanish
Worker Stability		
Stability	How many years have you worked for this company? (Ranked into Job Stability Criteria)	1 Less than 4 years 2 More than 4 years but less than 10 3 More than 10 years
Position	According to their position and location	1 Operatives in the Processing Plant 2 Operatives in the Farm 3 Manager or Supervisor 4 Executive
Age	When interviewed, according to year born	1 Less than 30 years old 2 Less than 40 years old 3 Less than 50 years old 4 More than 50 years old
First_position	Is this your first_position?	1 No 2 Yes
Rotated-promoted	Have you been in another position?	1 Promoted 2 Rotated
Job Security		
Security	How secure do you feel your position is in the company?	1 Insecure or somewhat insecure 2 Neither 3 Secure or very secure
Input	How frequently can you give your input or suggestions within this company	1 Never or Seldom 2 Occasionally 3 Regularly or Often
Input_method	How do you give input or suggestions to the company?	1 I do not 2 Yes, verbally 3 Yes, written 4 Yes, verbally and written

Appendix F, continued

Code	Description	Response Code	
Job Safety			
Safety	How would you rate the safety of your job?	1	Unsafety or somewhat unsafe
		2	Neither
		3	Safe or very safe
Potential	How frequently do you work to your full potential on the job?	Same as Q04	
Security & Safety	What is more important to you in your job: security or safety?	1	Safety
		2	Security
		3	Both
Additional Information			
Duration	Do you work full-time, part-time, or seasonal?	1	Part-time
		2	Full-time
		3	Part-time for mussel but full time
Hours	How many average hours do you work per week?	1	more than 50 hours
		2	41 to 50 hours
		3	less or equal to 40 hours
		5	No answer
		6	Not Sure or don't know
Education	What is the highest level of education you've completed?	1	Some High School, no degree
		2	High School graduate
		3	Some College, none,international
		4	Associate's or Bachelor's degree
Income	Please stop me when I reach the category that best describes your income.	1	Under or equal to $30,000
		2	$31,000-$40,000
		3	$41,000-$50,000
		4	More than $50,000
		5	No answer
		6	Not Sure or don't know
Income proportion	What is your estimated proportion of the household income	1	> than 50%
		2	< than 50%
Family	How many people live in your household?	1	1 person
		2	2 adults and 1-2 children
		3	2 adults and 3 or more children