Is the salmon farming industry externalizing its social and ecological impacts? An assessment using the Global Aquaculture Performance Index

by

Jennifer L.M. Gee
B.Sc, Thompson Rivers University, 2003

A Thesis Submitted in Partial Fulfillment
of the Requirements for the Degree of

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Supervisory Committee

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Abstract

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Neoliberal economists argue that the market provides the most efficient mechanism to address externalities. Theoretically then, the market value of a commodity should show a correlation with any changes in social and ecological performance. Alternatively, if the social and ecological costs of production are being externalized (not addressed by the market) then it is expected that the social and ecological costs of production would not be reflected in the market price. This study examined the extent to which social and environmental costs are externalized by the salmon farming industry and, by extension, to what level social and ecological impacts are reflected in the market, if at all. The salmon farming industry represents a classic example of how a relatively new industry functions within the confines of the current economic climate and was assessed to examine whether social and ecological impacts are reflected in the market. A novel tool called the Global Aquaculture Performance Index (GAPI) has been developed that addresses both the need for a quantitative measure of social and ecological performance and a tool that informs where policy is best directed to alleviate the impact of externalities. In applying the GAPI method, the market price for farmed salmon was not found to be correlated with changes in social and ecological performance and it may be assumed that these costs are externalized. GAPI provides a quantitative, performance based assessment of the salmon farming industry while the indicators of social and ecological performance provide clear starting points to improve salmon farming through a policy based context.

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Dedication

For my grandparents.

Chapter 1. Introduction

The dominant form of economic organization today is capitalist, and more specifically a capitalism strongly influenced by neoliberal ideology (Paul 2003). Neoliberalism is defined by the policies of privatization, deregulation and marketization —essentially a drive to minimize state intervention in economic activity (Paul 2003). Neoliberal economists argue, much as Smith did in the 1700's, that natural, human, social, manufactured and financial capital is most efficiently arranged through a free market (Sachs 1999). Many critics of the argument that the free market is the solution for economic organization point to the problem of externalities Externalities are either benefits or costs resulting from the production of a good or service, which are not accounted for by the market. Externalities suggest a gap in accounting by market-based valuations, thus leading to market failures and consequent sustainability problems.

There is increasing concern about social and ecological externalities within the industrial food system (Clark 2005). This study will examine whether social and environmental costs are externalized in the salmon farming industry by identifying the extent to which social and ecological impacts of salmon farming are reflected in market pricing. We would expect that if the market were adequately accounting for the social and environmental costs of the industry we would see a clear signal reflected in the value of goods when social and ecological impacts change. Alternatively, if the market were not adjusting for them these costs would be externalities and no correlation in market price would be apparent. A failure of the market to fully account for these costs would suggest that some form of policy-based intervention would be required to address them in order to preserve the social and ecological capital that the industry (and society) depends upon in the longer term.

Firms operating within the current economic system seek to maximize profits. In maximizing profits these firms side-step bearing the costs of their activities by externalizing the costs. Frequently, these externalized costs are placed on the environment and as firms grow and maximize profits through externalities their ability to further offset costs also grows. A market failing to optimize, or maximize, the production and distribution of commodities is defined as a type of market failure. There are four types of market failures: inefficient firms, externalities, information asymmetry and imperfect pricing (Cohen & Winn 2007). Externalities result when the market is unable to allocate the product or cost of producing that product to the party responsible for creating it. Externalities are either costs or benefits of production that are not reflected in the market price of a commodity. Pollution as a result of manufacturing a good is an example of an externalized cost of production. The production of a commodity results in the release of pollution, but the manufacturer does not bear the cost of the pollution, but an uninvolved third party does. The uninvolved third party can be either upstream or downstream from the production system generating the externalities (Cohen & Winn 2007). The difference between the cost of production for the producer with an unwanted effect externalized (borne by a third party/society) and the cost of that externality for society is shown below in figure 1. This figure shows that when a producer does not have to pay the costs of pollution, more units of a good are produced than would be if the costs of pollution were not externalized.

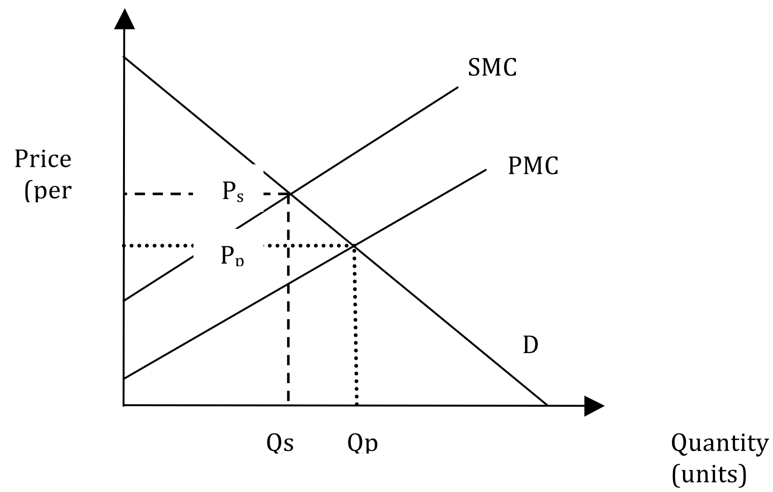

Figure 1. Externalities on a supply curve. D = demand for goods. SMC = Social marginal cost. PMC = Private marginal cost. Qs = quantity of goods produced at equilibrium state when taking cost to society into account and Ps = price for goods when produced at equilibrium quantity for internalizing social costs. Qp = quantity of goods produced at equilibrium state when the costs to society are externalized (maximum benefit for producer) and Pp = price for goods when produced at equilibrium quantity with social costs externalized.

In today's capitalist system a successful firm is likely a global firm that produces commodities in locations with low production costs and where environmental costs can be externalized to the greatest degree. Commodities are goods or services produced or used for selling in the capitalist system (Oxford English Dictionary 2010). Commodities are created by producing homogeneous items that share the same characteristics and are interchangeable in the marketplace. They are not differentiated by location of production nor producer and this means that a commodity may be produced anywhere and sold on any market that exists for a particular commodity. The production of commodities allow corporations to produce goods anywhere in the world while still having access to the same markets and this allows the corporations to seek out locations that allow for the lowest costs of production. The price for the commodity the firm produces is set in the market and does not necessarily reflect the value of the product in terms of either positive or negative social and ecological costs of production.

As industries grow and expand the supply of goods also increases, while prices for these goods decrease (as demand decreases). Competition between firms also leads to decreased prices for goods. Both competition and increased supply lead to lower profits for firms so they must seek out solutions to lower production costs. Production costs include materials, labour and manufacturing and the need to lower these costs necessitates increasing the scales of production where manufacturing costs are off-set through increased production quantities (Stanford 2008). Profits are defined as the amount of capital remaining after the firm pays not only the explicit costs of materials, energy, machinery, buildings and labour, but also the implicit costs of the owner's labour and a return on their investment (Paul 2003).

Firms are legally bound to maximize profits for shareholders and only government regulations can force firms to internalize what are otherwise externalities (Porritt 2005). As firms often do not bear the full costs for these externalities, their profits are greater than those firms who do bear some or all of the costs of the externalities. Profit maximization combined with a lack of laws and regulations that would mandate accountability for externalities mean that externalities are, in fact, important components of profit maximization for firms.

1.1 Atlantic Salmon Farming

The salmon farming industry is a classic example of the capitalist system where the wider implications of the farming practices can be analyzed to help determine whether economic performance can be correlated with social and ecological impacts. Atlantic salmon farming is a hatchery based industrial monoculture system. The young fish are raised in freshwater for the first 12 to 18 months before being transferred into floating pens in the ocean (Marine Harvest 2010). Fish are harvested anywhere from 18-24 months after being transferred to salt water pens (Marine Harvest 2010). Net pens can be upwards of $24m^2$ and 18 m deep and are joined together, often in groups of 6 pens. The Atlantic salmon are kept at densities of around $20kg/m^2$ (Jones 2004). To raise such a large number of fish in a small space results in a great dependence on inputs. Salmon are a carnivorous species therefore their feed contains other fish species. The feed pellets are a mixture of fish meal and oil along with other plants, livestock, vitamins and minerals (Tacon & Metian 2008). The high fish density requires inputs far greater than those available in the ecosystem surrounding the farms so resources must be drawn in from around the world.

Commercial salmon farming grew out of the post World War II period in Europe and subsequently spread across the world. Increasing production in the top four producing countries of Canada, Chile, Norway and the UK is shown in Figure 2. Atlantic salmon farming began in the 1960's in Norway and the United Kingdom (Kirk 1987). In 1969 the first floating sea-pen trial was completed in Norway and in the UK in 1970 (FishStat Plus 2008). The small quantity of farmed salmon that was produced in the early years drew high prices and increased interest in the industry in other countries (Bjørndal 2002). In Canada the first commercial harvest of farmed Atlantic salmon was in 1979 (FishStat Plus 2008). Farmed Atlantic salmon were first harvested in Chile in 1987 and by 2000 Chile was the second largest producer of Atlantic salmon (FishStat Plus 2008).

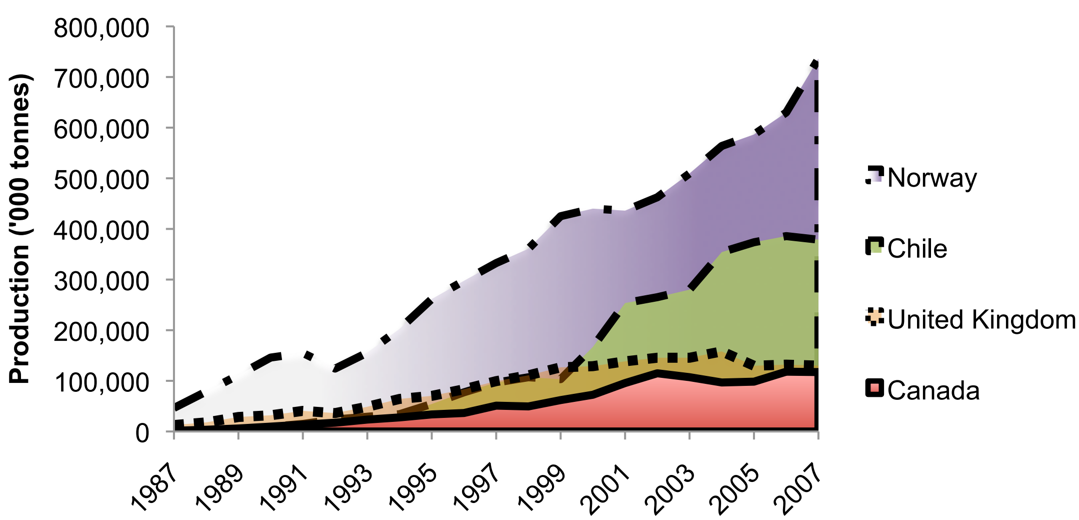

Figure 2. Production of farmed Atlantic salmon in Canada, Chile, Norway and the UK 1987-2007

Atlantic salmon production began to have an exponential growth curve in 1982. In 2000 Atlantic salmon aquaculture produced168 434 metric tonnes more than the total combine wild capture of all salmon species (FishStat Plus 2008). Since then aquaculture production of Atlantic salmon has increasingly continued to exceed wild capture of all salmon species, as shown in Figure 3.

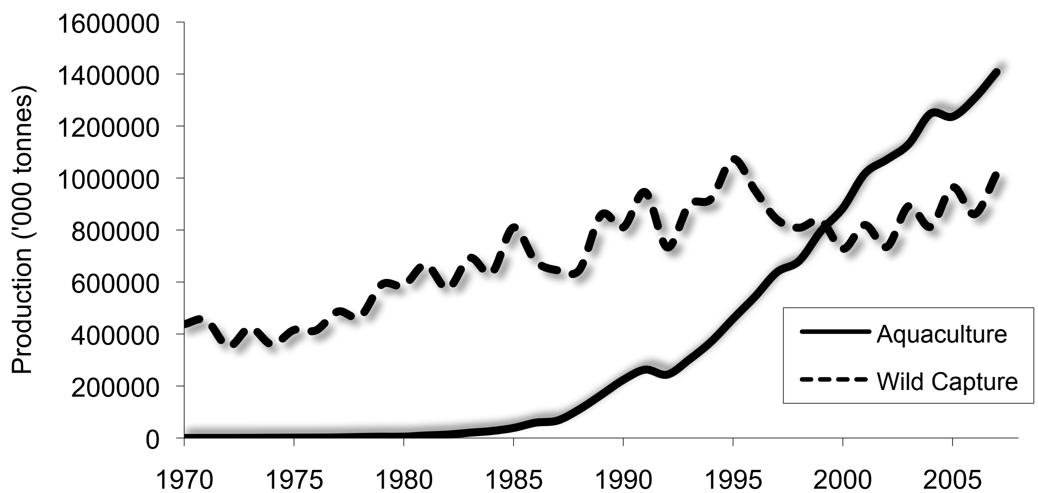

Figure 3. Production of Atlantic salmon aquaculture and capture of all wild salmon species from 1970 to 2008

Salmon farming began with small producers scattered across coastlines selling to local markets (Willoughby 1999 & Hjelt 2000 in Liu 2007). The industry grew and intensified while farms became concentrated, both in terms of ownership and location, and the fish have become an export commodity. Industrial salmon farming has also resulted in the commoditization of salmon (Volpe 2009). At one time salmon was a seasonal food available only in specific regions around the world. Now, the year round rearing of salmon in both the northern and southern hemisphere has led to salmon being available on the global market year round, fresh or frozen.

Table 1. Decrease in salmon farm companies in top four producing nations. Data for 1994 and 1999 from www.cermaq.com in Montero 2004 and 2007 data from Marlab 2008, Fiskeridir 2009, SalmonChile 2008, MAL 2008.

	1994	**1999**	**2007**
Canada	40	25	16
Chile	65	35	24
Norway	360	467	186
UK	131	95	38

As the salmon farming industry has grown and expanded globally there have been several periods of consolidation within the industry, first in the late 1980s and more recently around the turn of the millennium which has resulted in a significant decrease in the number of producers (Table 1). In addition to consolidation within the industry there has been vertical integration where one company controls all of the steps of production and supply for a commodity. For example, in Chile more than half of all the firms involved in the production of farmed salmon are integrated with at least one other stage (e.g. shipping and fishmeal supply) (Olson & Criddle 2008). Both the global expansion and consolidation and commoditization within salmon farming firms is consistent with the pattern seen in capitalist economies as companies merge in the flight from competition and seek out new sites with lower production costs.

1.2 Social Impacts of Salmon Farming

The workers on salmon farms represent a portion of the human and social capital that are required for salmon farming operations to function. At the same time the foundations of human capital, health, knowledge, skills and motivation, are threatened by poor working conditions (Porritt 2005). The drive towards ever-decreasing production costs has led to the expansion of salmon farming on a global scale as the industry has sought out jurisdictions that allow for decreased production costs through cheaper labour.

These social impacts are manifested at the interface of industry and worker where low salaries, dangerous working conditions, temporary rather than permanent employment, and disparities in wages and positions between genders decrease production costs (Marshall 2001; Moreno 2005; Barrett, Caniggia, Read 2002; Barton 1997; Muir 2005; Phyne and Mansilla 2003; HSE 2009; Statistics Norway 2003; SalmonChile 2004; WorkSafe BC 2007).

Salaries have been reported below the poverty line for some salmon farm workers in Chile (Pinto & Kremerman 2005), a situation known to negatively impact workers and their families in numerous ways. Inadequate wages prevent workers from being able to access the resources required to satisfy their basic human needs while low wages decrease the quality of life significantly as their income is consumed entirely in meeting only the most basic of needs and leaves no room for savings. A lack of permanent positions and job security further lowers their quality of life and leaves workers unable to plan for the future. There has also been an increasing tendency for regular full time employment to be replaced by subcontractors (Phyne & Mansilla 2003). Low salaries and low job security further tip the balance of power in favour of industry as workers lack the bargaining power to demand better job security or higher wages. The skewed power relationship results in a large poorly compensated labour force, further exacerbated by unsafe working conditions. Farm sites are inherently dangerous worksites as they are nothing but net structures with floating walkways on the ocean, with the conditions for scuba divers under the water equally as hazardous. The nature of the work has led to higher than average levels of injury, and even death, in producing countries (Estrada 2006, Statistics Norway 2003).

1.3 Ecological Impacts of Salmon Farming

As in any production or manufacturing system, salmon farming necessarily involves inputs and results in outputs. The ecological impacts of industrial salmon farming come in the form of both natural resources extracted and utilized in the production of the farmed salmon as well as the discharges and pathogens that are released into the environment. As a result, salmon farm operations generate ecological impacts along with their profits and products

Some ecological impacts of salmon farming include: parasite and disease transfer to wild populations (Krkošek et al. 2005; Krkošek et al. 2006); release of parasiticides and antibiotics into the environment (MAL 2003; Statistics Norway 2008); escapes of farmed fish (Volpe et al. 2001; MAL 2003; Statistics Norway 2008); benthic impacts from farm sites (Ackefors & Enell 1990; Gowen et al 1991; Barg 1992); impact of anti-foulants on the environment (Burridge et al 2008); use of fish meal and oil putting pressure on wild fish stocks (Hannesson 2003; Campbell & Alder 2006; Tacon 2009); and the use of biological and chemical energy (Tyedmers 2000; Troell et al 2004).

1.4 Global Aquaculture Performance Index

The ecological and social impacts of salmon farming have been well documented, as have the profits from the operations. The next step after surveying the social and ecological costs of salmon farming is the development of a methodology to quantify the impacts in a quantitative manner that allows for a comparison between countries. Aquaculture sustainability indices have been created to assess different scales and factors of impacts, but none met our needs to produce quantitative scores based on performance (Wilson et al. 2007). Some indices focus on ecological impacts while ignoring socio-economic conditions (Dietz & Neumayer 2007) and others focus only on the socio-economic impacts of ecological destruction (Human Development Report 2006). There is a clear need for a quantitative measure of both social and ecological impacts of aquaculture that incorporate all of the research that has been conducted on the impacts of aquaculture and allows for direct comparisons in performance between countries. Often, the connection between social, ecological and economic performance is left unexplored. As a result of this gap in the literature, an approach was developed in order to simultaneously analyse and visualize the interactions and performance of all three - the Global Aquaculture Performance Index (GAPI). The framework for the GAPI procedure is heavily borrowed from the Pilot 2006 Environmental Performance Index (EPI) (Esty et al. 2006) and updated in both 2008 and 2010 (Esty et al. 2008, Emerson et al 2010). The EPI was developed through Yale and Columbia Universities in response to the growing demand for a more quantitative foundation for decision making on key environmental issues for policy development. EPI tracks the performance of 163 countries across indicator groups such as climate change, air pollution, deforestation, fisheries sustainability, and biodiversity (Emerson et al. 2010). The full methodology for GAPI is described in Chapter Two. GAPI provides a novel and elegant tool for the quantitative evaluation and comparison of social and ecological performance, which allows for an assessment of performance to test whether differences in social and ecological costs of production are reflected in the market price (where market price is a proxy for cost of production) for farmed Atlantic salmon. Further, if indeed the market is externalizing social and ecological costs then GAPI has a second utility by offering insights into the extent of the externalization of these costs and where policy may be best focused to make improvements.

Question: Can absolute ecological and social performance in the salmon farming industry be evaluated with unvarying metrics?

Question: Does the price of farmed salmon reflect the cost of social and ecological impacts from production?

Null Hypothesis: The price of farmed salmon does not predict social and ecological costs of production

Chapter 2. Methods

Chapter 2. Methods

2.1 Indicators to Measure Sustainability: the Global Aquaculture Performance Index

The Global Aquaculture Performance Index (GAPI) has been developed to provide a tool that allows for quantitative assessment of performance across social and ecological indicators. The indicators were selected and developed through literature reviews and expert opinion and, when necessary, panels of experts were assembled to provide insight into the best measures of performance. Once the indicators and targets were set the data was transformed onto a one hundred point scale that measured the performance as a distance from target. The second step in data analysis that makes GAPI an effective and novel tool for measuring performance in aquaculture is the use of the statistical technique called Principal Component Analysis (PCA) that sets the indicator weightings according to their informative value. The GAPI methodology of performance based on distance from target and PCA informed indicator weightings is based on the Environmental Performance Index (Emerson et al. 2010). This allowed quantitative assessment of aquaculture performance at the nominal level of resolution of assessment of country - species (e.g. Norway - Atlantic salmon).

Other sustainability initiatives typically measure the performance of one actor (i.e. country) as a function of its performance relative to other actors, yielding a unitless (and thus uninformative) ranking. For instance, being ranked “number one” among an array of producers gives no indication if the leader is simply the best of a pool of poor performers or is actually a sustainability leader. Further, one has to make the assumption that the level of performance separating ranks one and two is equivalent to that separating two and three, and so on. This is rarely the case and only serves to further obscure potentially import policy-relevant information.

The proximity-to-target methodology measures the social and environmental performance of a country-species. As such, GAPI generates a cumulative performance score, not relative ranks, and provides unambiguous quantitative insight allowing comparison between countries' performance in each category of social and ecological performance along with economic performance. Capable of utilizing data in a broad array of formats and from all sources, GAPI uses the statistical method of principal component analysis (PCA) to uncover the patterns of interaction between social, economic and environmental drivers underlying the performance of aquaculture production for a species in a given country. PCA was used to show the underlying trends in data and was used to set indicator weighting by establishing how the different indicators explain the variation in each country's scores.

The first step in the GAPI approach is to establish indicators of performance that ensure data quality, relevance, performance orientation and transparency.

- *Relevance*: The indicator clearly tracks the issue of concern.
- *Performance Orientation:* The indicator is empirically derived and therefore tracks on-the-water conditions or is a best available data proxy for such outcome measures.
- *Transparency*: Baseline measures are clear, what? can track performance changes through time, and data sources in addition to methodology are transparent.
- *Data Quality:* Data used by the indicator should meet basic quality requirements and be the best and most appropriate measure available.

A review of the current seafood and sustainability indicator efforts was conducted to determine which areas of performance were measured most frequently .
Twenty-six sustainable seafood initiatives were assessed initially to determine if they met with the criteria of having clear indicators with targets that measured performance in a quantitative manner. The seven initiatives that met with these minimum standards were:

- Blue Oceans Institute/ Guide to Ocean Friendly Seafood
- Global Aquaculture Alliance
- Greenpeace/ Red Grade Criteria for Aquaculture
- Monterey Bay Aquarium/ Seafood Watch Program
- Marine Conservation Society
- Whole Foods
- WWF Benchmarking Study

If areas of sustainability, represented by indicators, appeared repeatedly it was deemed that they had successfully passed some form of a peer review and were likely strong candidates for inclusion as a GAPI indicator (see Appendices A & B for a review of assessed seafood initiatives and their indicators). Fourteen quantitative metrics of social and ecological aquaculture sustainability were identified with all of these indicators (or similar analogs) being cited in the majority of initiatives assessed.

From the seven selected initiatives fourteen indicators were identified to be included as a result of either being present in all of the initiatives, identified in the literature, or through expert opinion. The indicators include: antibiotics; biochemical oxygen demand; copper; escapes; ecological energy; feed; industrial energy; parasiticides; pathogens; (workplace) accidents; (workplace) deaths; Gini index; HDI performance; wage difference from the poverty line. Most indicator groupings were covered by all of the initiatives, with the exception of sustainability of feed source fish, energy use, and escapes, which were only included in some of the initiatives. The final form of the ecological indicators was informed through a process of consultations with experts in the field. The indicators design for biochemical oxygen demand, antibiotics, parasiticides and copper were the result of indicators two intensive workshops were held that brought together multiple experts to weigh in on the formation of the indicators. The number of social indicators and potential measures of economic performance was limited by data availability. Indicators had to have data available in all four production countries and across the twelve years of time series data.

For each indicator a target value had to be defined so performance could be measured. Setting quantitative target values was a critical component in establishing GAPI as only having a country's score for each indicator leaves one with a relative measure of performance, while having a target set for each indicator means that the performance for each country can be measured from the target value. Each target has been set to zero for all of the ecological indicators. A target value of zero sets a goal of no impacts on the environment from the aquaculture operation. The target values for the social indicator HDI was a value of 1, as set by the HDI protocol where a score of 1 represents the best performance (HDR 2009). The remainder of the targets for social performance were set to zero. No injuries or deaths in the workplace indicate a safe workplace. The Gini index was measured on a scale of 0-1 with zero representing optimal distribution of wealth and the GAPI target was set to zero in accordance with this. The difference between the average worker's salary and the poverty line was also set to zero as, at the very least, the average worker needs to be paid above the poverty line to have access to the means to lead a meaningful, self-directed life. The target value represents the best possible performance or "gold standard" for each indicator which are derived from the scientific literature and/or expert opinion.

In the absolute simplest terms, the overall performance of a particular aquaculture production system is the sum of the distances separating the fourteen targets from their fourteen empirically derived performance values. The following section details the basis for each of the indicators and how the indicator scores are calculated.

2.2 Indicators

Economic Performance

Economic performance was measured as the farmgate price of farmed salmon per kilogram of whole fish reported as reported to FAO every year (FishStat Plus 2008). Market price is used as a proxy for the cost of production for Atlantic salmon due to limited data availability of the costs of production from private companies. The Canadian dollar (CAD) value per kilogram did not include value added activities such as filleting the fish, which occur after the fish leave the farm, as this would distort the comparison of social and ecological performance with the economic performance of the salmon farming industry. The value of production per kilogram is only one of several potential measures of economic performance, but it was selected as it was the most consistently reported measure over the temporal data series. Other potential measures of economic performance could include cost of production per kilogram; profit per kilogram; the industry's contribution to GDP; a comparison between the industry's contribution to GDP compared with the overall profits, and which other countries the profits of salmon farming flow to outside of the host country. The value of the salmon farming industry is often tied in with other industries such as fishing, or grouped with agriculture products, and this made obtaining values for contribution to GDP on a yearly basis from 1995 onwards challenging. Profit and cost of production were not reported frequently or consistently enough to be included as data points.

Social Performance

Social performance was measured at two scales: a country level and an industry level. Ideally, social scores would be measured solely at the industry level, but this was prohibited by limited data availability.

Gini Index (Gini)

A wealthy industry does not necessarily translate into a wealthy workforce (Phyne & Mansilla 2003). To quantify the distribution of wealth—or whether the income paid by the industry is concentrated among a few upper level managers or more evenly distributed between management and wage-labourers within the salmon farming industry—the Gini index was used. The Gini index is measured by the United Nations

Development Programme (UNDP) and released in the Human Development Report (HDR 2009). Due to constraints on the scope of the project, farm site specific data could not be collected. The national level of performance was used as a proxy for industry performance based upon the assumption that the conditions at a national level reflected the conditions on the industry level as an equal distribution of wealth is often the result of government policy. At a national level, the Gini Index is the most commonly used measure of inequality (HDR 2009) and is a measure of the discrepancy of distribution of wealth within a country. Using a measure of a nation's general performance risks missing industry specific performance, but no such industry –level data was available going back to 1995. A proxy measure was best utilized for industry performance to provide at lease a baseline for industry performance. In a country where wealth is distributed evenly between all people the score would be 0, while in a country where wealth is distributed with complete inequality (one person has all of the wealth) the score would be 100 (HDR 2009).

Calculation: The Gini Index score was sourced from the yearly HDR Reports available from http://hdr.undp.org/en/reports/
Target: Zero
Assumptions

- The Gini index is not reported for every country in each year. If the Gini score was not reported for that year the Gini score from the previous year was used. An average of the previous years was not used as the infrequency of reporting could result in the data being excessively smoothed and masking any changes in performance. Further, the next year's score was not used as this may have artificially inflated the score (as most countries' score improve over time).

HDI score (HDI)

Economic profit or even growth does not necessarily translate into people having the freedom to lead a life they find fulfilling. This indicator provides another measure beyond salary to assess the work place conditions of salmon farm employees and, again, the assumption was made that national conditions would be a fair representative of industry conditions. The Human Development Index (HDI) is released in the Human Development Report (HDR) and is measured at a national level by the UNDP. Where the Gini index measures distribution of wealth, the HDI scores measures the ability of people to lead fulfilling lives they have the freedom to choose. The HDI score (see Appendix C for example) is used to give an overview beyond GDP of the conditions that people of a country live in. It is reported on a scale of 0 (worst performance) to 1.0 (top performance). The HDI measures indicators within the three dimensions of well-being: a long and healthy life, education, and a minimum standard of living (HDR 2009). Within those three categories the indicators include: life expectancy at birth; adult literacy rate; combined gross enrolment ratio for primary, secondary and tertiary schools; purchasing power parity (PPP) in US dollars.

Calculation: HDI score for each year provided from the yearly HDR documents available from http://hdr.undp.org/en/reports/
Target: 1.0
Assumptions

- The HDI is not reported for every country in each year. If the HDI was not reported for that year the HDI score from the previous year was used. An average of the previous ears was not used as the infrequency of reporting could result in the data being excessively smoothed and masking any changes in performance. Further, the next year's score was not used as this may have artificially inflated the score (as most countries' score improve over time).

Wage Difference From Poverty Line (POV)

The difference between the average salary for a salmon farm employee and the poverty line is calculated for each year. The poverty line is established as being 60% of the per capita purchasing power parity (PPP) for a given year (Poverty Site 2009). PPP is used rather than GDP because it is a measure of exchange rate that takes into account price differences between countries (HDR 2008) thereby providing a more accurate portrayal of conditions in each country. People earning less than the poverty line have "resources that are so seriously below those commanded by the average individual or family that they are, in effect, excluded from ordinary living patterns, customs and activities." (Poverty Site 2009).

Calculation: (Average salmon farm employee salary [country/year]) – (60% of country's PPP for current year)
The average wage for salmon farm employees is reported in national data released by the industry, through governmental bodies or in the grey literature. PPP is presented in the Human Development Reports available from http://hdr.undp.org/en/reports/

Target: Zero
Assumptions

- If the average wage for salmon farming employees was not available the average wage for the closest industry sector was used
- If the average wage for salmon farming employees was not available for a similar sector the average employee wage from a previous year was used

Workplace Deaths (Deaths)

A safe workplace where employees do not fear for their lives is a crucial building block of a socially sustainable industry. Death rates are used as an indicator of safety in the workplace. Death rates per 100,000 workers are reported to remove any skewing of safety data as a result of the salmon farming industry employing a magnitude of order more employees in Chile than the UK.

Calculation: Deaths per 100,000 workers per year for the salmon farm sector.
Data on workplace deaths was collected from governmental safety boards, industry reports and journal publications
Target: Zero deaths
Assumptions

- General aquaculture sector data was used for death rates is salmon farming specific data is not available for a country

Workplace Injuries (Injuries)

Minimal workplace injuries are another factor of building socially sustainable industries where workers are protected from both short and long term injury. Injury rates are used as an indicator of safety in the workplace. Injury rates per 100,000 workers are reported to remove any skewing of safety data that results from the salmon farming industry in Chile employing an order of magnitude more employees than in the UK. Further, depending on governmental regulations on reporting the severity or nature of injuries may influence the number of injuries reported.

Calculation: Injuries per 100,000 workers per year for the salmon farm sector. Data on workplace deaths was collected from governmental safety boards, industry reports and journal publications

Target: Zero injuries.
Assumptions

- General aquaculture sector data was used for injury rates is salmon farming specific data is not available for a country
- Injury rates are an aggregate of injury reporting for health care only claims, short term disability and long term disability claims.

Ecological Indicators

Pathogens (PATH)

In fish culture, if production fish share a common environment with wild potential hosts (open net pens) the transfer of pathogens and parasites is a virtual certainty (Johnsen & Jensen 1991, Krkosek et al. 2007). Introduction, transmission, (McVicar 1997) and amplification (DFO 2006) of pathogens are frequently cited as causes for concern. The potential effect of diseases and pathogens on the wild community are the primary focus of this indicator as they may reduce the viability of local fish populations. The impact of farm-derived pathogens (or biological agents that cause diseases in their hosts) is estimated using three variables. These three variables are: on-farm production loss (measured as proportion of total pathogen-related loss), pathogenicity (the ability of a pathogen to cause an infectious disease in an organism) and the abundance of susceptible species in the wild.

Farm sector performance in the context of pathogens is reflected in production loss data. It is assumed that an increase of on-farm pathogen impacts results in a proportional increase in the wild pathogen load in susceptible species. This indicator uses the change in farm site pathogen loads as a proxy for the magnitude of impacts on native fish species that are susceptible to those pathogens.

For each pathogen identified in a production system, its host range, life cycle and pathogenicity are identified and used to predict impact on wild populations.
Host range specificity - It is assumed that all members of a Family are susceptible to a pathogen when two or more genera are known to be susceptible (Lafferty 2009 *pers. comm*.). In cases where a parasite has a complex life history (utilizes one or more intermediate hosts), each life stage is counted as a separate pathogen and a diet filter is applied in the calculation.

Pathogenicity - the relative proportion of total production losses that are ascribed to the pathogen in question. If on-farm pathogen specific mortality data are unavailable, pathogenicity is split equally among pathogens on record to have occurred in those production systems.

Proportional biomass of host range - the proportion of species in the ecosystem susceptible to the pathogen in question. This estimate is derived from Ecopath models (Christensen and Walters 2004; <http://www.ecopath.org/>) using a trophic mass balance approach to quantify ecosystem biomasses of the world's 66 large marine ecosystems (LMEs). Specific LME models were obtained from Christensen *et al.* (2009) and additional published Ecopath ecosystem models.

In cases where LMEs are described by only functional group data and not specific species biomass data, the catch ratio of the species relative to the whole functional group was used to infer biomass proportion.

Calculation: Sum of Pathogen specific wild loss*
Target : Zero pathogen impacts, equivalent to no disease transmission
Units: Metric Tonnes
*****_Pathogen specific wild loss= (Pathogen specific production loss)** x (proportion host range biomass in ecosystem)_
Pathogen specific production loss =(Total production loss) x (pathogenicity)

Assumptions
If total production loss from pathogens is not available, the following may be substituted:

- an average from obtainable years production loss from "dead fish" (as opposed to escapes, bad quality etc.)
- estimated proportion of diseased fish from expected survival rate (e.g. Canada Atlantic salmon have an expected survival rate of ~90%, and 25% of dead fish are due to disease and parasites - the resulting production loss from pathogens is 2.5%)

If no proportional loss (relative pathogenicity) information is available, the following may be substituted:

- pathogen occurrence, frequency or health event data, economic loss (converted into a proportion of production loss), a combination of either the above and/or production loss e.g. UK Atlantic salmon in 2000 with an annual average production loss from pathogens of 3% plus a CMS loss of 1% (0.5 rounded up).
- If none of these are available for a given year, pathogenicity is spread equally amongst pathogens known to be present

Antibiotics (ANTI)

Aquaculture production systems require the application of medications for the treatment of diseases and parasites. Open net pens are not isolated systems and most medications (antibiotics and parasiticides) are applied as a bath treatment or in feed where the medications then enter the surrounding environment (Burridge et al 2008). As such, these chemicals may comprise a significant part of the damaging farm-derived effluent released into the ecosystem. Many have been associated with selection for antibiotic resistant bacteria (Burka et al 1997, Cabello 2006), persistence in sediments and water column (Cabello 2006, Hektoen et al 1995) and potential toxicity to non-target organisms (Christensen et al. 2006, Holten-Lützhøft et al. 1999). It is important to assess the potential overuse of antibiotics considered critical in human or veterinary use.
Data from a joint meeting of FAO (Food and Agriculture Organization of the United Nations), WHO (World Health Organization) and OIE (World Organisation for Animal Health) was used to develop an antibiotic score (FAO/WHO/OIE 2008). This score reflects crucial antibiotics whose efficacy must be maintained; with overuse there is a risk of developing antibiotic resistance. Two lists were compiled and compared, one for those important in human use (WHO) and the other in veterinary (OIE):

WHO list – Human Antibiotics

Criterion 1 - Sole therapy or one of few alternatives to treat serious human disease.
Criterion 2 - Antibacterial used to treat diseases caused by organisms that may be transmitted via non-human sources or diseases caused by organisms that may acquire resistance genes from non-human sources.

On the basis of these criteria, the following three categories were established:
Critically important - meet criteria 1 and 2
Highly important - meet criteria 1 or 2
Important antimicrobials - meet neither criteria 1 nor 2

OIE list – Veterinary Antibiotics

Criterion 1 - Response rate to the questionnaire regarding Veterinary Critically Important Antimicrobials.
(This criterion was met when a majority of the respondents (more than 50%) identified the importance of the antimicrobial class in their response to the questionnaire.)
Criterion 2 - Treatment of serious animal disease and availability of alternative antimicrobials.
(This criterion was met when compounds within the class were identified as essential against specific infections and there was a lack of sufficient therapeutic alternatives.)

On the basis of these criteria, the following three categories were established:
Critically important - meet criteria 1 and 2
Highly important - meet criteria 1 or 2
Important antimicrobials - meet neither criteria 1 nor 2

If an antibiotic was categorized differently by each group, the highest rank of importance was used. The scores resulting from this as used in the Antibiotic indicator are as follows:

Table 2. Importance category and score for antibiotic use from WHO and OIE.

Category	**Score**
Critically important - WHO and OIE	7
Critically important in either	6
Highly important - WHO and OIE	5
Highly important in either	4
Important - WHO and OIE	3
Important in either	2

Score*: amount (kg) x WHO/OIE score*

Target : Zero input of antibiotics in bath or feed treatments

Units: kg

Amount (kg) active ingredient

WHO/OIE score = antibiotic importance score

Assumptions

- If amount data is not available, the recommended dosage is assigned for all antibiotics known to be in use.
- If data is not available for a given year, an average value (in kg/mT of fish produced) from known years is applied (for all antibiotics used for more than 1 year).
- If WHO/OIE score is not available, another from the same family of antibiotics is substituted.

Parasiticides (PARA)

In addition to medical treatment through the application of antibiotics, chemicals known as parasiticides are used for reducing parasite infestations in aquaculture. Parasiticides are applied using the same methodology as antibiotics, either in medicated baths or feeds. Many are toxic to non-target organisms, especially aquatic invertebrates (Burridge et al 2008). When used in open system facilities, parasiticides typically manifest effects beyond their intended recipients and it is important to take into consideration the ecological implications of their application.

Calculation: *amount* (kg) x [(1/*LC50*)+1] x *persistence* (days)

Amount(kg) used in active ingredient

Target : Zero input of parasiticides in bath or feed treatments

Units: kg

LC50 (mg/L) – lowest lethal value (this is used to represent the organism most harmed by each substance)

Persistence (half-life) (days) - (independent of substrate, as long as the substance persists in the system it is potentially doing harm)

Assumptions

- If amount (Kg) data is not available at all, the recommended dosage is assigned for all chemicals known to be in use.
- If data is not available for a given year, an average value (in Kg active ingredient/tonnes of fish produced) from known years is applied (for all parasiticides used for more than 1 year).
- LC50 of active ingredient when used in other antiparasitics is assumed to be the same for aquaculture purposes (e.g. LC50 for Ivermectin in equine gels is the same as that used in oral treatment for salmon).
- If persistence value is not available, another from the same family of chemicals is substituted

Escapes (ESC)

The intrinsic impact of non-native species on ecosystems has been well documented (Costa-Pierce 2002, ICES 2005). The near inevitability of escapes from aquaculture facilities has led to the recommendation that introductions of species for aquaculture should be considered an introduction to the wild, even if the facility is considered a closed system (FAO 1995). Debate exists with regards to quantifying the full impact of escapees on recipient community structure and services, however there is consensus that any introduction or translocation of organisms carries risk (ICES 2005). In all cases escape impacts are density dependant and therefore the magnitude of impact is tied to escape numbers. In those cases where genetic introgression of wild populations is possible, the *per capita* impact of escapees increases with each generation in culture as deviation from the wild gene pool increases (Araki et al 2007).

A *GAPI Invasiveness Score* (see Appendix D) was inspired by the Marine Fish Invasiveness Screening Kit (MFISK) tool developed by Copp et al. (2007). This approach uses a mixed quantitative-qualitative process that assigns an invasion impact score based on several broad categories: domestication, climate & distribution, invasion elsewhere, undesirable traits, feeding guild, reproduction; dispersal mechanisms and persistence attributes. The species in question is assessed with regard to these characters using 31 questions where the answers to most questions add to the invasiveness score in an additive fashion (i.e. response are scored as 0 or 1). For five questions the responses may range as high as six. The summed score to these 31 questions is then multiplied by the responses to seven additional questions which probe larger order species and production attributes.

Calculation: (*GAPI invasiveness score)* x (Number of escapes for that species)
Target : Zero
Units : Number of escapes * invasiveness score

Biochemical Oxygen Demand (BOD)

The benthic impacts of aquaculture have been widely documented (Ackefors and Enell 1990; Gowen et al 1991; Barg 1992). Water quality issues associated with aquaculture are dominated by organic nutrient loading driven primarily by uneaten feed and fish feces (Wu 1995). The tractable method for estimating the ecological effect of these wastes is via estimation of the biochemical oxygen demand (BOD) required to process these materials. Specifically, BOD is an appraisal of the amount of oxygen required to oxidize dissolved and particulate organic matter (uneaten feed and feces) released into the environment as a consequence of rearing one tonne of product. The underlying calculations are taken from Boyd (2009).

The BOD of feed represents a measure of the relative oxygen-depletion effect of waste contaminants and are defined as the amount of oxygen required to oxidize organic carbon (C) and nitrogen (N) from feed inputs which are not recovered in the biomass at harvest. The BOD indicator captures not only the total amount of material introduced but also the spatial area in which this occurs. A given amount of nutrient loading spread across a large area will on average have a lesser impact than the same loading concentrated in a small area. Therefore the BOD indicator balances magnitude of material introduced with the distribution of the farms (*farm distribution*) and the *area of impact*.

BOD is calculated by assessing the total carbon and nitrogen per unit of feed: Amounts of molecular oxygen necessary to oxidize 1 Kg organic carbon and 1 Kg ammonia nitrogen are 2.67 Kg and 4.57 Kg, respectively. These relationships allow the biochemical oxygen demand of feed to be estimated with the *BOD* equation.

To determine farm distribution, the country's coastal area is divided into 30km x 30km grid cells. Farm sites are identified within each cell and the number of cells required to account for 25% of the country's production are divided by the total number of cells that contain farm sites.

Calculation: (*BOD*) x (*Area of Impact*) x (*Farm distribution*)
Target: Zero
Units: mg/L / km^2

BOD = (total N in feed – total N in salmon) x (4.57 + (total C in feed – total C in Salmon) x (2.67)
Area of Impact (km^2) – total area of 30km by 30km grid cells containing farms
Farm distribution – the smallest number of grid cells needed to obtain 25% of the country's production divided by the total number of grid cells that contain farm sites.

Assumptions

- If percents of Nitrogen or Carbon are missing for a fish species, use values for the most closely related known species
- If Carbon in feed is unknown, use 45% (Boyd, pers. comm. 2009)
- If Nitrogen in feed is unknown, use crude protein 6.25%

Copper (COP)

The accumulation of organisms on nets reduces water flow through cages, decreases the dissolved oxygen level, reduces buoyancy and affects the durability of the nets (Braithwaite et al 2007). Antifoulant coatings and paints are applied to marine net cages to prevent the colonization of such marine organisms. Copper is the primary active ingredient in the vast majority of these applications (Burridge et al 2008) which leaches from the nets over time. Large amounts of copper are also introduced when nets are cleaned. Copper is known to be highly toxic to a wide range of aquatic organisms including algae (Franklin et al 2001), copepods (Bechmann 1994), amphipods (Ahsanullah and Williams 1991), echinoderms (Fernandez and Beiras 2001) and larger microbial communities (Webster et al 2001). Copper in excess of recommended maximum concentrations may co-occur with aquaculture facilities (Chou et al 2002) and remains potentially lethal even when bound in sediments. The copper indicator is calculated using total production (tonnes) and the proportion of it that uses copper-based antifoulants.

Calculation: (Tonnes Production) x (% of production using copper-based antifoulants)
Target : Zero tonnes produced using copper based antifoulants
Units: Tonnes

Assumptions

- In the absence of verifiable data, it is assumed 100% of production uses copper based antifouling paints

Sustainability of Feed Source (FEED)

Fishmeal and oil continues to play an integral role in fulfilling the nutritional requirement of aquaculture raised species (Tacon & Metian 2008; Deutsch et al. 2007; Kristofersson & Anderson 2006; Naylor et al. 1998; Naylor et al. 2000), particularly for carnivorous species such as Atlantic salmon which are fed compound feeds. The targets of reduction fisheries are fish species that not only constitute major components of marine ecosystems but also comprise the primary prey of economically important carnivorous species. If the species being fished are not being harvested at sustainable levels the survival of the entire stock is put in jeopardy.

Harvest performance – is measured as the difference between the actual catch and the set management catch limits for each species-year combination. The management target is taken from Fish Source (http://www.fishsource.org) and is either the biological maximum sustainable yield (BMSY) or total allowable catch (TAC). If the actual catch exceeded the management catch limit, the score is that difference. If the actual catch was lower than the management catch limit, the fishery is scored as "1".

Stock Status and Management Score, FAO - The 2005 FAO assigned categorical values to the health of fish stocks. The four categories range from "underexploited" to "overexploited-depleted". These categorical scores are converted to numeric scores of 1-4, with 1 being the best performance (underexploited) and 4 being the worst performance (overexploited-depleted). The State of Exploitation score assigned by the FAO was based on catch data for each species from 1950-2002 and the score for each species was applied for every year of the GAPI assessment.

Stock Status and Management Score, Sustainable Fisheries Partnership - The Sustainable Fisheries Partnership produced the report "Sustainability overview of world fisheries used for reduction purposes" (2009). Reduction fisheries are assessed as to whether they used biological reference points (BRP's) to determine the lower limit and upper target reference point for catch. BRP's are derived with a variety of approaches. Ecosystem based management is considered to be the best representation of sustainability in the setting of upper target reference points while B_{20} or Biomass / Recruitment models are considered the best way to set lower limit reference points.
The lowest score is applied to management regimes that do not use methods to establish catch thresholds. The GAPI score system assigned a numeric value between 1-9 where 9 represented the worst performance (no BPR used) and 1 the best (Ecosystem based management / B20).

Calculation: [∑((*group component*) x (proportion) x (*sustainability score*))] x *transfer coefficient*
Target: Zero tonnes from unsustainably fished stocks

Units: tonnes

Group component = The fishmeal and fish oil components of feed are first identified as to forage species, country of origin and the proportion of each in the final feed formulation.
*Sustainability score = (harvest performance) * (stock status) * (management score)*
Transfer coefficient = (Tacon & Metian 2008) calculated as pelagic equivalent inputs to farmed fish outputs (Kg:Kg)

Assumptions

Species Composition of Feed

- If the species composition of feed used in country is unknown use composition from known most similar production country
- If the proportion of species in feed is unknown use proportion of species from total catch in reduction fishery supplying that feed or global reduction fishery species proportions
- If species composition unknown for any production country for species being farmed use breakdown of species caught for reduction fisheries for that year

Management Score

- If the BMSY is unavailable for species use TAC
- If TAC unavailable for species use spawning stock biomass (SSB) or other management catch limit set
- If no management catch limit set use best of BMSY, TAC, or management catch limit (in order of preference) from most recent year
- If no management catch limits has ever been set assume over-harvesting and set difference to worst performance score from species group for that year
- Atlantic Menhaden stock monitored closely, but not in comparable manner to other species.
    - If management scores are acceptable and reporting acceptable fishing mortality and fecundity then accept actual catch levels below what set limits would be.

Ecological Energy (ECOE)

Feed acquisition, processing and transport, account for up to 94% total energy consumption in modern intensive aquaculture production systems (Tyedmers 2000, 2009 *pers. comm.*). Fishmeal and fish oil continues to play an integral role in fulfilling the nutritional requirement of most aquaculture species (Tacon & Metian 2008; Deutsch et al. 2007; Kristofersson & Anderson 2006; Naylor et al. 1998; Naylor et al. 2000), which is particularly so for carnivorous species being fed compound feeds. In 2006 the aquaculture sector consumed the equivalent of 16.6 million tonnes of pelagic fish in the form of 3.7 million tonnes of fishmeal and 0.8 million tonnes of fish oil (Tacon & Metian 2008). In order that GAPI may account for this appropriation of ecological production, the mass of fishmeal and oil consumed are standardized as units of net primary productivity (NPP) (grams of carbon or g C) per kilogram of product (Tyedmers 2000). Discards, by-products and by-catch may be seen as a reasonable and sustainable feed alternative, however these too are the product of NPP investment, the removal of which from the system have ecological ramifications.

It is also necessary to account for the NPP of the agriculture and livestock components of the feed. Poultry is used as a proxy for all potential livestock used in the feed. This approximation is viable since chicken is a major non-marine protein input and typically displays similar feed conversion rates to swine and is slightly higher than cattle (Tyedmers 2000). For the plant proportion a composite value is used for wheat, corn, soy and any other plants included in the feed formulations. Feed Components (calculated as per Industrial Energy) are the proportion of feed comprised of fish, livestock and plants are calculated from either industry figures for feed composition or literature published on diet compositions.

Calculation: $\Sigma P_{\text{feed inputs}}$

P (g C per kg primary productivity) = $(m/9) \times 10^{(T\text{-}1)}$ (Tyedmers 2000)

m = tonnes wet mass organisms

T = trophic level organism

Target: Zero NPP

Units: primary productivity g C per kg $^{-1}$

Assumptions

- No non-marine livestock used in Norway or United Kingdom feed mixtures due to EU regulations
- If proportion of fish/plant/livestock unknown use most recent known data for that country

Industrial Energy (INDE)

As feed acquisition, processing and transport account for up to 94% total energy consumption in modern intensive aquaculture production systems (Tyedmers 2000, 2009 *pers. comm.*).The energetics of feed *are* the energetics of aquaculture and, as such, feed is used as the lens through which energy investment is viewed. Industrial energy is a measure of other non-solar (fossil fuel or hydroelectric) resources consumed by an aquaculture production system to support production.

The Industrial Energy indicator takes into account the energetic costs of the transformation of feed components from their raw state to farm-ready use. This indicator does include production energy embedded in terrestrial agriculture and livestock inputs. Less than 10% of industrial energy is used on the farm and this energy use is not captured by this indicator. Industrial energy consumption is calculated as the energy use (Gigajoules) embedded in feed used to produce one tonne of product in that country.

Calculation: ∑ (proportion fish/livestock/plant) x (*knife coefficient*)* x (total feed consumed / tonne of product)

Target: Zero industrial energy inputs

Units: Gigajoules

**Knife coefficient = average energy per tonne for fish, livestock or plant component of feed from Tyedmers (2009 pers comm.)*

Assumptions

- No livestock used in Norway or United Kingdom feed mixtures due to EU regulations

- If proportion of fish/plant/livestock unknown use most recent known data for that country

2.3 Data Standardization & Transformation

Following the establishment of a target value for each indicator and the collection of the relevant data, a three step process yields the GAPI Score for that particular country-species pairing and exposing the policy-relevant multivariate trends embedded in the data.

1. Data Standardization and Transformation
2. Proximity to Target Calculation
3. Indicator weighting via PCA

Standardization and Transformation

The first step in data processing was to set all data on a 0 - 100 scale. Data come in all manner of units and the distance separating leaders and laggards can be a matter of a few units or many orders of magnitude. Therefore standardization of all data is necessary in order to allow direct comparison across the entire data set. Addressing the effect of extreme outliers in the raw data set was the next step in data standardization. A single or small number of extremely high or low numbers would have the effect of distorting the distribution of the entire dataset. Such extreme values in the context of environmental performance are typically measurement artefacts rather than legitimate extreme high/low performers (Esty et al. 2008). The standard accepted statistical method for handling such artefacts is the process of Winsorization. Those values above or below two standard deviations from the mean (95th and 5th percentile respectively) are set equal to the 95th and 5th percentile values, respectively. This standardizes the measurement relative to the worst performer. It is an important distinction that the data outside the 95th and 5th percentile values are not discarded from the data set, but rather outliers are moved towards the mean and still included in the data set. Following standardization and adjustment for outliers the data are ready for the proximity to target calculation.

For indicators where small observations indicate better performance:
100 – [(winsorized value – target value) x 100 / (95th percentile value – target value)]

Example:
Winsorized Value = 4500
Target = 120
95th Percentile = 5100
Proximity to target = 100-[(4500-120)*100/(5100-120)] = 100-[87.95] = 12.05

Once the score had been calculated for each indicator it was normalized against production for that year. Normalizing against production is an important step as it prevents the scores from being highly weighted by large production numbers and it gives a better representation of the efficiency of the operations in each country.

In a recent review of sustainability assessment methodologies Singh et al (2008) demonstrated that normalization and weighting of indicators used in sustainability assessments was typically associated with subjective judgments and revealed a high degree of arbitrariness without mentioning or systematically assessing critical assumptions such as data weighting. A superior approach is to weight indicators so they reflect their ability to explain a variation between good and poor performances. In order to avoid the pitfalls indentified by Singh et al. (2008), such an approach must be data driven and completely objective.

A standard statistical procedure for such a task is the Principal Component Analysis (PCA). PCA is an ordination technique for analyzing data derived from several variables such as sustainability indicators. PCA finds linear trends ("principal components") within the clouds of data points in multidimensional space. For instance, the fourteen indicators generated a "cloud" of data in fourteen dimensional space. The relationship between any two or three variables is easily assessed, however, interactions among data in greater than three dimensions are not so easily illustrated. Further, the interaction effects between variables are oftentimes not linear, which adds to the complexity of the data. Ordination techniques seek to make explicit the informative core internal structure of multivariate data. PCA can be thought of as revealing the internal structure of the data in a way which best explains the variance in the data. If a multivariate dataset is visualized as a set of coordinates in a high-dimensional data space (1 axis per variable), PCA supplies the user with a lower-dimensional picture, a "shadow" of this object when viewed from its most informative viewpoint. The analysis probes the data set and asks "what combination of indicators, when taken together best explains the discrepancy between performance leaders and laggards". That subgroup of indicators forms a natural dimension of environmental performance. The proportion of total variation explained by each indicator in the subset is calculated as an eigenvalue. The eigenvalue is an empirically derived metric equal to the informative value of that indicator to explaining the overall variation in the dataset (Norman & Streiner 2000). Thus, the eigenvalue is an accurate expression of that indicator's relative weight. PCA is an iterative process, the residual variance within the total dataset remaining after construction of the first principal component is reassessed and the second principal component is constructed (this being the second dimension of natural environmental performance). This process continues until all indicators and assignable variation are accounted for.

In short, PCA is a statistical tool that reduces the number of dimensions in the data set necessary to identify latent but informative patterns residing in multivariate datasets. PCA identifies how individual indicators interact (positive, neutral or negative associations) and ascribes a weight to each indicator reflecting that particular indicator's relative contribution to explaining the performance difference between country–species pairs. A key feature of this approach is that indicators are grouped and weighted objectively by the data (through the PCA analysis) and not by *a priori* assumptions on the part of the investigator(s). As a result, GAPI outputs are objective, transparent and readily updatable. It is important to keep in mind that the PCA analysis results may also indicate that the indicators weight equally and, in this case, the indicator weightings are all ascribed equal weightings using an arithmetic mean.

Country Selection

Atlantic salmon comprise more than 90% of the quantity of all species of salmon that are farmed (FishStat Plus 2008). The global Atlantic salmon production for 2007 was calculated for each production country and countries were then ranked by production and aggregated until at least 95% of global production was accounted for. Norway, Chile, United Kingdom, and Canada (in descending order of production magnitude) collectively accounted for 96.8% of the global Atlantic salmon production in 2007 (FishStat Plus 2008). Time series data were collected for Norway, Chile, United Kingdom and Canada for the years 1995-2007. This temporal range was selected as it provided the opportunity to examine the salmon farming industry over a number of years with the most robust data set available.

Statistical Analysis

To determine if social and ecological performance varied dependently, or co-varied with economic performance, a correlation, linear regression analysis and an analysis of variance (ANOVA) were run, utilizing a null hypothesis that the value of production is correlated with social and ecological performance. The statistical analysis was conducted using the SPSS GradPack 17.0 software (SPSS 2008). Linear regression was used to determine the goodness of fit, which was reported as the R^2 value where 0 represented no correlation and 1 perfect correlation of a model. As well as the goodness of fit, the linear regression also gave the correlation between the three variables and whether they are positively or negatively correlated. The ANOVA was used to determine the significance F with a confidence interval of 95%. If significance F was >0.05, then the null hypothesis that the variables were correlated would be accepted.

Using the measures of social and ecological performance outlined in this chapter the GAPI methodology offers a robust analysis of social and ecological performance in the salmon farming industry. Once social and ecological performance have been determined they are tested with the value of production to determine if the social and ecological are reflected in the value of production . If the null hypothesis that there is not a correlation between value of production and social and ecological performance is rejected it would appear that the salmon farming industry is accounting for the social and ecological costs. On the other hand, if the null hypothesis is not rejected then it would appear that the salmon farming industry is not fully accounting for the social and ecological impacts and they are being externalized.

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Chapter 3. Results

Using the GAPI assessment for social and ecological performance, a performance score was calculated for Canada, Chile, Norway and the UK for 1995-2007 along with an economic measure of value of production (CAD$) per kilogram. Some variation in performance between countries was seen in the economic and ecological performance, while a greater performance range was observed within the social indicators. The overall value of production increased between 1995 and 2007, while ecological performance also improved. Over the same period, ecological performance ranged between scores of 21.7 to 56.7 out of 100. The mean social performance of 69.7 /100 for all of the countries was far higher than the ecological performance of 42.4 /100. The social performance showed a clear separation in performance of leaders and laggards. Canada, Norway and the UK all performed similarly, while Chile lagged behind with a score of lower than 50. Although clear trends in performance were visible, there was no correlation between social and ecological performance and cost of production. As the null hypothesis was not rejected it appears that the salmon farming market is not fully accounting for social and ecological costs of production and these costs are being externalized.

3.1 Economic Performance

The mean value of production ranged from a low of 3.08 CAD per kilogram in Norway and the UK (2003, 1996 respectively) to the highest during 1995 in Canada at 6.27 CAD per kilogram. Using a two-tailed T test assuming unequal variances, it was determined that the only significant differences in the mean cost of production were between Canada and Chile (as shown in tables 3 and 4).

Table 3. Mean value of production (CAD$) +/- 2SD and the maximum and minimum values for 1995-2007.

	Mean			Max	Min
Canada	5.21	+/-	1.79	6.27	3.70
Chile	5.62	+/-	1.78	7.74	4.97
Norway	3.85	+/-	1.15	4.98	3.08
UK	4.47	+/-	1.61	6.13	3.08

Table 4. Two-tailed T test of value of production (CAD$) for Canada, Chile, Norway and the UK for 1995-2007. T critical two-tail (p value).

	Canada	Chile	Norway	UK
Canada		2.06(0.25)	2.08(0)	2.06(0.04)
Chile			2.06(0)	2.06(0)
Norway				2.06(0.03)

The value of production appears to be volatile as seen in figure 4 where sharp increases and drops can be observed from year to year in the mean cost of production. No general trends were apparent in the mean value of production for all four countries increased from 1995-2007.

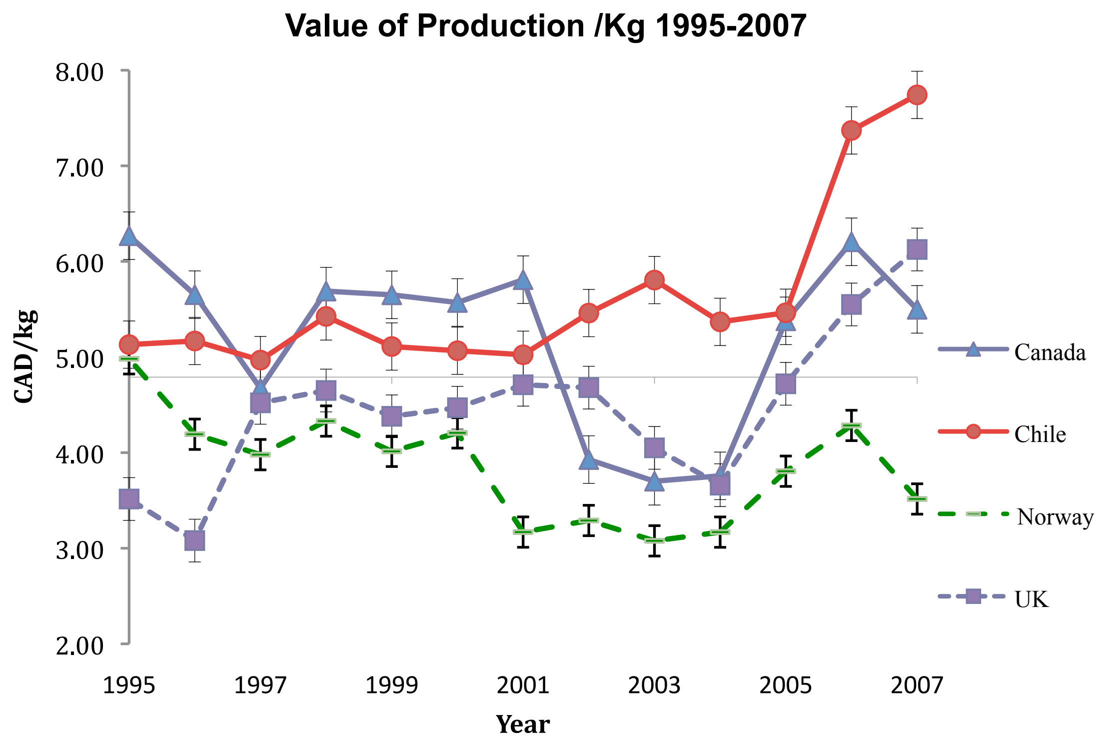

Figure 4. Mean value of production per kilogram (CAD$) from 1995-2007 for Canada, Chile, Norway and the UK. The x-axis crosses at 4.79 CAD, the mean for all countries from 1995-2007.

3.2 Social and Ecological Performance

Social performance was measured using five indicators: the Human Development Index (HDI) score, Gini index (Gini), Cost of Living less Poverty Line (POV), Workplace Deaths (Deaths) and Workplace Injuries (Injuries). Ecological performance was measured using nine indicators: Pathogens (PATH), Parasiticides (PARA), Antibiotics (ANTI), Biochemical Oxygen Demand (BOD), Escapes (ESC), Copper (COP), Sustainability of Feed Source (SFS), Ecological Energy (ECOE) and Industrial Energy (INDE). The score for each indicator was transformed to a scale of 0-100, with 100 representing the best possible performance (i.e. the value met the target set for that indicator). The performance in every indicator for each country is shown in Table 4.

Canada had the best performance for the death indicator as no salmon farming related deaths were reported between 1995-2007. Chile had the lowest performance across all social indicators including deaths. None of the four assessed countries performed well for the Gini indicator as they all had mean scores below 56/100.

For ecological indicators the four countries performed more similarly. The feed scores all showed great improvement from 1995-2007 with scores increasing from a low of 0 to the high of 93.06/100. Performance for the INDE indicator also increased over the time series, but in 2007 performance was still poor with an average of 20.18 (+/- 6.62).

Table 5. Social performance across all indicators 1995-2007

Year	Country	HDI	GINI	Death	Injury	POV
2007	Canada	76.77	43.27	100	67.92	96.68
	Chile	20.78	4.47	13.93	0	90.12
	Norway	80.94	55.11	81.55	32.52	100
	UK	67.84	37.36	99.41	88.43	100
2006	Canada	76.77	43.27	100	56.10	100
	Chile	20.78	4.47	13.93	64.83	67.31
	Norway	80.94	55.11	97.31	48.36	100
	UK	67.84	37.36	99.95	97.94	100
2005	Canada	76.77	43.27	100	56.10	100
	Chile	20.78	4.47	13.93	64.83	44.48
	Norway	80.94	55.11	97.31	74.94	100
	UK	67.84	37.36	99.95	97.94	0
2004	Canada	70.22	43.27	100	54.66	100
	Chile	16.02	4.47	13.93	70.28	43.31
	Norway	79.15	55.11	78.86	32.52	100
	UK	64.26	37.36	62.35	97.83	25.04
2003	Canada	69.62	43.27	100	61.44	100
	Chile	13.04	4.47	13.93	64.83	46.80
	Norway	77.96	55.11	78.86	16.14	100
	UK	63.67	37.36	84.94	97.73	96.19
2002	Canada	66.05	43.27	100	61.44	100
	Chile	4.10	4.47	13.93	54.62	47.50
	Norway	73.79	55.11	78.86	33.49	100
	UK	61.88	37.36	60.73	97.47	100
2001	Canada	62.48	43.27	100.00	61.44	100
	Chile	0	4.47	13.93	49.06	51.60
	Norway	66.65	55.11	78.86	37.34	100
	UK	58.31	37.36	57.50	97.70	100
2000	Canada	64.26	43.27	100	51.80	100
	Chile	0	0.64	13.93	41.11	39.11
	Norway	65.45	55.11	78.86	39.27	100
	UK	57.12	37.36	74.72	97.94	100
1999	Canada	61.88	43.27	100	51.80	100
	Chile	0	0.64	13.93	37.39	45.82
	Norway	63.67	55.11	78.86	48.36	100
	UK	54.14	37.36	75.79	97.84	100
1998	Canada	61.28	42.40	100	42.16	100
	Chile	0	1.51	13.93	26.21	0
	Norway	60.69	55.11	78.86	48.36	100
	UK	51.16	37.36	70.95	98.02	100
1997	Canada	59.50	45.19	100.00	48.91	100
	Chile	7.08	0	13.93	6.65	0
	Norway	56.52	55.11	78.86	48.36	100
	UK	51.16	35.97	63.96	97.85	100
1996	Canada	59.50	45.19	100.00	50.84	100
	Chile	7.08	0	13.93	1.36	0
	Norway	56.52	55.11	78.86	64.74	100
	UK	51.16	35.97	59.12	97.52	100
1995	Canada	76.18	45.19	100	46.98	100
	Chile	36.27	4.66	13.93	0.00	0
	Norway	66.05	55.11	78.86	48.36	100
	UK	58.90	35.97	58.04	98.47	100

Table 6. Ecological performance across all indicators 1995-2007.

Year	Country	ANTI	BOD	COP	ESC	FEED	ECOE	INDE	PARA	PATH
2007	Canada	86.15	33.84	28.29	51.54	93.06	51.54	25.53	62.51	89.50
	Chile	0	18.57	28.29	45.85	93.06	45.85	24.87	89.42	91.68
	Norway	99.88	51.62	28.29	17.26	93.06	17.26	18.08	95.20	87.01
	UK	98.32	55.21	65.00	10.37	93.06	10.37	11.25	56.54	96.65
2006	Canada	86.65	33.84	28.29	51.54	81.49	51.54	25.53	67.68	30.25
	Chile	0	18.57	28.29	45.85	81.49	45.85	24.87	89.42	94.60
	Norway	99.68	51.62	28.29	17.26	81.49	17.26	18.08	90.06	83.08
	UK	94.19	55.21	70.58	10.37	81.49	10.37	11.25	91.61	99.98
2005	Canada	75.95	33.84	28.29	51.54	77.17	51.54	25.53	59.84	89.58
	Chile	0	18.57	28.29	45.85	77.17	45.85	24.87	89.42	93.27
	Norway	99.71	51.62	28.29	17.26	77.17	17.26	18.08	87.75	83.30
	UK	98.17	55.21	75.81	10.37	77.17	10.37	11.25	94.53	97.87
2004	Canada	58.07	33.41	28.29	51.54	25.33	51.54	25.53	0.00	89.58
	Chile	0	18.04	28.29	45.85	25.33	45.85	24.87	89.42	94.69
	Norway	99.72	51.30	28.29	17.26	25.33	17.26	18.08	88.04	81.32
	UK	99.96	54.92	83.86	10.37	25.33	10.37	11.25	0.00	88.90
2003	Canada	55.92	32.98	28.29	51.54	22.67	51.54	25.53	41.29	60.49
	Chile	0	17.51	28.29	45.85	22.67	45.85	24.87	61.98	90.50
	Norway	99.78	50.98	28.29	17.26	22.67	17.26	18.08	87.08	69.94
	UK	99.36	54.63	71.10	10.37	22.67	10.37	11.25	88.65	94.67
2002	Canada	69.53	32.55	28.29	51.54	20	51.54	25.53	46.79	0.00
	Chile	0	16.98	28.29	45.85	20	45.85	24.87	92.49	90.50
	Norway	99.64	50.65	28.29	17.26	20	17.26	18.08	84.57	72.83
	UK	98.12	54.34	73.27	10.37	20	10.37	11.25	36.71	96.23
2001	Canada	79.22	32.12	28.29	51.54	17.33	51.54	25.53	23.91	68.52
	Chile	0	16.45	28.29	45.85	17.33	45.85	24.87	82.08	90.50
	Norway	99.80	50.33	28.29	17.26	17.33	17.26	18.08	80.48	83.19
	UK	98.12	54.05	73.27	10.37	17.33	10.37	11.25	36.71	97.00
2000	Canada	56.93	30.88	28.29	64.60	14.67	64.60	25.53	9.52	51.86
	Chile	0	14.93	28.29	60.88	14.67	60.88	24.87	89.42	90.50
	Norway	99.79	49.40	28.29	48.42	14.67	48.42	22.83	77.84	85.18
	UK	98.12	53.21	73.27	44.12	14.67	44.12	16.40	36.71	96.92
1999	Canada	66.88	24.45	28.29	41.94	12.00	41.94	19.81	24.09	57.01
	Chile	0	7.02	28.29	34.93	12.00	34.93	19.09	89.42	90.50
	Norway	99.81	38.63	28.29	0	12.00	0	6.18	88.22	85.46
	UK	98.12	48.86	73.27	0	12.00	0	6.18	36.71	0.00
1998	Canada	51.77	23.99	28.29	57.72	9.33	57.72	19.81	0.00	27.01
	Chile	0	6.44	28.29	53.08	9.33	53.08	19.09	89.42	90.50
	Norway	99.74	38.25	28.29	27.56	9.33	27.56	7.70	56.05	76.20
	UK	98.12	48.54	73.27	27.56	9.33	27.56	7.70	36.71	0.00
1997	Canada	35.02	23.52	28.29	57.72	6.67	57.72	19.81	0.00	64.92
	Chile	0	5.87	28.29	53.08	6.67	53.08	19.09	89.42	90.50
	Norway	99.69	37.88	28.29	23.28	6.67	23.28	4.42	37.15	59.10
	UK	98.12	48.23	73.27	23.28	6.67	23.28	4.42	36.71	87.50
1996	Canada	57.69	16.16	28.29	25.33	4	25.33	7.37	0.00	0.00
	Chile	0	0	28.29	43.98	4	43.98	13.32	89.42	90.50
	Norway	99.51	31.89	28.29	20.92	4	20.92	5.39	59.80	57.53
	UK	98.12	43.24	73.27	20.92	4	20.92	5.39	36.71	98.72
1995	Canada	42.58	15.66	28.29	38.28	0	38.28	4.89	12.60	87.96
	Chile	0	0	28.29	54.86	0	54.86	13.32	89.42	90.50
	Norway	98.32	31.49	28.29	26.72	0	26.72	0	85.45	72.81
	UK	98.12	42.91	73.27	26.72	0	26.72	0	36.71	91.27

3.4 Principal Component Analysis

A principal component analysis (PCA) was run separately for the social and ecological indicators to explain the variance in the scores. The initial PCA for the social scores yielded only one component with an eigenvalue of one or greater so it was necessary to rotate the data set using a varimax rotation with Kaiser normalization (Abdi 2003). Varimax rotation was selected as it offers a simplified interpretation of the data as each original variable is associated with one or only a few variables (Abdi 2003). As a result of the varimax rotation, the first three principal components had eigenvalues greater than one. Principal components with eigenvalues less than one were excluded under the Kaiser criterion (Norman & Streiner 2000). The relative weighting of the indicators within the components was then used to determine which indicators fell under which principal components.

Table 7. Initial and rotated weightings on principal components and eigenvalues for social performance.

	Eigenvalues				Rotated Eigenvalues		
Principal Components	Total	% of Variance	Cumulative %	**Principal Components**	Total	% of Variance	Cumulative %
1	3.49	69.69	69.69	1	3.33	47.05	47.05
2	0.9	17.96	87.65	2	1.95	27.62	74.67
3	0.45	9.035	96.69	3	1.47	20.83	95.5
4	0.11	2.184	98.87	4	0.21	2.94	98.44
5	0.06	1.13	100	5	0.11	1.56	100

Indicator	**Principal Compenents**		
	1	2	3
HDI	**0.949**	-0.095	-0.228
Gini	**0.953**	-0.17	-0.084
Injury	0.382	**0.924**	-0.02
Deaths	0.945	-0.065	**-0.184**
POV	0.799	-0.049	**0.599**

Table 8. PCA based weightings of components and indicators for ecological performance.

Component	**Component Weighting (%)**	**Indicator**	**Indicator Weighting (%)**
1	50	HDI	25
		Gini	25
2	28	POV	28
3	22	Death	11
		Injuries	11

Once the weightings for each indicator were determined they, cumulatively, formed the social score for each of the countries for 1995-2007. Performance scores were measured on a scale of 0-100, with 100 representing the best possible performance. The social performance scores for Canada, Norway and the UK were tightly grouped, while Chile consistently performed at a much lower level. Figure 2 shows the social score for each year with Canada, Norway and the UK closely clustered around the mean score for all years and countries.

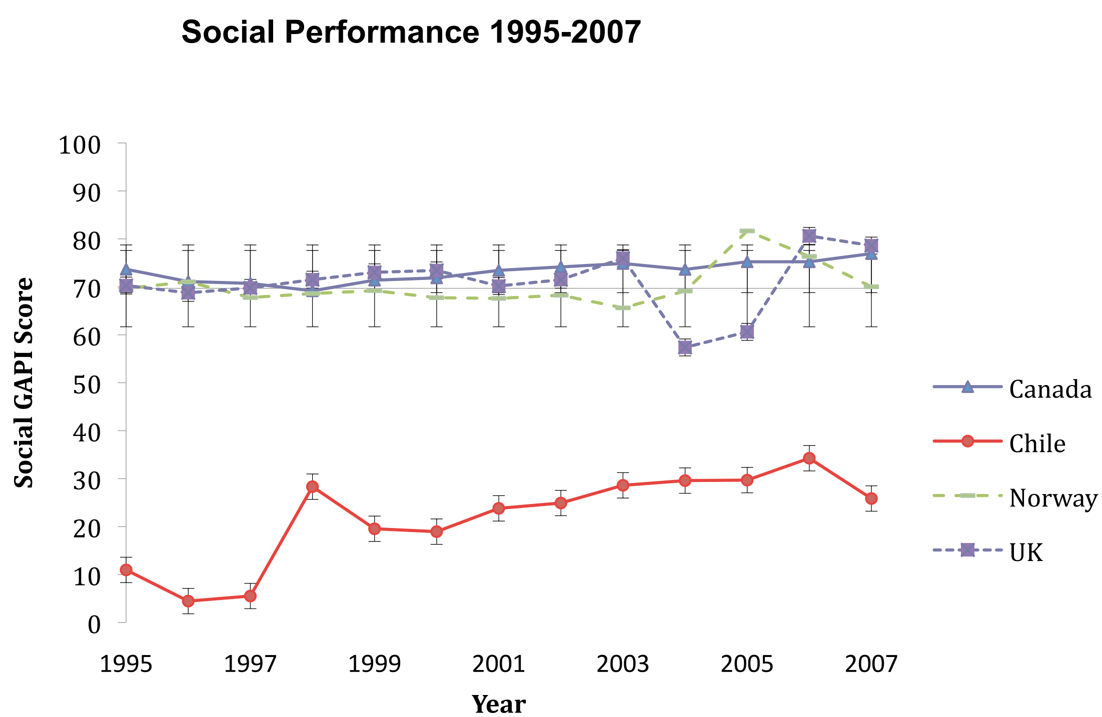

Figure 5. Social performance from 1995-2007 for Canada, Chile, Norway and the UK. The x-axis crosses at 69.7, which is the mean social performance for all of the countries and years.

Norway had the highest social score of 80.5 in 2005 while Chile had the lowest overall score of 3.6 in 1997 (Table 7). A two-tailed T test revealed the similarity in scores between Canada and Norway while Chile and the UK had mean social scores significantly different from the mean social scores of the other countries (Table 8).

Table 9. Social performance mean (+/- 2 SD) and the maximum and minimum values for 1995-2007.

	Mean	Max	Min
Canada	72.39 +/- 4.17	75.05	68.65
Chile	22.43 +/- 19.24	32.90	3.63
Norway	70.84 +/- 6.57	80.46	68.87
UK	68.19 +/- 15.31	75.72	50.39

Table 10. Two-tailed T test of mean of social performance for Canada, Chile, Norway and the UK for 1995-2007. T-critical two-tail (P value).

	Canada	Chile	Norway	UK
Canada		2.16 (0.000)	2.09(0.957)	2.15(0.035)
Chile			2.132(0.000)	2.07(0.000)
Norway				2.12(0.039)

Table 11. Weightings on principal components and eigenvalues for ecological performance.

	Eigenvalues		
Principal Compoenents	Total	% of Variance	Cumulative %
1	4.21	46.77	46.77
2	1.86	20.66	67.43
3	1.13	12.60	80.03
4	0.79	8.83	88.86
5	0.45	5.01	93.87
6	0.31	3.40	97.26
7	0.22	2.49	99.75
8	0.02	0.25	100.00
9	0.00	0.00	100.00

Indicator	Principal Compenents		
	1	2	3
ANTI	-0.849	-0.096	**0.358**
BOD	**-0.852**	0.143	0.405
COP	**-0.723**	-0.087	-0.072
ECOE	**0.923**	-0.179	0.164
ESC	**-0.031**	0.742	0.533
FEED	0.923	-0.179	**0.164**
INDE	**0.725**	0.318	0.486
PARA	0.108	**0.81**	-0.294
PATH	0.021	**0.671**	-0.421

Table 12. PCA based weightings of components and indicators for ecological performance.

Component	Component Weighting (%)	Indicator	Indicator Weighting (%)
1	58	BOD	11
		COP	11
		ECOE	11
		ESC	11
		INDE	11
2	26	PARA	13
		PATH	13
3	16	ANTI	8
		FEED	8

The principal component analysis that was run with the ecological scores had three principal components with eigenvalues greater than one. The indicators that weighed most heavily in those components were assigned weights based on the cumulative variance explained by each principal component.

The weighted ecological scores were combined to form the cumulative ecological score for each country and year. The cumulative ecological scores remained on a scale of 0-100, with 100 representing the best performance possible (i.e. the values met their target for all of the indicators). The ecological performance for all of the countries was similar and showed a gradual improvement, as shown in Figure 3. Norway had the highest mean score across all years, while Chile had the lowest mean performance. A two-tailed T tests in Table 9 suggest that Chile- Norway and Chile-UK are the only two pairs with significant differences between their mean ecological performances. Norway and the UK are the best performers with Canada close to both of their scores and Chile lagging behind in performance. The greatest separation in performance was observed from 1995-1997, but overall, all countries have improved. Chile's improvement has been by the greatest margin and by 2007 all four countries ecological performance was closely grouped.

Table 13. Ecological performance mean (+/- 2 SD) and the maximum and minimum values for 1995-2007

Country	Mean			Max	Min
Canada	42.04	+/-	19.23	56.62	21.68
Chile	35.19	+/-	7.90	41.84	29.57
Norway	44.89	+/-	11.51	54.18	37.37
UK	44.26	+/-	12.46	53.90	31.76

Table 14. Two tailed T test of mean of ecological performance for Canada, Chile, Norway and the UK for 1995-2007. T critical two tail (P value).

	Canada	Chile	Norway	UK
Canada		2.12(0.091)	2.09(0.120)	2.08(0.153)
Chile			2.08(0.000)	2.09(0.000)
Norway				2.06(0.805)

Performance rankings differ for social and ecological indicator across the time series and between the four countries as shown in Table 14. For example, in 2007, Canada had the highest ecological performance at 57, while the UK's social performance of 78 was the best social score. Other than Chile, which has shown improvement in social performance, the social performance was static for the countries. Ecological performance showed a slow and steady improvement while value of production increased and decreased several times over the time series. Figure six shows snap shots of indicator performance for each of the countries for every two years from 1995-2007. The most noticeable improvement for all of the countries was performance in the FEED category, while ECOE performance declined from 1995-2007. Performance for ESC, COP and INDE was consistently poor throughout the time series. The general consistency of performance between countries is also seen for the social indicators with the exception of Chile's performance. Until the most recent years that were assessed Chile performed very poorly for all social performance indicators.

Table 15. Cost of production (CAD$) per kilogram, Social and Ecological Performance for Canada, Chile, Norway and the UK 1995-2007

Year	Country	Cost/Kg	Social	Ecological
2007	Canada	5.846	76.929	57.996
	Chile	8.923	25.863	48.622
	Norway	4.470	70.024	56.408
	UK	4.928	78.607	55.196
2006	Canada	3.330	75.228	50.757
	Chile	2.727	34.265	47.662
	Norway	2.156	76.344	54.093
	UK	3.724	80.616	58.340
2005	Canada	4.990	75.228	54.809
	Chile	3.923	29.701	47.033
	Norway	2.372	81.659	53.382
	UK	3.724	60.616	58.971
2004	Canada	4.195	73.630	40.365
	Chile	3.569	29.602	41.372
	Norway	2.385	69.129	47.399
	UK	2.899	57.368	42.774
2003	Canada	3.279	74.868	41.139
	Chile	4.193	28.616	37.502
	Norway	2.407	65.613	45.703
	UK	3.345	75.976	51.451
2002	Canada	2.101	74.153	36.196
	Chile	3.596	24.925	40.537
	Norway	2.944	68.250	45.396
	UK	3.502	71.488	45.628
2001	Canada	1.980	73.439	42.001
	Chile	2.688	23.814	39.026
	Norway	1.944	67.591	45.779
	UK	2.882	70.174	45.386
2000	Canada	2.259	71.868	38.542
	Chile	1.751	18.960	42.714
	Norway	2.013	67.739	52.760
	UK	2.688	73.426	53.060
1999	Canada	2.069	71.392	35.156
	Chile	2.097	19.558	35.131
	Norway	2.174	69.199	39.843
	UK	3.150	73.025	30.571
1998	Canada	2.282	69.171	30.626
	Chile	2.471	28.332	38.805
	Norway	2.417	68.604	41.188
	UK	3.150	71.498	36.534
1997	Canada	5.809	70.720	32.630
	Chile	2.160	5.533	38.445
	Norway	2.765	67.770	35.529
	UK	2.834	69.787	44.611
1996	Canada	5.943	71.105	18.239
	Chile	3.062	4.475	34.831
	Norway	2.965	71.045	36.473
	UK	1.952	68.754	44.588
1995	Canada	2.894	73.669	29.836
	Chile	3.062	10.973	36.804
	Norway	3.162	69.676	41.090
	UK	2.203	70.277	43.969

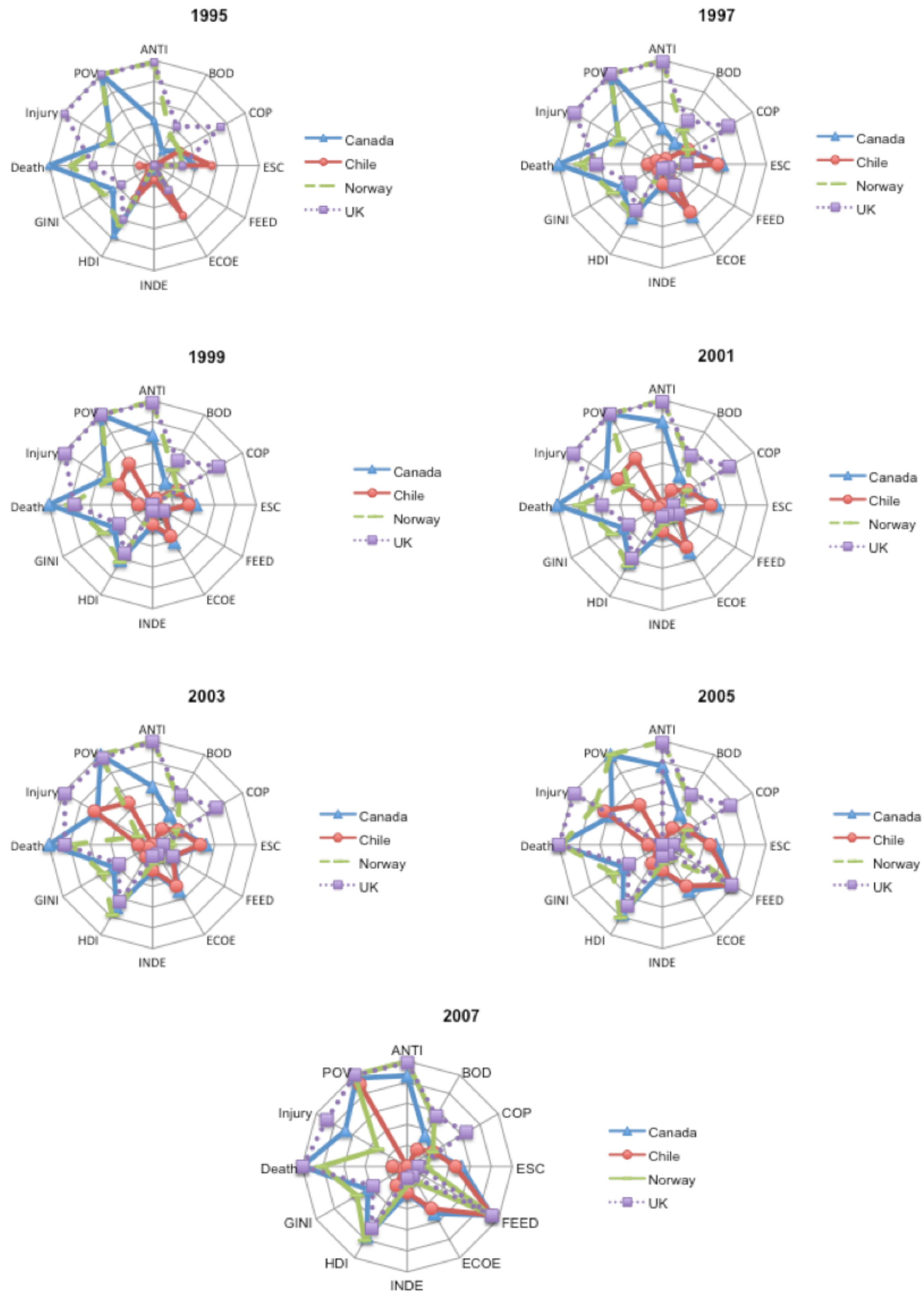

Figure 6. Ecological performance from 1995-2007 for Canada, Chile, Norway and the UK. The mean ecological performance for all countries 1995-2007 was 42.4.

Table 16. Comparison of economic, social and ecological performance between Canada, Chile, Norway and the UK in years with similar GAPI scores.

Country	Year	GAPI Score	Cost of Production (CAD /Kg)	Social Performance	Ecological Performance
Canada	2006	63.08	3.33	74.47	50.75
Chile	2007	37	8.92	30.9	41.84
Norway	1998	62.11	2.42	69.93	42.36
UK	1996	63.13	1.95	74.52	51.07

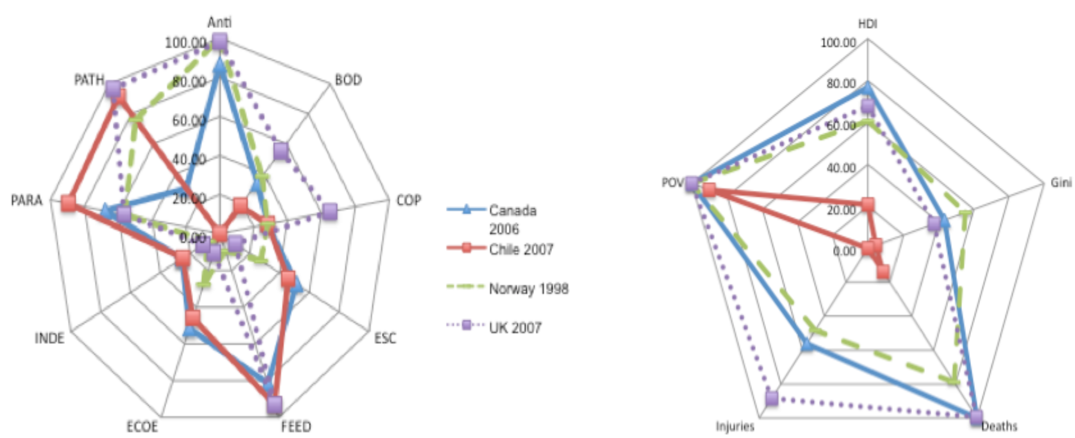

Figure 7. Comparison of performance by social and ecological indicators for Canada, Chile, Norway and the UK in years with similar GAPI scores.

The indicator scores for each of the countries when they had similar country scores was examined in Table 16 and Figure 8. Canada, Norway and the UK all scored approximately 63 /100, although in different years. Chile's best score overall was 37 /100 and to highlight how variable performance within indicators can be for similar scores each country was examined. Canada and Chile had similar performance scores for ecological indicators, despite a very different overall performance. Norway and the UK tracked each other's performance most closely, but differences in performance in indicators such as copper and pathogens allow a deeper insight into the different performance between countries that would benefit from improvement. For social indicators Chile's performance was noticeably worse than the other three countries that, with the exception of the UK's very good score for the injuries indicator, were all very close.

3.5 Statistical Analysis

To examine the relationship between economic, social and ecological performance a linear regression analysis was conducted followed by an analysis of variance (ANOVA), utilizing a null hypothesis that the three factors were not correlated with a confidence interval of 95%. Linear regression was used to determine the goodness of fit, which was reported as the R^2 value. An R^2 value of one would indicate a perfect fit for the data.

Table 17. Regression and ANOVA results for the economic, social and ecological performance.

	Sum of Squares	df	Mean Square	F	Sig.
Regression	0.326	2	0.163	0.091	0.913
Residual	87.471	49	1.785		
Total	87.797	51			

R	0.061
R Square	0.004
Adjusted R Square	-0.037
Std. Error of the Estimate	1.336

Table 18. Correlation matrix for cost of production (CAD$) per kilogram, social and ecological performance. Pearson correlation (sig. two-tailed), N = 52. **Correlation is significant at the 0.001 level (two-tailed).

	Correlations		
	cost	psocial	pecol
cost	1	-0.017 (0.908)	0.043 (0.764)
social		1	.499** (0.000)
ecological			1

The R^2 value was low therefore the goodness of fit was low, which means the regression line added little predictive power to the model. The p value for the F test was greater than 0.05, so the null hypothesis that there was not a correlation between the value of production, social and ecological performance was not rejected. The ANOVA and regression results shown in Table 17 show that the value of production did not track either good nor poor social and ecological performance and therefore did not reject the null hypothesis that the value of production was not correlated with social and ecological performance. A test for correlation was also run to determine if a relationship could be detected amongst economic, social and ecological performance. Table 18 shows the only significant positive correlation found was between social and ecological performance. The null hypothesis was not rejected and this could mean that social and ecological costs of production are not being fully accounted for by the market so they are being externalized by the salmon farming industry.

Chapter 4. Discussion

Neoliberal economists argue that the market provides the most efficient mechanism to address externalities. Theoretically then, the market value of a commodity should show a correlation with any changes in social and ecological performance. Alternatively, if the social and ecological costs of production are being externalized (not addressed by the market) then it is expected that the social and ecological costs of production would not be reflected in the market price. This study examined the extent to which social and environmental costs are externalized by the salmon farming industry and, by extension, to what level social and ecological impacts are reflected in the market, if at all. The salmon farming industry represents a classic example of how a relatively new industry functions within the confines of the current economic climate and was assessed to examine whether social and ecological impacts are reflected in the market. A tool called the Global Aquaculture Performance Index (GAPI) has been developed that addresses both the need for a quantitative measure of social and ecological performance and a tool that informs where policy is best directed to alleviate the impact of externalities. In applying the GAPI method, the market price for farmed salmon was not found to correlate with changes in social and ecological performance. The stable patterns of the data limited my ability to make any inferences of cause and effect between social and ecological performance and production values. What was established in my thesis was that both social and ecological performance can be quantitatively measured. Further, the social and ecological performances are very poor and the GAPI methodology allows performance by indicator to be tracked. The indicators of social and ecological performance are clear starting points to improve salmon farming through a policy based context

Social performance in Chile was variable, but very poor with a mean score of 22.43 (+/- 19.24) out of 100. This falls in line with the frequently cited reason for the salmon farming industry's move to Chile that labour standards are significantly lower than those in the other major producing countries. Overall, the social performance trend showed improvement, however Chile remained a clear laggard falling well below the mean performance for the other countries, which was around 69.7 (+/-22.5) out of 100. Two of the indicators measured performance at a national rather than industry level yet these results did follow the trend of poor social performance in the salmon farming industry shown in the literature (Marshall 2001; Moreno 2005; Barton 1997; Phyne & Mansilla 2003). Chile's low cost of labour and less stringent ecological regulations are often cited as the main factors cultivating economic success for the salmon farming industry in Chile (Marshall 2001; Moreno 2005; Barton 1997; Phyne & Mansilla 2003). It can be argued that this is because the negative social impacts on the workers and communities from the salmon farming industry are externalities and are not valued or fully accounted for through traditional market mechanisms.

Ecological performance followed a trend of improved performance yet still fell well below social performance with a mean of 42.4 (+/- 8.4) out of 100. There was some differentiation in performance between countries but with the GAPI method of independent scoring, such poor performance all around suggests little basis for one country's performance being described as the best, or even better than the others. One of the defining features of GAPI is that it generates scores for each country based on their performance relative to the target values. By overlooking the score and just considering the ranking of each country relative to the other there is a risk of missing the informative value of each country's actual score. Rearing species in high densities, especially in a monoculture, necessitate that the fish must be fed. As salmon are carnivorous their feed contains other fish species and this leads to a high demand being placed on ecological and industrial energy to capture and reduce the food fish into feed pellets. All of the feed, antibiotics, parasiticides and any other inputs freely enter the surrounding environment so the burden of a large number of inputs being drawn from around the world are concentrated as outputs from farm sites. At both the input and output stage of the production cycle the ecological costs are externalized.

The farmgate value of farmed Atlantic salmon was used as a proxy for cost of production. As a first cut, farmgate value makes for a reasonable proxy, but with better data resolution and availability I expect that cost of production would offer a more clear and stable signal.. Market values of farmed salmon were volatile over the period of 1995-2007. The commodity of farmed salmon is sold on markets around the world for a price set, at the most basic level, through the interactions of supply and demand (Xie et al 2009). The cost of an item does not represent its value rather is only what people are willing to pay for it, not what has been invested and used to create the product (Patel 2010). From 2005-2007 Chile's price per kg increased sharply, but this change is simply a sample of the fluctuations in market value for all countries. During that time there was virtually no change in the country's ecological or social indicator performance, therefore a higher price per kilogram does not automatically translate to the costs of ecological and social impacts being internalized by the industry. Since 2007, the salmon farming industry in Chile has had high production losses due to the spread of Infectious Salmon Anemia disease (Mardones et al. 2009). The spread of disease through the industry not only increases production costs with an increased demand for medications to treat or prevent infection, but large numbers of the farmed fish also die or are culled. The decreased number of fish going to market means that the cost of production per kilogram is much higher when compared to years with lower mortality rates. A more clear and stable value would offer greater opportunities to track both changes in costs of production over time as well as any covariation between social, ecological and economic values in the industry

Norway has stringent regulations surrounding social and ecological aspects of salmon farming which include strict data reporting guidelines. It is possible that a difference in reporting between Norway and the other countries resulted in the scores of the other countries being higher than they would be with full data. Future studies of performance would benefit from simultaneously examining both the regulations, enforcement and reporting requirements of the host countries.

Although no signal could be found in the data, there is a clear and logical case to be made that the salmon farming industry is externalizing these costs but further studies that probe the data more closely are needed to make a quantitative case for externalization of these costs. What was established in my thesis is that both social and ecological performance can be quantitatively measured. Further, the social and ecological performances are very poor and the GAPI methodology allows performance by indicator to be tracked. The salmon farming market appears to be externalizing social and ecological impacts of the production system, which suggests a failure of the market. The invisible hand of the market does not appear to be fully accounting for these impacts that are widely accepted as having a cost for society and the environment, despite not being assigned a value by the market. Externalities suggest a gap in accounting by market-based valuation leading to market failures and the consequent sustainability problems. The need to correct for these market oversights suggest the need for some form of policy-based intervention to preserve the social and ecological capital that both industry and society depend on in the long term. GAPI provides not only a tool to examine the social and ecological costs but also a mechanism that can help inform policy as it outlines performance by indicator and a directed approach can be utilized where most effective.

Five indicators of ecological performance (Biochemical Oxygen Demand, Copper, Escapes, Ecological Energy and Industrial Energy) had consistently poor performance across all four countries. Comparing these results with the indicator performance every two years presented in Figure 5 (Chapter 3) further highlights how poor performance across those five indicators was a consistent driver of lower ecological scores for all four countries. Policy tools directed to improve the performance for the output indicators, including escapes, from farm sites could be combined with directives to reduce ecological and industrial energy inputs into farm sites. For example, a policy tool directed to regulate the sustainability and type of feed ingredients would result in an improvement across three performance indicators- Feed, Ecological Energy and Industrial Energy. The Pathogens, Parasiticides and Antibiotics indicator performance has been fairly static within countries, though performance has consistently differed significantly between countries. The difference between countries for these indicators is most likely due to a combination of different regulations and different reporting between the countries. The social performance indicators, Human Development Index (HDI) and Gini Index, had consistently poor to moderate performance in Canada, Norway and the UK. Chile's only indicator with a good performance score was the Poverty indicator (the difference between worker's salary and the poverty line). The HDI and Gini indicators both measure performance at a national level, rather than an industry level, so policy directed at improving these indicators would also set a benchmark for improving social conditions for the entire nation. By addressing the specific areas where externalities arise there are opportunities to not only mitigate negative social and ecological impacts but to offer insights into where the industry has the opportunity to create new growth opportunities in a positive and sustainable manner (Cohen & Winn 2007).

The GAPI methodology demonstrates that both social and ecological performance of the salmon farming industry can be tracked and measured through quantitative assessments that measure performance. Clearly, the indicators of social and ecological performance would be ideal starting points for the improvement of salmon farming through a policy based context. The ability to probe which indicators are driving the countries' performance provides clear insights into current performance while tracking changes in the industry as well. As the salmon farming industry continues to expand it is essential that the sustainability of the communities and ecosystems impacted by salmon farming be guaranteed. The gradual improvement of social and ecological performance can be shaped and directed through indicator assessment to ensure that the maximum benefit for society as a whole is derived from the continued development of salmon farming.

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Appendix A
Surveyed Aquaculture Initiatives

In order to give initial direction to the development of ecological indicators for GAPI a scoping exercise of current initiatives was undertaken to assess indicators already in use. Initiatives (and indicators) that focus on seafood sustainability, more precisely aquaculture, were analyzed in terms of data quality, relevance, performance orientation and transparency. All initiatives surveyed adopted a set of indicators, such as habitat impact, biological or ecological effects among others. The level of resolution to which each initiative measured the performance of a given production system was assessed, specifically with regard to the quality and scope of an indicator, its relevance to sustainability, and most importantly if the indicator is expressed quantitatively. Only seven of 26 assessed initiatives were found to meet or exceed these modest expectations and were further assessed.

Criteria for inclusion/exclusion of initiatives

Initiatives were excluded if they lacked clear indicators, lacked targets or thresholds for these indicators, or were based on vague / qualitative standards. Also, those initiatives focused on a narrow subset of criteria, such as meeting an organic standard, rather than broader sustainability criteria were excluded.

Included Initiatives

- Blue Oceans Institute/ Guide to Ocean Friendly Seafood
- Global Aquaculture Alliance
- Greenpeace/ Red Grade Criteria for Aquaculture
- Monterey Bay Aquarium/ Seafood Watch Program
- Marine Conservation Society
- Whole Foods
- WWF Benchmarking Study

Excluded Initiatives

ABCC- Shrimp Quality Guarantee Brazil
- AB France
- Audobon Seafood Lover's Guide
- BioAustria - Austria
- Bio-Suisse
- CoC Certified Thai- Code of Conduct Certified Thai Shrimp Thailand
- Debio Norway- Norway
- Irish Quality Salmon and Trout- Ireland
- Krav- Sweden
- Label Rouge- France
- La Truite Charte Qualité- France
- Marine Stewardship Council
- Naturland
- Norway Royal Salmon- Norway
- Norge Seafood- Norway
- Scottish Code of Good Practices
- Sea Choice (Living Oceans, CPAWS, Sierra Club of BC & David Suzuki Foundation)
- Qualité Aquaculture de France- France
- Soil Association UK - United Kingdom
- SSOQ- Shrimp Seal of Quality Bangladesh
- Woods Hole/ Marine Aquaculture Task Force
- Tartan Quality Mark
- Thai Quality-ThailanOverviews of Selected Current Initiatives

Blue Ocean Institute: Guide to Ocean Friendly Seafood/Seafood MiniGuide

http://www.blueocean.org

Backgrounder:

The Blue Ocean Institute was founded in 2003 by Dr. Carl Safina and Mercèdés Lee to inspire a “closer relationship with the sea and devise practical solutions to conservation problems” through science, literature and art.

Scope of initiative:

Fish and shellfish harvested through farming or capture fisheries.

Target audience:

Consumers.

Developmental Stage of Initiative:

The initiative has established itself as a source of sustainable seafood information. No information is available on the frequency of updates, but the guide is in a mature state.

Co-operation/Collaboration:

Marine Stewardship Council, American Albacore Fishing Association, The American Sport Fishing Association, Chef’s Collaborative, Green Restaurant Association.

Indicators:

1. Cause phytoplankton blooms; 2. Collection of larvae/seed from wild; 3. Stocking density of not more than $25 kg/m^3$; 4. Water Quality; 5. % of fish meal/fish oil in diet; 6. FCR <1.3 7.Risk to other species.

Global Aquaculture Alliance: Responsable Aquaculture Program

http://www.gaalliance.org

Backgrounder:

The Global Aquaculture Association (GAA) is a trade organization that was formed in 1997 to operate as a non-profit society that representing members of the aquaculture community and promoting the development of aquaculture as sustainable.. The GAA has established operating guidelines titled "Best Aquaculture Practices" that act as the basis for its Responsible Aquaculture Program.

Scope of initiative:

General guidelines for aquaculture operations with specific best practice criteria for tilapia, channel catfish and shrimp farms.

Target audience:

Aquaculture operations, product retailers, suppliers, and consumers.

Developmental Stage of Initiative:

The Responsible Aquaculture Program was first developed approximately four years ago and has since been expanded to include a discreet section on shrimp aquaculture entitled "Codes of Practice for Responsible Shrimp Farming". A discussion of the codes set forth in both the general aquaculture section and the shrimp aquaculture section led to the establishment of the Best Aquaculture Practices standards. Currently specific guides for several fish species (including channel grouper and tilapia) are available to complement the shrimp section.

Co-operation/Collaboration:

The board of directors is made up of representatives from the following corporations and organizations: Salmon of the Americas; Eastern Fish Co., Inc.; Preferred Freezer Services; Darden Restaurants; Rich-SeaPak Corp.; Red Chamber Group; Fats and Proteins Research Foundation, Inc.; Cargill Animal Nutrition; Promarisco S.A.; Lyons Seafoods Ltd.; C.P. Indonesia.

Indicators:

1 Community Standards; 2. Food Safety Standards; 3. Tracebility; 4. Wetland Conservation and Biodiversity Protection; 5. Effluent Management with target values for : *ph; total suspended solids; soluble phosphorus; total ammonia nitrogen; oxygen demand; dissolved oxygen; chloride (mg/L - M); salinity; temperature; chlorophyll a; secchi disk visibility; total ammonia nitrogen;* 6. Fishmeal and Fish Oil Conservation; 7. Soil and Water Conservation; 8. Control of Escapes, Use of GMOs; 9. Storage and Disposal of Farm Supplies; 10. Animal Welfare.

Greenpeace: Challenging the Aquaculture Industry on Sustainability/Red Criteria for Unsustainable Seafood

http://www.greenpeace.org

Backgrounder:

Greenpeace is an environmental organization started in 1971 to protest nuclear testing who now have offices in 40 countries and operate as a non-governmental organization. Currently, Greenpeace lists six areas of campaign focus. The aquaculture initiative, "Challenging the Aquaculture Industry on Sustainability", falls under the 'Defending our Oceans' banner.

Scope of initiative:

Finfish aquaculture with a focus on salmon, shrimp, tilapia, and tuna ranching. Brief mention of benefits of seaweed cultivation.

Target audience:

Retailers and seafood processors developing sustainable seafood purchasing policies and consumers

Developmental Stage of Initiative:

The "Challenging the Aquaculture Industry on Sustainability" report was published with recommendations for action June 2008. Greenpeace is a relative new comer to the world of aquaculture policy and this initiative represents their first foray into establishing criteria/indicators.

Co-operation/Collaboration:

Indicators:

1. Sourcing eggs or juveniles from the wild; 2. Introducing alien species; 3. Transferring disease to the wild; 4. Locating aquaculture facilities in sensitive areas; 5. Using wild fish to feed farmed fish; 6. Contributing to human rights abuse; 7. Other general impacts on biodiversity; 8. Unsustainable components used in feed.

Marine Conservation Society: Fish Farming Policy Statement

http://www.mcsuk.org

Backgrounder:

The Marine Conservation Society (MSC) is a United Kingdom based environmental charity that was established in 1983. Their mandates focuses on issues affecting the marine environment. MSC seeks to further the use of environmentally sustainable practices in the finfish sector of aquaculture.

Scope of initiative:

Finfish aquaculture in the United Kingdom, with a particular focus on Scottish sea farm operations. Minimum standards are set from the Industry Code of Good Practice for Scottish Finfish Aquaculture while the top performance goals are called Gold Standards.

Target audience:

Farmed fish producers "wishing to further demonstrate their commitment to responsible fish farming" (Edition One: MCS Principles and Criteria for Sustainable Fish Farming). The secondary intent of the policy statement is to increase consumer awareness of the environmental concerns that surround the farming of fish species.

Developmental Stage of Initiative:

The Marine Conservation Society's "Fish Farming Policy Statement" was first published in May, 2007 with the intention to biennially review and update the criteria to reflecting the changing state of knowledge and industry standards.

Co-operation/Collaboration:

Indicators:

1. Environmental Assessment of Site; 2. Fish for feed from sustainable source; 3. Feed technology that reduce over feeding; 4. Minimal use of synthetic pesticides and chemotheraputants; 5. Cycle through fallow periods for each site; 6. Low stocking density to reduce disease magnification; 7. Use animal welfare standards for care levels of fish; 8. Cage and net design to prevent escapes; 9. Use non-lethal predator control; 10. Use environmental management system to monitor and minimize environmental impacts.

Monterey Bay Aquarium: Seafood Watch Program Pocket Guide

http://www.montereybayaquarium.org/cr/seafoodwatch.aspx

Backgrounder:

The Seafood Watch program was created through the Monterey Bay Aquarium's Fishing for Solutions exhibit that began in 1997 and ran until 1999. The Monterey Bay Aquarium opened in 1984 under the directive to raise awareness of the need for conservation in the world's oceans.

Scope of initiative:

The pocket guide, which is available in regional versions, and more in-depth online species analysis cover capture fisheries as well as aquaculture production of aquatic species (except algalculture).

Target audience:

Consumers. The product was developed to be carried in the wallet and used as a quick reference guide while at the supermarket or restaurant.

Developmental Stage of Initiative:

The aquarium developed their first list of sustainable seafood choices in 1997 which eventually led to the creation of the pocket guide. The pocket guides are updated twice a year, while changes are made online on an as required basis.

Co-operation/Collaboration:

The Seafood Watch Program is part of the Seafood Choices Alliance whose partner members include: Blue Ocean Institute, Canadian Parks and Wilderness Society, David Suzuki Foundation, Ecology Action Centre, Environmental Defense Fund, FishChoice, FishWise, Living Oceans Society, Natural Resources Defense Council, New England Aquarium, Ocean Conservancy, Sierra Club of British Columbia, World Wildlife Fund – US.

Indicators:

1. Risk of pollution and habitat impacts; 2. Use of marine resources; 3. Chemical inputs; 4. Risk of disease and parasite transfer to wild stocks; 5. Risk of escaped fish to wild stocks; 6. Feed composition; 7. Source of fish oil and fish meal; 8. Larvae and seed provenance; 9. Depletion of freshwater; 10. Effectiveness of management regime.

Whole Foods: Seafood Quality Standards

http://www.wholefoodsmarket.com/issues/seafoodsustainability/index.ht ml

Backgrounder:

Whole Foods is a natural and organic food retailer founded in 1980 in the United States and now has locations throughout North America and the United Kingdom.

Scope of initiative:

The "Whole Foods: Seafood Quality Standards" initiative addresses all seafood sold in the chain's 270 locations. Only MSC certified wild caught seafood is sold. Farmed salmon and shrimp standards are addressed specifically. Standards for other finfish species are addressed generally, with a brief mention made of standards for rainbow trout, tilapia, arctic char, and catfish.

Target audience:

Seafood suppliers, consumers and retailers.

Developmental Stage of Initiative:

Whole Foods Seafood Quality Standards, published on July 1, 2008.

Co-operation/Collaboration:

Marine Stewardship Council

Indicators:

1. No use or inclusion in feed of: antibiotics; growth hormones; methyl testosterone; in-feed veterinary medicines; limited parasitic bath treatments; synthetic pigments in feed; 2. Maximum stocking density 20kg/m^3; 3. Progress towards fish in: fish out ratio of 1:1; 4. Progress towards maximum levels of PCB's, WHO-TEQ's 5. Reporting of total N and P inputs and loads; 6. Redox potential levels > -100 mV nhe, or sulfide levels below 1300 micromoles;. 7. Detail protocols for preventing escapes and progress towards accounting for 100% of stock; 8. No acoustic harassment devices permitted.

WWF Benchmarking Study: Certification Programmes for Aquaculture

http://assets.panda.org/downloads/benchmarking_study_wwf_aquaculture_standa rds_new_.pdf

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Backgrounder:

The World Wildlife Foundation (WWF) was founded in 1961 and is now one of the world's largest environmental organizations. WWF's mission statement: To stop the degradation of the planet's natural environment and to build a future in which humans live in harmony with nature.

Scope of initiative:

Marine and freshwater aquaculture finfish, mollusks and crustaceans with a focus on shrimp, salmon, catfish, tilapia, trout, and molluscs.

Target audience:

Consumers.

Developmental Stage of Initiative:

WWF began working on aquaculture related studies in 1994 and since 1998 has focused research into all aspects of aquaculture.

Co-operation/Collaboration:

Seafood Choices Alliance for the production of sustainable seafood guides for consumers in Europe.

Indicators:

1. Habitat Sensitivity & Habitat Conversion; 2. Deforestation (ha); 3. Discharge of Effluents (N + P); 4. Use, Handling & Discharge of Chemicals and Hazardous Goods; 5. Spread of Pathogens and Parasites into the Wild; 6. Escape of Cultured Species into the Wild; 7. Introduction of New Species; 8. Escape of Cultured Species into the Wild; 9. GMO's as Cultivated Species; 10. Efficiency of Feed Conversion; 11. Source of Fish Oil & Fish Meal; 12. Source of Other Feed Ingredients; 13. GMO in Feed from Agricultural Crops; 14. Broodstock and Seedlings; 15. Depletion of Freshwater; 16. Deterioration of Freshwater by Salinization; 17. Disturbance of Hydrology; 18. Land Use; 19. disturbance & Deterioration of Soil; 20. General Impacts on Local Wildlife; 21. Energy Efficiency (kWh/tonne): Source of Energy :Air-Freight for Shipment.

Appendix B

Indicators of the Surveyed Aquaculture Initiatives

Grey shading in cell indicates analagous indicator used by initiative ■ Indicator was used by initiative in that column.	Greenpeace Red Grade Criteria for Aquaculture	Global Aquaculture Alliance	Marine Conservation Society	Whole foods	Blue Ocean Institute Guide to Ocean Friendly Seafood	WWF Benchmarking	Monterey Bay Aquarium Seafood Watch Program
FCE: Fish Oil/Meal							
Feed composition (fishmeal/oil % in diet; FCR <1.3 (target))	■	■	■		■		■
Feed						■	
Efficiency of Feed Conversion						■	
Fish in:Fish Out = 1:1				■			
Does the main production system use feed that requires more than 3 kg of wild fish, caught specifically to make fish meal and oil per 1 kg of aquacultured fish produced?	■		■				
Annual reporting on progress toward meeting Maximum Fish In, Fish Out ratio of 1:1				■			
Sustainability of Feed Source Fish							
Source of Fish Oil & Fish Meal			■			■	■
Use of sustainable feed sources			■				
Does this farm's main production system use feed known to contain any components sourced from fisheries that are ranked red in our wild-capture	■		■				

assessment?							
Source of Other Feed Ingredients	■			■		■	
GMO in Feed from Agricultural Crops	■			■		■	
Does this farm's main production system use any plant components in the fish feed that are sourced from genetically modified crops, and/or crops associated forest destruction?	■		■	■			
No antibiotics, parasiticides, hormones, or avian or mammalian by-products permitted in feed.	■		■	■			
Disease/ Parasites							
Disease/parasites						■	
Spread of Pathogens and Parasites into the Wild	■			■		■	
Risk of disease and parasite transfer to wild stocks		■	■	■			■
Main production system linked to increased levels of disease in wild species in vicinity of farms	■						
Energy Use							
Energy Efficiency (kWh/tonne)						■	
Source of Energy						■	
CO_2 Footprint							
CO_2 Footprint						■	
Air-Freight for Shipment						■	
Escapes: Genetics and Competition							
Escapes						■	
Preventing escapes - "as close to zero as possible"				■		■	

Risk of escaped fish to wild stocks			■				■
Risk of escaped fish to wild stocks	■						
Native or Introduced				■			
Introduction of New Species						■	
Escape of Cultured Species into the Wild						■	
High number of escapes of non-native or domestic breeds likely to have negative impact on wild species	■						
GMO's as Cultivated Species (none permitted)				■		■	
Main production system produces genetically engineered organisms	■						
Benthic Impacts: Water Quality and Community Impacts							
Nutrient Loading and Carrying Capacity						■	
Water Quality					■		
Minimising effects of marine pollutants			■				
Discharge of Effluents (N + P)						■	
Redox potential levels > -100 mV nhe, or sulfide levels below 1300 micromoles				■			
Chemical inputs							■
Use, Handling & Discharge of Chemicals and Hazardous Goods						■	
No antibiotics permitted				■			
No growth hormones or methyl testosterone permitted				■			

No in-feed veterinary medicines, including parasitic treatments such as emamectin benzoate, permitted				■			
No organophosphates permitted				■		■	
No malachite green, crystal violet, or Tributyltin compounds permitted.				■		■	
No parasiticide treatments allowed				■			
Only non-synthetic pigment sources included in feed				■			
Judicious therapetic agent		■					
Max level: PCBs 0.011 ppm				■			
Max level: WHO-TEQs: 2.16 pptor pg/g				■			
Max level: Mercury: 0.22 ppm				■			
No preservatives permitted, including sodium bisulfite, sodium tri-tripolyphosphate (STP), and sodium metabisulfite				■			
Is the main production system associated with adverse impacts on populations of species in the area?	■						
Benthic impacts and siting	■						
Siting of farms	■	■	■				
Main production system require large-scale land or seabed alterations in areas of high ecological sensitivity	■						
Biological effects (phytoplankton blooms)					■		

Ecological effects (Larvae collection)					■		
No conversion of ecologically sensitive areas (e.g. wetlands, mangroves) into new farms or sites, or for expanding current farms, permitted	■			■			
Restoration of at least a hectare of new habitat for each hectare of wetland or mangrove forest previously converted to ponds (i.e. a 1:1 ratio)				■			
Habitat Sensitivity & Habitat Conversion						■	
Deforestation (ha)						■	
Risk of pollution and habitat effects							■
Minimising wider ecosystem effects			■				
Use of marine resources							■
On-site operation (open pen or closed containment) Stocking density $25kg/m^3$					■		
Maximum stocking density for open net pens: 20 kg/m3	■			■			
Depletion of Freshwater				■		■	■
Water Consumption vs. Water Availability		■					
Deterioration of Freshwater by Salinization						■	
Disturbance of Hydrology						■	
Land Use						■	
Disturbance & Deterioration of Soil						■	
Risk to Other species					■		
General Impacts on Local Wildlife	■					■	

Broodstock/Larvae Source							
larvae and seed provenance (1-10 cod every 1-3 yrs)	■						■
Broodstock and grow-out stock must be hatchery-raised				■			
Shrimp post-larvae must come from SPF or SPR broodstock				■			
Broodstock and Seedlings						■	
Main production system rely on restocking with eggs or juveniles from the wild AND would this broodstock fishery be graded red by the wild caught assesment	■						
No Acoustic Harassment Devices	■			■			
Social Issues							
Social Issues		■					
Is the main production system associated with well-documented third-party evidence of human rights abuses and/or poor workers rights within the last five years?	■						
Effectiveness of the management regime							■
Continuous improvement and research		■	■				

Appendix C
Human Development Index Scores 2003

Excerpt from the 2005 HDR report (available from http://hdr.undp.org/en/reports/) showing the top 40 HDI scores including Norway, Canada, United Kingdom and Chile.

TABLE 1

Monitoring human development: enlarging people's choices . . .

Human development index

HDI rank [a]	Human development index (HDI) value 2003	Life expectancy at birth (years) 2003	Adult literacy rate (% ages 15 and above) 2003 [b]	Combined gross enrolment ratio for primary, secondary and tertiary schools (%) 2002/03 [c]	GDP per capita (PPP US$) 2003	Life expectancy index	Education index	GDP index	GDP per capita (PPP US$) rank minus HDI rank [d]
HIGH HUMAN DEVELOPMENT									
1 Norway	0.963	79.4	.. [e]	101 [f]	37,670	0.91	0.99	0.99	2
2 Iceland	0.956	80.7	.. [e]	96	31,243	0.93	0.98	0.96	4
3 Australia	0.955	80.3	.. [e]	116 [f]	29,632	0.92	0.99	0.95	7
4 Luxembourg	0.949	78.5	.. [e]	88 [g]	62,298 [h]	0.89	0.95	1.00	–3
5 Canada	0.949	80.0	.. [e]	94 [i, j]	30,677	0.92	0.97	0.96	2
6 Sweden	0.949	80.2	.. [e]	114 [f]	26,750	0.92	0.99	0.93	14
7 Switzerland	0.947	80.5	.. [e]	90	30,552	0.93	0.96	0.96	1
8 Ireland	0.946	77.7	.. [e]	93	37,738	0.88	0.97	0.99	–6
9 Belgium	0.945	78.9	.. [e]	114 [f]	28,335	0.90	0.99	0.94	3
10 United States	0.944	77.4	.. [e]	93	37,562	0.87	0.97	0.99	–6
11 Japan	0.943	82.0	.. [e]	84	27,967	0.95	0.94	0.94	2
12 Netherlands	0.943	78.4	.. [e]	99	29,371	0.89	0.99	0.95	–1
13 Finland	0.941	78.5	.. [e]	108 [f]	27,619	0.89	0.99	0.94	3
14 Denmark	0.941	77.2	.. [e]	102 [f]	31,465	0.87	0.99	0.96	–9
15 United Kingdom	0.939	78.4	.. [e]	123 [f, i]	27,147	0.89	0.99	0.94	3
16 France	0.938	79.5	.. [e]	92	27,677	0.91	0.97	0.94	–1
17 Austria	0.936	79.0	.. [e]	89	30,094	0.90	0.96	0.95	–8
18 Italy	0.934	80.1	98.5 [e, k, l]	87	27,119	0.92	0.95	0.94	1
19 New Zealand	0.933	79.1	.. [e]	106 [f]	22,582	0.90	0.99	0.90	3
20 Germany	0.930	78.7	.. [e]	89	27,756	0.90	0.96	0.94	–6
21 Spain	0.928	79.5	97.7 [e, k, l]	94	22,391	0.91	0.97	0.90	3
22 Hong Kong, China (SAR)	0.916	81.6	93.5 [k, l]	74	27,179	0.94	0.87	0.94	–5
23 Israel	0.915	79.7	96.9	91	20,033	0.91	0.95	0.88	2
24 Greece	0.912	78.3	91.0 [e]	92	19,954	0.89	0.97	0.88	2
25 Singapore	0.907	78.7	92.5	87 [m]	24,481	0.89	0.91	0.92	–4
26 Slovenia	0.904	76.4	99.7 [e, k]	95	19,150	0.86	0.98	0.88	4
27 Portugal	0.904	77.2	92.5 [e, k, l]	94	18,126	0.87	0.97	0.87	5
28 Korea, Rep. of	0.901	77.0	97.9 [e, k, l]	93	17,971	0.87	0.97	0.87	6
29 Cyprus	0.891	78.6	96.8	78	18,776 [j]	0.89	0.91	0.87	2
30 Barbados	0.878	75.0	99.7 [e, k]	89 [j]	15,720	0.83	0.96	0.84	9
31 Czech Republic	0.874	75.6	.. [e]	80	16,357	0.84	0.93	0.85	7
32 Malta	0.867	78.4	87.9 [n]	79	17,633	0.89	0.85	0.86	3
33 Brunei Darussalam	0.866	76.4	92.7	74	19,210 [j, o]	0.86	0.86	0.88	–4
34 Argentina	0.863	74.5	97.2	95	12,106	0.82	0.96	0.80	12
35 Hungary	0.862	72.7	99.3	89	14,584	0.80	0.96	0.83	5
36 Poland	0.858	74.3	99.7 [e, k, l]	90	11,379	0.82	0.96	0.79	12
37 Chile	0.854	77.9	95.7	81	10,274	0.88	0.91	0.77	17
38 Estonia	0.853	71.3	99.8	92	13,539	0.77	0.97	0.82	4
39 Lithuania	0.852	72.3	99.6	94	11,702	0.79	0.97	0.79	8
40 Qatar	0.849	72.8	89.2 [n]	82	19,844 [j, p]	0.80	0.87	0.88	–13

Appendix D
GAPI Invasiveness Score Routine

Is the species domesticated anywhere in the world?	No=0 Yes=1
Has the species naturalized (established viable populations) beyond its native range?	Native or No =0, Few(<3)=2, Many=3
Does the species have invasive congeners?	No=0 Yes =1
Is the species poisonous or poses other immunochemical predation defenses?	No=0 Yes =1
Is the species parasitic of other species?	No=0 Yes =1
Is the species likely unpalatable to natural predators?	Yes=1 No=0
Is the species likely to be a novel predator to native forage species?	No=0 Yes =1
Does the species host, and/or is it a vector for, recognized pests and pathogens, especially non-native?	No=0 Yes =1
Does the species achieve a large ultimate body (> 30 cm FL)?	No=0 Yes =1
Does species tolerate a wide range of salinity?	No=0 Yes =1
Habitat diversity	(Value Range 0-1) x 3
Does feeding or other behaviours of the species reduce habitat quality for native species (i.e. ecosystem engineer)?	No=0 Yes =1
Adult wild trophic level	SAUP Value
Does it exhibit parental care and/or is it known to reduce age-at-maturity in response to environmental conditions?	No=0 Yes =1
Do production fish produce viable gametes?	No=0 Yes =1
May the species hybridize with one or more native species?	No=0 Yes =1
Is the species hermaphroditic?	No=0 Yes =1
Is the species dependent on another species or specific habitat feature(s) to complete its life cycle (including diadromy)?	No=1 Yes=0
Does natural dispersal occur as a function of egg or larval dispersal?	No=0 Yes =1
Does the species tolerate or benefit from environmental disturbance?	No=0 Yes =1
Are there effective natural enemies of the species present in the risk assessment area?	Yes=0 No=1
Does the species tolerate a wide range of water quality conditions (e.g. hydrodynamics, pollution, oxygen)?	0-low, 3-high
If native, # generations from wild type	native = # generations (max =3), exotic =1
Resilience	Very Low=0, Low=1 Medium=2 High=3
Identified in IUCN Global Invasive Species Database	No=0 Yes=3
Effective distance	(Max range degrees) / 60
FINAL SCORE	