A MODEL TO CALCULATE ENERGETIC RETURNS AND AN ECOLOGICAL FOOTPRINT OF AN INDUSTRIAL FISHERY WITH A CASE STUDY OF THE 1980S NORTHWEST ATLANTIC COD FISHERY

RAJAT SHARAN

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A thesis submitted to the School of Graduate Studies in partial fulfillment of the requirements for the degree of Master of Science (Environmental Science)

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Abstract

This research project focused on developing a general energetic balance model that evaluates an industrial fishery. It was constructed by incorporating methodologies developed by Tyedmers (2000) and other energetic principles to give both a energetic return for a fishery and an evaluation of ecological efficiency for that fishery. The energetic measurement is a comparison of all energy inputs that are derived from net primary production (NPP), whether recent or ancient in the form of fossil fuels, and the energy received in the form of food from the fishery. The ecological efficiency in this study uses the metric of an Ecological Footprint (EF). This model was used then to compare the different fishery vessel length classes of the cod fishery for the period of 1982-1986 found in what is defined by the Northwest Atlantic Fisheries Organization as 3K and 3L. This region lies mainly off of the coast of Newfoundland, Canada.

The model can be used as a comparative tool to compare different fisheries or different fishery methods for ecological efficiency. The utility of knowing which fishery method is more ecologically efficient could allow those in managerial roles within the fishery to select those fisheries with optimal return and reduced ecological impact. This would be beneficial as fisheries are often an important food resource.

The case study results indicated that the energetically and ecologically most efficient cod fisheries by vessel class ranked in the following order: twenty-five to thirty four feet, thirty-five to forty-four feet, forty-five to sixty-four feet and finally less than twenty-five feet class. The trend observed in three of the four vessel classes saw the efficiencies diminishing with time, probably reflecting a

decreasing cod stock. Industrial fisheries methods have effectively increased human reliance on ancient NPP to perform these fisheries. In the past, energy from wind and currents was used. The energy is now derived from the combustion of fossil fuels, ancient NPP.

Dedication

To Alok, Nupur and Sharada your presence warmed our hearts, and your spirits remind us of our duties.

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List of Abbreviations

Abbreviation	Full Form
C	Carbon
CPUE	Catch Per Unit Effort
CR	Caloric Return
DFO	Department of Fisheries and Oceans
EF	Ecological Footprint
EF_M	Ecological Footprint Marine
EF_T	Ecological Footprint Terrestrial
EROI	Edible Return On Investment
g	gram
Ha	Hectare
K	Kilogram
L	Litre
LIV	Large Inshore Vessel (25 – 34 feet)
LNV	Large Nearshore Vessel (45 -64 feet)
m	metre
MJ	Mega-joule
NAFO	North Atlantic Fisheries Organization
NPP	Net Primary Production
SIV	Small Inshore Vessel (less than 25 feet)
SNV	Small Nearshore Vessel (35 – 44 feet)
t	Tonne
VGCM	Vessel and Gear Construction and Maintenance

1. Introduction

1.1 Background

Life exists on Earth, an open system with respect to energy but a closed system with respect to matter. Energy flows in and out of Earth's system, whereas other than extremely trace amounts (via meteors) matter does not do so. The overwhelming amount of energy the Earth receives comes from the sun, with relatively minimal levels from the surrounding universe. Energy from the sun is the driving force for the ongoing experiment of life.

Powered by energy from the sun, plants and microorganisms (primary producers) take matter from the Earth's crust and carbon dioxide from the atmosphere and create living organic matter. Primary producers convert the energy of the sun into chemical energy in organic matter. All other forms of life are dependent on the net of primary production (NPP) whether directly, i.e. animals, which feed on living organic matter, or indirectly, i.e. bacteria and fungi, which survive on or due to other organic matter. As the system is closed to matter, all products of life must be assimilated within the system.

Life has affected the chemistry and geography of the planet. Primary producers altered Earth's atmospheric composition. With the early evolution of primary producers atmospheric carbon dioxide levels decreased with time. Between the respiration of primary producers and other organisms the atmospheric equilibrium is different today than when the Earth first formed. Levels of oxygen have increased and those of carbon dioxide have decreased.

Animals, bacteria and fungi are organic combustion organisms deriving their energy from the organic matter they consume. Via respiration animals take in oxygen and through internal biological reactions combust it with food to provide energy to the organism. The other products of the reactions are carbon dioxide (respiration), water and matter that is not digestible.

In order for animals to stay alive, they must consume more calories than they expend from all their activities. Energy is required to maintain their body as well as for any and all other activities, including seeking food. The experiment of life is such that animals require strategies for procuring calories (foraging strategy) which exceed the amount of calories required to keep them alive. Those individuals, populations or species, whose foraging strategies do not accomplish this, perish. Ecosystems and the players within it are in dynamic equilibrium. The system is constantly changing. Therefore foraging strategies that work at a given point, may not work in future conditions. Any strategy that does not provide an energetic surplus will, over a long run lead to the death of an individual or population.

A recent result of the experiment of life are *Homo sapiens*, humans. Apart from the Antarctic, the human species migrated and settled in all parts of the world. Foraging strategies for humans varied according to the environments in which they lived. Certain regions of the world had indigenous plants which produced high yields in small areas. The possibility of domesticating these plants was probably discovered by accident. Plants began to grow in waste areas, resulting in the observation that plants could be grown with human influence. Certain human populations determined that the growing of the plants warranted attention and began to assist plant growth by tending them. The experiment to the domestication of plants, a foraging strategy that could if given the right types of plants and growing conditions, lead to large yields of food (calories). Agriculture independently arose in possibly nine different regions of the world (Diamond 1997) and spread to regions beyond the initial discovery. In many cases, the introduction of high yield, non-indigenous plants made it worthwhile to pursue agriculture in regions where environmental conditions were good, but the indigenous plants were not of a high yield variety. It should be noted that farming the non-indigenous species with high yields allowed people to then farm the indigenous species of plants which did not have high yields, but were sought after for taste or other reasons. This allowed humans to have a varied diet.

While developing skills to domesticate plants, humans were developing husbandry practices to domesticate and take care of both land and aquatic animals and exploring different fishing strategies. Overall, humans were developing new types of foraging. These methods of agriculture, animal husbandry and fisheries were foraging strategies that gave a net surplus of calories. This energetic surplus allowed humans to develop more complex societies and economic activity (Diamond 1997).

Even before the discovery of agriculture, humans were able to harness and manipulate the environment to assist in foraging strategies or to perform work. Modern humans, *Homo sapiens sapiens*, probably inherited the knowledge of harnessing and starting fires from our predecessors, *Homo erectus* (Wright 2004). Fires of combustible organic matter allowed humans to perform work which could not be done otherwise. Fires could be used for heat, cooking food, to melt metals so that they could be shaped into tools, ornaments, etc. Fires and the products of these fires were used in the foraging strategies for humans as well for other work and leisure pursuits. Over time, humans interacting with the environment learned of fossil fuels that could be found in the Earth's crust. Fossil fuels, coal and petroleum are organic matter (net NPP) trapped in the crust of the Earth for millions of years that have been transformed by geothermal reactions into fossilized high concentrate combustible organic material. By harnessing fossil fuels, humans found another source for combustion to allow work to be performed. The NPP formed millions of years ago became available to humans.

Fossil fuels are large and highly portable sources of energy. These ancient reserves have allowed the human species the ability to perform large amounts of work with a minimal amount of human effort as in the case of transportation, heating, housing and material construction. In the more industrial societies almost every facet of work involves some use of energy derived from non-food energy. The vast majority of the energy is from fossil fuels, either coal or petroleum.

Other species must make use of energy either from food or external real-time power sources, e.g. wind for flying animals as a part of their food gathering (foraging) strategy. Fossil fuels, relative to real time external energy, wind and sunlight, are enormous concentrated power sources. Real time energy sources generally can only be harnessed when conditions are present, not utilized at will, effectively finite in both concentration, but effectively infinite with respect to time. The agriculture and fisheries food gathering strategies that resulted in an overall energetic surplus allowing humans time for "leisure activities" (Diamond 1997) are no longer constrained by calories of food available or the NPP available to the organisms performing the work towards agriculture (humans and the domesticated animals used in farming). The work constraint can now include the ancient reserves of NPP. By the nineteen seventies, studies indicated certain types of agriculture were consuming more calories in producing food than they were returning. The energetic deficit was being supplied by fossil fuels (Daly 1991).

Through the use of fossil fuels, humans can move away from a foraging strategy which results in an energetic surplus (relative to recent NPP or real-time power sources). But how much and for how long can this go on? Or more to the point, why develop foraging strategies with low energetic returns? These will increase our dependency on ancient reserves of NPP, which are effectively finite, versus any current real-time NPP. This is an especially precarious outcome as human history is littered with failed foraging strategies that have led to the collapse of societies: Sumerian circa 3,500 BC (Wright 2004), Maya late 9th and early 10th century A.D, Anasazi circa mid 12th to early 13th century A.D. (Diamond 2005).

In recent centuries the impact on the Earth from the work of human society has increased due to larger numbers of people and, even more significantly, highly industrial human activity. All of life's products remain in the thin crust that supports life. Humans, through the use of fossil fuels, are introducing the ancient reserves of NPP previously trapped in the crust. The combustion of fossil fuels re-introduces the carbon removed from the system millions of years ago in the form of atmospheric carbon dioxide. The carbon dioxide must be sequestered by primary producers to maintain the carbon dioxide equilibrium of the atmosphere. The problem of sequestering re-introduced carbon is compounded as the planet is being de-forested and land taken up for other human activity.

Current economic activity is affecting the planet on a large scale, Vitousek *et al*. (1986) calculated that 40 % of global net primary production is appropriated by humans. Compounding existing conditions is the fact that lesser industrialized nations are industrializing in a similar fashion as did the current industrial nations. Rees and Wackernagel (1994) show that if a western style economic system were to spread throughout the rest of the world, all else being the same, the economic system would require a resource base twice that of the present capacity of the Earth to satisfy human resource demands.

This thesis focuses specifically on the energetic returns and the ecological demands of an industrial fishing strategy by developing a case study of an industrial cod fishery off the coast of Newfoundland, Canada. Measuring the foraging strategy is a relatively straightforward exercise. What is required is to determine the number of calories used in pursuing fishing versus the number of calories available from the fish caught. In this study, I have considered the energy used in both constructing and maintaining the vessel and gear, as well as the fuel used in fishing. The purpose of this exercise is to illustrate the energetic return of an industrial fishery based on energy derived from NPP, whether current or ancient in the form of fossil fuels. Unlike the pre-industrial fisheries, where the external energy was derived from the sun through the wind and currents, the industrial fishery is almost entirely dependent on energy derived from the sun through NPP. Therefore a calculation of energetic returns gives an idea of how much energy is required from NPP.

To measure the ecological costs requires a different analytical tool. The price of goods in the current market system does not reflect the ecological costs of a fishery; energetic return is one aspect of the ecological costs. Foraging strategies that require more resources than are produced in real-time will function for a period, but then effectively fail. Eventually, the failure of the foraging strategy becomes obvious and the equilibrium shifts in a negative direction for the species resulting in diminished health of the individual or the population. According to Folke et al. (1998, S63), "despite being a prerequisite for these activities, the support of ecosystems is not accounted for in market prices of fish and shellfish, seldom included in models of fisheries and aquaculture management, and often not even perceived by those in charge of managing human activities in coastal and marine environments." The price of goods in a competitive market system is based largely on the cost of labour, capital, raw material inputs required for production, the value of the currency in which the good is produced, and the expected or hoped for profit margin. Thus the cost of producing the good does not reflect the ecological demands of a good being produced. Another analytical tool is therefore required.

One tool that has become increasingly used for measuring the ecological demands of an activity is an Ecological Footprint (EF) analysis. An EF is the physical geographic area required to produce the good or perform the service. Wackernagel and Rees (1996, p61) define EF as, "how much land and water area is required on a continuous basis to produce all the goods consumed, and to assimilate all the wastes generated by that population."

Calculations of the area required will vary according to the good or service being examined. Tyedmers' (2000) Ph.D. thesis <u>Salmon and Sustainability: The Biophysical Cost of Producing</u>

Salmon Through the Commercial Salmon Fishery and the Intensive Salmon Culture Industry is a comparative ecological evaluation of the different salmon fisheries and salmon aquaculture in British Columbia, Canada. The primary evaluation tool is Ecological Footprint (EF) analysis. Tyedmers's (2000) methodology results in an EF with two components, an EF marine (EF_M) and an EF terrestrial (EF_T). EF_M is the foraging region required to raise the fish to harvesting age, plus the marine area required as a result of human consumption of marine resources for the period in which the labour are engaged in fishing activity. For the terrestrial calculation, Tyedmers (2000) converted all the inputs of the fishery (vessels, human effort, and fossil fuel) into its fossil fuel equivalent. The region required to sink all the carbon dioxide produced represents the EF_T. The variables for the sink region are the total amount of carbon dioxide produced and the sequestration rate used to sink the carbon dioxide. The sequestration rate for a region is based on the average amount of net primary production for the vegetation of that area. Therefore the sequestration rate will depend on the forest type that is being used. The general forest NPP gradient is that the more tropical the forest type the higher the NPP, and therefore the greater the sequestration rate.

EFs are an assessment of the ecological resources required to biologically sustain an activity during the period of evaluation. Ecosystems are dynamic systems. EFs are effectively a snap shot of the resources required during the period of study. Folke (1998, S64) explains:

> Ecosystems are complex systems with nonlinearities, thresholds, and discontinuities (Costanza 1993), but the footprint is a static measure. Still, the footprint concept illuminates the "hidden" requirements for ecosystem support, and puts the scale of fisheries and aquaculture within an ecosystem framework. It also demonstrates that human activities, which at first glance may seem separated from nature, would not function without ecosystem support. The work of ecosystems, which forms the precondition for seafood production and

consumption, is hidden because people and policy seldom perceive it, but nevertheless it is real.

EFs are more reflective of the ecological costs of the price of a good than is the dollar or monetary value determined by the market place. Ekins *et al* (1994) indicate that EFs illustrate the dependence of economic activities on ecosystems. This dependence is not indicated in the pricing that drives world trade.

As compared with the monetary cost of a good, an EF better demonstrates the physical demand of an activity. It shows the area of NPP required to perform the activity or produce the good. Real-time NPP is limited by three factors: the number of primary producers available to convert energy, the efficiency of converting solar energy to NPP, and the finite amount of solar energy that arrives on the Earth each day. As indicated, this NPP must be shared by all organisms on the planet. Therefore the demands by humans on NPP will affect the ecological systems of the Earth. A logical strategy for humans would be to limit the NPP to sustain human society. By reducing the duress placed on ecological systems, they could increase the likelihood of the continuance of current ecological conditions, which have certainly led to the prosperity of the human species with respect to range and numbers (population).

To illustrate and emphasize the utility of EFs would be to draw on the analogy of humans living off the interest provided by some invested principal. Ecosystems represent the principal, while NPP is the interest from which humans and other organisms must live. If annual spending (economic activity) is less than the interest provides, then one can live off the annual interest indefinitely. Once the annual spending goes beyond the level of interest returned, the extra money required must come from the principal. For each year where income drawn is greater than the interest available, the principal diminishes. If for example, the spending (economic activity) is greater than interest available and is increasing each year (economic growth), the effect is that the principal decreases each year and the interest available will also decrease each year. In this scenario, the spending (economic activity) will reach its zenith when the last cheque drawn will lead to insufficient funds. If the case described is applied to ecosystems, the consequence is ecological collapse.

Calculating EF of human activity provides a rough equivalence to spending in the analogy described, as it measures the NPP region required to sustain an activity or produce a good. According to calculations by Wackernagel *et al.* (2002), in 1999 humans required 1.1 Earths of NPP, i.e. 1.1 Earths are required to sequester the CO_2 produced to sustain the activities of humans. As there has been continued growth in human activity, this means more Earths will be required. This is obviously not possible, therefore there must be some ecological consequences. With continued growth, fewer primary producers are available to sequester the carbon dioxide produced. This will stress existing ecological systems. Therefore calculating and comparing EFs of similar activities can be a useful measure when trying to evaluate impacts from human activity.

To further illustrate the region of NPP required, as part of the EF exercise I have used Dukes (2003) calculations to estimate the ratio of current fuel demands to the original amount of NPP required to create the fossil fuel. I have calculated the Ancient NPP region required, which in this thesis is considered EF_M Ancient.

Unlike other species or past human society, currently humans can devise foraging strategies with optimal results based on experiments and historical knowledge. Other species certainly do not have the cognitive capability to review their foraging strategies. Humans have the cognitive ability and using several disciplines of study, have the ability to determine how previous societies functioned. This would allow humans to recognize what caused the decline or demise of that society. As well, humans could continue to test foraging strategies using domesticated primary producers and livestock animals leading to optimal strategies. Humans certainly have the tools to ensure their societies do not repeat the failures of the past.

A general energetic balance model that evaluates a fishery is constructed using principles developed by Tyedmers (2000) and other energetic principles. The model gives both energetic return for a fishery and an EF for that fishery. The model is then used to evaluate the different fishery vessel length classes found in the cod fishery off of the coast of Newfoundland, Canada between 1982 - 1986.

As explained earlier, knowing which fishery method is more ecologically efficient could allow those in managerial roles in the fishery to select towards those methods. This would aid in trying to preserve fisheries, which are often an important food source. As well, help bring the EF of trade fisheries in line with their energetic output.

1.2 Objectives

- Utilizing the methodology developed by Tyedmers (2000) and other general energetic and ecological principles, construct a general model which with input effort indicators returns the energetic returns and an EF for a fishery. This model requires the user input variables associated with a fishery.
- Utilizing the model, evaluate the cod fisheries in the nineteen eighties off the coast of Newfoundland, Canada returning energetic return and an EF of that fishery.

1.3 Pre-Amble to Hypothesis

Inshore and nearshore fisheries off the coast of Newfoundland have been pursued since at least the fifteenth century by many western Europeans, if not earlier by the Basques (Kurlansky 1997). In the pre-industrial period, all external (non-human) power for the fishery was derived from either wind and/or currents. Since the industrial age, with the introduction of engines, the external energy has been derived from petroleum, a fossil fuel. The energy of wind and currents plays a much smaller role than in the past.

All fishery vessel types use engines and fossil fuels. Human effort (labour) is generally more economically expensive than mechanized effort. Larger vessels can hold larger loads and therefore theoretically could be cheaper to operate. However, as the scale is greater they require more mechanical assistance to pull in nets and power the vessels and thus will consume more fuel. The energy required from the increased mechanization demands more fossil fuel. Therefore nearshore classes could price-wise be very competitive to inshore classes, but may have lower energetic returns per tonne and require more ecological resources per tonne of fish landed.

In addition, it would be expected that the inshore fisheries developed fishing methods over a long period without the use of fossil fuels, which would optimize energetic returns. Thus with the introduction of engines and fossil fuels, the power source may have changed, but could still result in an optimal energetic return.

1.4 Hypothesis

- As a result of the small size and relatively low intensity of mechanization the small inshore vessel classes, less than twenty-five feet, will have the best energetic returns and the lowest EF values per tonne.

- The energetic returns will decrease and the EFs will increase with increasing vessel length.

1.5 Contribution

The Newfoundland cod fishery was closed commercially in 1992. The energetic return and ecological footprint model provides insight into the eco-efficiency of the various fleet segments engaged in the fishery that existed prior to the collapse of the cod populations. Was there an optimal vessel class for energetic return and EF at that time? What, if any, trends existed prior to the cessation of the cod fishery? This information could be used as the basis for comparisons with other fisheries. If a trend is identified, it could be the trend of a collapsing fish stock.

The model could be used to determine which types of fisheries among those analyzed give optimal energetic returns and low EFs. Other than energy inputs, variables for this model can be found in the appendices, e.g. percentage utilization of a fish species found Appendix A, allow the model to be transferable to evaluate other fisheries. Once a functional model is developed, enhancements to it can be made. One enhancement would be to include some classical economic parameters. This was not possible in this study, but would certainly be a useful metric to have in a model.

2. Methodology

The methodological description is divided into three sections. The first section gives some background information on energetics (energetic returns) and Ecological Footprints. It also describes the input parameters for the study and the general assumptions. This is followed by a section giving the methodology of the general model developed to evaluate both energetic return and EFs for a given fishery. The last section gives the methodology for the case study of the industrial cod fishery off the coast of Newfoundland, Canada during the nineteen eighties.

2.1 General Model

The purpose of the model is to calculate the energetic return and the EF per tonne of live weight fish landed by a fishery. In order to calculate the energetic return, all inputs and outputs need to be converted to energetic equivalents. There are three general inputs to a fishery that are considered here: fuel, vessel and gear construction and maintenance (VGCM), and human effort (labour). The output is the fish caught. All need to be converted into some metric of energy. In this model these values are converted to their megajoule equivalents.

$$\text{Fishing}_{\text{Energy}} = \text{Fuel}_{\text{Energy}} + \text{VGCM}_{\text{Energy}} + \text{Human Effort}_{\text{Energy}} \quad (1)$$

The energetic return that is being sought is simply the ratio of the energy input versus the energy received from fish. Therefore, for ease of calculation it is easier to convert the inputs and outputs to megajoule equivalents rather than calories.

Converting fuel into its megajoule equivalence is a straightforward exercise. Simply multiply the number of megajoules per litre by the number of litres consumed. The conversion of VGCM into energy is performed by using Tyedmers (2000) conversion of a vessel into its energy equivalence. This value is then divided by the vessel length to get a per foot energy value by vessel type.

$$\text{Vessel Per Foot}_{\text{Energy MJ ft}^{-1}} = \text{VGCM}_{\text{Energy}} \,/\, \text{Total Vessel Length}_{\text{ft}} \qquad (2)$$

Taking the per foot value for vessel type and then multiplying it by the number of vessels and the average vessel length per vessel class will give the total energy equivalence for the vessel gear construction and maintenance. Conversion of human effort into energy is performed by multiplying the total number of people days at sea by the average joules expended per day by an individual.

The conversion of the output of a fishery is done by taking the total landed biomass of fish, multiplying it by the percentage of that species that can be consumed for food (percentage utilization) and the number of joules available per kilogram of that species type. Dividing the joules available from fish by the joules consumed from fishing will give the return on investment for that fishery with respect to energy, i.e. energetic return.

For the EF analysis the inputs need to be converted into the equivalent hectares required to sequester the carbon dioxide produced from the construction of that input. The total hectares required is divided by the catch to give the ecological footprint terrestrial (EF_T) per tonne. The three broad inputs into a fishery again are: fuel, vessel and gear construction and maintenance and human effort. To convert fuel into its equivalent EF region, take total litres of fuel used, multiply it by the number of grams of carbon dioxide produced per litre and then divide this product by the number of grams of carbon dioxide sequestered by the appropriate forest type. This will give the total land area required to sequester all the fuel that is combusted. The conversion of a vessel and gear construction and maintenance into EF is performed by again taking Tyedmers (2000) conversion of a vessel into its EF equivalence, see Appendix B. Dividing the EF value by the vessel's length gives a per foot EF value by vessel type. Taking the per foot value for vessel type and multiplying it by the number of vessels and the average vessel length per vessel class will give the total EF equivalence for the vessel and gear construction and maintenance. The third general input is human effort. This requires the total number of days of human effort expended on fishing divided by the number of days in a year. Taking this value and multiplying it by the per capita EF_T for that nationality (Wackernagel 1999) will give the EF from human effort for that crew. Dividing the total EF of the three inputs by the total catch will give the EF terrestrial per tonne for the fishery type.

Fisheries EF analysis has a marine component as well (EF_M). The marine component consists of the minimum area of productive aquatic ecosystem required to sustain the production of one tonne of the species being harvested (forage area required for one tonne of the species), plus the EF_M for the marine area that humans use by way of consumption of marine products during the period of fishing. The forage area is calculated by taking the Net Primary Production (NPP) required to grow a tonne of that fish species type and dividing it by the NPP of the ocean region where the fish forage. The human marine component of the EF_M is calculated by taking the number of days fishing in people years and multiplying it by the EF_M for a person of the nationality of the fishing crew (nations per capita consumption differs and therefore EFs per nationality differ), found in Appendix C. Dividing this value by the tonnes of fish caught, gives the EF_M from human effort. Adding the EF_M of the forage area with the EF_M for the marine consumption will give the total EF_M required per tonne.

The following section gives a detailed explanation of all the input parameters required in the calculation of the energetic return and the EF. In addition, it indicates in which appendices the table for the range of types of that parameter can be referenced.

2.1.1 Input Parameters – General Model

The following information is required as input parameters for the model: days fished, fuel consumed, forest type being used for carbon sequestration, forest type, human effort, landings, nationality of the crew (average per capita consumption rates of resources varies by country, therefore citizens of different nations will have different average EFs), number of crew, ocean region, percentage effort attributable to species being evaluated, species type, vessel length and vessel type.

[Parameter: Symbol Used in Formulas in this thesis : (Used in) Energetics and/or EF analysis : Explanation why it is a parameter : unit type]

Days Fished: **DF**: Energetics and EF : Required in determining the human effort expended in catching the fish : days

Fuel Consumed: **FC** : Energetics and EF: For energetics, fuel consumed is an input value in the amount of energy expended in the pursuit of the fishery. In EF calculations, fuel consumption is a determining factor in amount of CO_2 waste produced. This is required in calculating sink region: Litres (L)

Forest Type: **FT**: EF : Different forests types have different sequestration rates. Sequestration rates are used in determining the sink region for carbon dioxide produced by an input. Appendix D contains a table of the different sequestration rates based on forest type : g CO_2 Ha^{-1} (Grams Carbon Dioxide per Hectare)

Fuel Type: **FU** : Energetics and EF: Different fuel types release different amounts of energy and carbon dioxide per litre upon combustion. Appendix E contains tables indicating the varying energy and carbon dioxide levels produced based on fuel type: g CO_2 L^{-1}

Human Effort: **HE** : Energetics: Daily energy expended by a person fishing. MJ Day^{-1} Appendix F.

Landings: **LA** :Energetics and EF: Required for calculation of energetic return and the EF per tonne : tonne (t)

Nationality of Crew: **NC**: EF : People of different nationalities have different average consumption rates and therefore different average per capita EFs. The per capita EF is used in determining the EF attributable to human effort. Appendix C lists per capita EF by nation.

Number of Crew : NU : Energetics and EF: Factor in determining human effort expended.

Ocean Region: **OR** : EF : Regions of oceans have varying NPP rates. The ocean region best associated with the growth of the stock should be used in calculating the forage area required. Appendix G contains a table taken from Longhurst et al. (1995) indicating the NPP rates by ocean region : g C m^{-2} yr^{-1}

Percentage Effort : **PE**: Energetics and EF: Percentage of Effort attributable to the fish being studied versus total fish caught by fleet.

Percentage Utilization: **PU** : Energetics and EF : Percentage of the fish that can be used as food for human consumption.

Species Type: **ST** : Energetics and EF : For energetics evaluation species type determines two aspects. Different species have different percentage utilization of landed mass towards food, a table is found in Appendix A. As well the per kilogram energy content varies by species type found in Appendix H. Species type is also a factor in EF calculations in that different fish species require differing amounts of NPP to grow. Therefore it is a determining factor for the forage area required.

Appendix B contains a table of species type and their respective NPP required (Pauly & Christensen 1995).

Vessel Length: **VL** : Energetics and EF : Total vessel length is required as input values in determining both energetic returns and EFs : feet (ft)

Vessel Type: **VT** :Energetics and EF : Vessels are constructed of different materials therefore will have different energy value and EF values per foot. Appendix I contains tables indicating the different vessel hull types and their corresponding energy and EF value per foot (Tyedmers 2001). MJ ft^{-1} and ha ft^{-1}

2.1.2 Assumptions

The following assumptions are for the general model that has been constructed.

- The percentage utilization from one tonne of a given type of fish is uniform, regardless of where the fish is caught, type of vessel, the age, the size of fish or time of year.
- The energetics of growing fish to harvesting age are not included. This is done by nature and no human effort was involved in raising the fish, i.e. an ecosystem service.
- The life and maintenance costs for vessels participating in most industrial fisheries will not be sufficiently different from the salmon fishery on the west coast of Canada to justify different calculations. Vessels of the same size class will have similar lifetimes and yearly maintenance requirements.
- The per foot energy and EF values used in calculating vessel and gear construction and maintenance is uniform. This is despite the fact that with increasing length the beam of the vessel increases. Therefore not all increases in length will result in equal ecological demands in construction per foot. A low per foot value is used as a conservative estimate.

2.1.3 General Model - Energetics

Formula	Explanation	Equation
$Fishing_{Energy} = Fuel_{Energy} + VGCM_{Energy} + Human\ Effort_{Energy}$	General formula adding all three inputs determines total fishing energy.	(1)
$Fuel_{Energy} = Volume\ of\ Fuel_{L} \times Energy\ per\ litre_{MJ\ L^{-1}}$	Multiplying the number of litres used by amount of energy released per litre of that fuel type gives the total energy from fuel expended.	(2)
$VGCM_{Energy} = Vessel\ Per\ Foot_{Energy\ MJ\ ft^{-1}} \times Total\ Vessel\ Length_{ft}$	Multiply energy per foot value with the total vessel lengths gives total energy from vessel and gear construction and maintenance.	(3)
$Human\ Effort_{Energy} = Days\ at\ Sea \times Number\ of\ Crew \times Daily\ Energy\ Expended$	Multiply the total number of days spent at sea by the number of crew and average daily energy expenditure gives total energy from human effort.	(4)
$Fish_{Energy} = Fish_{kg} \times Percentage\ Utilized \times Calories\ Available_{Cal\ kg^{-1}} \times Conversion_{MJ\ Cal^{-1}}$	Energy from fish is calculated by multiplying total fish caught (kg) by the percentage utilized of a fish species, calories available per kilogram and the conversion factor from calories to mega joules.	(5)
$Energetic\ Return = Fish_{Energy\ MJ} / Fishing_{Energy\ MJ}$	Energy available from fish divided by energy expended catching fish.	(6)

2.1.4 General Model - Ecological Footprint

Formula	Explanation	Equation
$\text{Fishing}_{EF} = EF_{\text{Terrestrial (T)}} + EF_{\text{Marine (M)}}$	General formula total EF is the sum of $EF_{\text{Terrestiral}}$ and EF_{Marine}	(7)
$\text{Fishing}_{EF} = \text{Fuel}_{EF(T)} + \text{VGCM}_{EF(T)} + \text{HE}_{EF(T)} + \text{HE}_{EF(M)} + \text{Forage}_{(M)}$	Fishing EF is the sum of all the inputs.	(8)
$\text{Fishing}_{EF(T)} = \text{Fuel}_{EF(T)} + \text{VGCM}_{EF(T)} + \text{Human Effort}_{EF(T)}$	EF_T is the sum of all terrestrial inputs.	(9)
$\text{Fuel}_{EF(T)} = \dfrac{\text{Volume of Fuel}_{L} \times \text{Fuel}_{\text{Energy MJ/L}} \times \text{Carbon Dioxide Emitted}_{\text{G CO2 MJ}^{-1}}}{\text{Sequestration Rate}_{\text{G CO2 Ha}^{-1}} * \text{Total Fish}_{\text{Tonne}}}$	$\text{Fuel}_{EF(T)}$ numerator is calculated by multiplying the number of litres of fuel used, by the amount of energy released from combusting a litre of that fuel type and the amount of carbon dioxide released per mega joule. The numerator is divided by the denominator, which is the product of the sequestration rate multiplied by the number of tonnes of fish caught.	(10)
$\text{VGCM}_{EF(T)} = \text{Vessel Type}_{EF\ ft^{-1}} \times \text{Total Vessel Length}_{ft}$	Select the EF per foot for vessel type that best matches the fleet of vessels being investigated and multiply by the total length of all vessels in the fleet to give the EF from vessel and gear construction and maintenance.	(11)
$\text{Human Effort}_{EF(T)} = \{ [\text{Fishing}_{\text{days}} \times \text{Number of Crew}]/365.25_{\text{days/year}} \} \times \text{Person}_{EF(T)}$	The EF for human effort is calculated as the product of the number of fishing years by the annual EF terrestrial per person for the nationality of those doing the fishing. The number of fishing years is calculated as the	(12)

product of the number of days at sea by the number of crew, divided by number of days in a year.

$$\text{Ancient}_{EF\ M} = \frac{\text{Fuel per Tonne}_{L} \times \text{Fuel}_{g\,C\,L^{-1}} \times \text{Ratio to Ancient Carbon}}{\text{Conversion}_{m^2\,ha^{-1}} \times \text{NPP of Ocean Region}_{g\,C\,m^{-2}}}$$

The numerator is litres of fuel per tonne multiplied by grams of carbon found per litre multiplied by ratio of ancient carbon required to current carbon. The value for the numerator is divided by the product of the Conversion factor of m^2 to ha and the NPP of the ocean region where the petroleum was supposedly formed. (13)

$$\text{Human Effort}_{EF\,(M)} = \{[\text{Fishing}_{days} \times \text{Number of Crew}]/365.25_{days/year}\} \times \text{Person}_{EF\,(M)}$$

Human effort marine is derived in the same fashion as the human effort terrestrial, the difference is the number of people years fishing is multiplied by the annual marine EF value per person of that nationality. (14)

$$EF_{Forage} = PPR_{Tonne\ g\,C} / [PPR_{g\,C\,m^{-2}\,yr^{-1}} * 10{,}000_{m^2\,ha^{-1}}]$$

EF forage area is the primary production required (PPR) divided by the product of primary productivity value for the ocean region type and conversion factor from m^2 to hectares. (15)

2.2 Case Study - Northwest Atlantic Cod Fishery

The fisheries data were taken from Costs and Earnings of Selected Inshore and Nearshore Fishing Enterprises in the Newfoundland Region compiled by the Economics Branch of the Department of Fisheries and Oceans for Canada Newfoundland Region for the years 1982 through to 1986. The data collected were through the use of a volunteer survey. The information was presented by categorizing the vessels into fishing zones and fishing vessel lengths. There is no information to indicate that there is a bias towards underreporting of landings or income.

The survey requested the following information: type of gear used, days at sea, fishing days by gear type, landings (round weight) by gear type, landings by species, landed value (in current dollars) by species, the cost of operating the vessel, the number of people involved in the fishing activity (labour), their designation, and the amount that was earned by the individuals involved in the fishery activity.

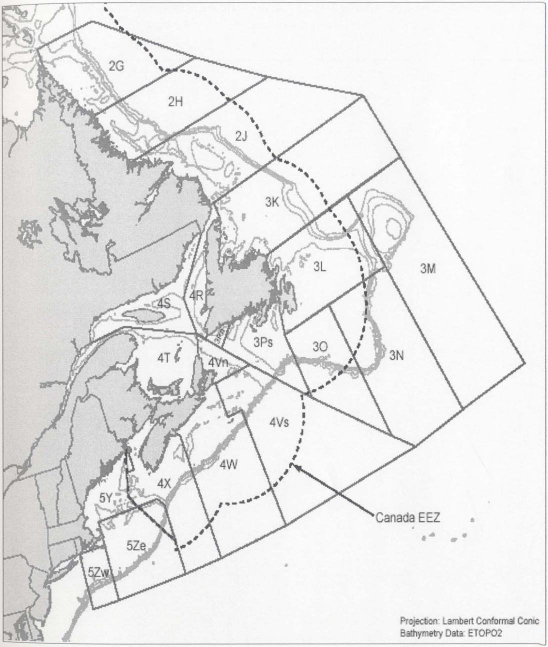
The data used for this thesis from the surveys was taken from the published reports. The published reports indicated mass caught by vessel and gear type. However, by using the published data it is not possible to determine by which vessel class. Unfortunately the method in which the information of the surveys was displayed in the reports it did not appear possible to calculate the efficiency by gear type. All vessel classes harvested a wide variety of categories and species: groundfish, pelagic and estuarial, shellfish and seals as composition of their landings. The published reports indicated that a variety of fishing gears were used as well: gillnets, hand lines, jiggers, pots, seines and trawls according to the aquatic life attempting to be harvested. It should be noted that according to the reports it could be inferred that a crew member may end up serving on more than one vessel. As labour is counted per vessel class, the crew member effort is indicated as day spent at sea. Therefore for the purposes of this study, whether a member of the crew served on two vessels is not a significant factor. The fleet being evaluated was

The reports classified the vessel classes into four vessel length categories, two defined as inshore and two defined as nearshore. Inshore vessels are defined as those that are less than twenty-five feet, small inshore vessel (SIV) and those that are between twenty-five feet to thirty-four feet, large inshore vessel (LIV). Nearshore vessels are thirty-five feet to forty-four feet, small nearshore vessel (SNV) and forty-five feet to sixty-four feet, large nearshore vessel (LNV).

The data collection was for fishing zones as labeled by the Northwest Atlantic Fisheries Organization (NAFO) as 3K, 3L and 3Ps. For the purposes of this study only fisheries information from 3K and 3L were used. These are fishing zones that border the island of Newfoundland on the northeast coast. Latitudinal boundaries for division 3K are 49°15' North and 52°15' North. The eastern boundary is 54°30' West and the western boundary is the Island of Newfoundland. Division 3L is defined as: Latitudinal boundaries 46°00' North and 49°15'

North; eastern boundary is 54°30' West longitude and the western boundary for the fishing zone is the island of Newfoundland with a rhumb line between Cape St. Mary to 46°00' North. Both zones are illustrated in figure 1. The physical definition of the fisheries zone is taken from NAFO's website (2005).

The published data were presented by giving the average numeric (e.g. cost, landed mass, revenue, etc.) value for the fishing vessels in each of the four vessel categories. Multiplying the number of vessels in the category by the average value gives the total numeric value. The number of people that participated in the surveys was listed per year, by vessel length and NAFO zone. This five year period was chosen as the Department of Fisheries had collected and displayed the information in a consistent manner, therefore allowing easy comparability between the different years. Only the Cod fishery was evaluated in the case study as it was the primary fishery for the region. And again the data available for cod through this five year period allowed greater comparability.



(Devine 2006)

Figure 1. Map of North Atlantic Fisheries Organization Divisions

2.2.1 Input Parameters - Case Study

Days Fished: DF: Taken from DFO (1982-1986).

Fuel Consumed: FC :Taken from DFO (1982-1986).

Forest Type: FT: Canadian boreal forests. The dominate forest type on the island (Chen et al. 2003).

Fuel Type: FU : Gasoline. Gasoline has a lower carbon emission value than petro-diesel values. As the fishing fleet used varying mixtures of petroleum, the lower value is used to create a conservative estimate. MJ L^{-1} and g C L^{-1}

Human Effort: HE : Energetics: 8.37 MJ Day^{-1} (Institute of Medicine of the National Academies 2002)

Landings: LA : Taken from DFO (1982-1986).

Nationality of Crew: NC : Canadian

Number of Crew: NU :Taken from DFO (1982-1986).

Ocean Region: OR : Northwest Atlantic (Longhurst et. al 1995).

Percentage Effort: PE :Calculated per year and fishing vessel class.

Percentage Utilization: PU : 32 % (Cull 2000).

Species Type: ST :Cod.

Vessel Length: VL :Taken from DFO (1982-1986).

Vessel Type: VT : Fibre Glass Gillnetter. The fishery fleet involved in this study is likely to be of mixed construction therefore the vessel type with the lowest per foot energy and EF value is used.

2.2.2 Assumptions

- As multiple species are caught regardless of gear and vessel type, there needs to be a method to calculate effort attributable to cod. The assumption is that all kilograms of catch regardless of species type is comparable in effort. This means that the same proportion of fuel or human effort is required in catching a kilogram of cod versus mackerel, capelin, et cetera. Therefore percentage effort attributable to cod is taken as the percentage of cod landed versus the total mass landed of all species.

- The yield of food from one tonne of cod is uniform, regardless of where the cod is caught, type of vessel, the age, size of cod, and time of year harvested.

- The energetics of growing cod to harvesting age is not included. This is done by nature and no human effort was involved in raising the cod.

- The construction, maintenance and lifetime for vessels participating in the east coast cod fishery is not markedly different from the salmon fishery on the west coast of Canada.

- The survey data was representative of the fleet fishing NAFO zones 3K and 3L.

- The reporting through the volunteer was fair and accurate. That is there is no under or over estimation of landings and income.

- Vessel length per foot is uniform despite the fact that vessels beam increases proportionally as vessels get longer.

2.2.3 Case Study - Energetics Northwest Atlantic Cod Fishery

Formula	Explanation	Equation
$\text{Energy}_{\text{Fishing}} = \text{Energy}_{\text{Fuel}} + \text{Energy}_{\text{VGCM}} + \text{Energy}_{\text{Human Effort}}$	General Formula	(16)
$\text{Fuel}_{\text{Energy}} = \text{FC}_{\text{L}} \times \text{PE}_{\text{Cod}} \times \text{FT}_{\text{MJ L}^{-1}}$	Multiplying the number of litres of fuel consumed by percentage effort and the number of mega joules available per litre gives total energy from fuel. Number of litres was determined by dividing total money spent on fuel by the cost per litre given in the Annual Cost of Fuel and Utilities Newfoundland and Labrador (NSA 1986).	(17)
$\text{VGCM}_{\text{Energy}} = \text{VT}_{\text{MJ ft}^{-1}} \times \text{Number of Vessels} \times \text{Average Vessel Length}_{\text{ft}} \times \text{PE}_{\text{Cod}}$	Multiplying the energy per foot according to vessel type by the number of vessels, average vessel length, and percentage effort gives energy from the vessel and gear construction and maintenance.	(18)
$\text{Human Effort}_{\text{Energy}} = \text{DF}_{\text{Days}} \times \text{Number of Crew} \times \text{PE}_{\text{Cod}} \times \text{HE}_{\text{MJ Day}^{-1}}$	Energy from human effort is calculated by multiplying the number of days at sea by number of crew, percentage effort and daily energy expenditure.	(19)
$\text{Fish}_{\text{Energy}} = \text{Fish}_{\text{kg}} \times \text{PU}_{\text{Cod}} \times \text{Calories Available}_{\text{Cal kg}^{-1}} \times \text{Conversion Rate}_{\text{MJ Cal}^{-1}}$	Multiply kilograms of fish caught by percentage utilized, calories available per kilogram and the conversion factor from calories to mega joules.	(20)
$\text{Energetic Ratio} = \text{Cod}_{\text{Energy}} / \text{Fishing}_{\text{Energy}}$	Food energy from cod divided by energy spent catching cod.	(21)

2.2.4 Case Study – Ecological Footprint Northwest Atlantic Cod Fishery

Formula	Explanation	Equation
$\text{Cod Fishing}_{EF} = \text{EF}_{\text{Terrestrial (T)}} + \text{EF}_{\text{Marine (M)}}$	General formula	(22)
$\text{Cod Fishing}_{EF} = \text{Fuel}_{EF\,(T)} + \text{VCGM}_{EF\,(T)} + \text{HE}_{EF\,(T)} + \text{HE}_{EF\,(M)} + \text{Forage}_{(M)}$	General formula indicating the input types.	(23)
$\text{EF Fuel}_{T} = \dfrac{\text{FC}_{L} \times \text{PE} \times \text{FU}_{MJ\,L}^{-1} \times \text{Carbon Dioxide Emitted}_{g\,CO_2\,MJ^{-1}}}{\text{FT}_{g\,CO_2/ha} \times \text{Fish}_{\text{Tonne}}}$	The number of litres of fuel used fishing is calculated by dividing the amount of money spent on fuel by the cost per litre (NSA 1986). Multiplying the number of litres of fuel consumed by percentage effort attributable to cod, energy released per litre and grams of carbon dioxide released per mega joule gives the total amount of carbon dioxide released. This figure is then divided by the product of sink rate of carbon dioxide of the forest and tonnes of cod to give the EF Fuel $_T$.	(24)
$\text{EF}_{VGCM} = \text{Number of Vessels} \times \text{Average Vessel Length}_{ft} \times \text{VT}_{EF\,ft}^{-1} \times \text{PE}_{\text{Cod}}$	Multiplying the number of vessels by average vessel length, EF value per foot based on vessel type and percentage effort attributable to cod gives the EF $_{VGCM}$. The lowest EF value per foot was the fibre glass gillnetter. Considering that the fishing fleet involved in this study is likely to be of mixed construction, the lowest value taken was the fibre glass gillnetter to give the more conservative EF value.	(25)
$\text{HE}_{EF\,T} = [(\text{DF} \times \text{Number of Crew} \times \text{PE}_{\text{Cod}})/365.25_{\text{days year}}^{-1}] \times \text{Person}_{EF\,T\ \text{year}}^{-1}$	The EF for human effort is calculated as the product of the number fishing years by the annual EF terrestrial per person for a Canadian. The number of fishing years is calculated as the product of the number of days at sea by the number of crew, divided by number of days in a year.	(26)
$\text{Ancient}_{EF\,M} = \underline{\text{Fuel per Tonne}_{L} \times \text{Fuel}_{g\,C\,L}^{-1} \times \text{Ratio to Ancient Carbon}}$	The numerator is litres of fuel per tonne is multiplied by grams of carbon found per litre	(27)

$\text{Conversion}_{m^2\,ha^{-1}} \times \text{NPP of Ocean Region}_{g\,C\,m^{-2}}$	multiplied by ratio of ancient carbon required to current carbon. The value for the numerator is divided by the product of the Conversion factor of m2 to ha and the NPP of the ocean region where the petroleum was supposedly formed.	
$\text{Forage}_M = \text{PPR}_{\text{Tonne}\,g\,C} / [\text{PPR}_{g\,C\,m^{-2}\,yr^{-1}} \times 10{,}000_{m^2 ha^{-1}}]$	Primary Production Required (PPR) grams of carbon required per tonne of cod (Pauly & Christensen 1995) divided by the product of primary productivity for the ocean region (PPR) off the coast of Newfoundland (Longhurst et al 1995) and the conversion factor from square metres to hectares gives the EF Forage.	(28)
$\text{HE}_M = [(\text{DF} \times \text{Number of Crew} \times \text{PE}_{\text{Cod}})/365.25_{\text{days year}^{-1}}] \times \text{Person}_{\text{EF M year}^{-1}}$	This is the same procedure as that for EF_T human effort except it is multiplying the number of people years spent fishing by the marine EF component for a person living in Canada.	(29)

3. Results

The chapter is divided into three sections. The first section presents the results of the energetic return evaluation. This is followed by the EF and lastly an examination of the effort attributable to cod. At the beginning of the first two sections is a general explanation of the results followed by tables, figures and an explanation of the results based on the vessel length classes.

It should be noted for the purposes of this study that the vessel and gear construction and maintenance cost (VGCM) with respect to energy and EF is the same per year for the lifetime of the vessel. However, as the fishing effort attributable to cod varies per year so will the level of energy and EF attributable from the vessel's construction and maintenance towards the total energy and EF.

3.1 Energetics - Energetic Return

The energetic return derived from cod for human consumption versus that expended on procuring cod is shown in Table 1. This is the energetic return cost for just fishing cod, and does not include the processing, transportation, refrigeration and cooking required before human consumption.

Table 1. Energetic Return by Year and Vessel Class

Vessel Class	1982	1983	1984	1985	1986	Average
Less Than 25' (SIV)	0.23	0.22	0.19	0.15	0.15	0.19
25'-34' (LIV)	0.75	0.67	0.69	0.58	0.48	0.63
35'-44' (SNV)	0.40	0.45	0.45	0.46	0.38	0.43
45'-64' (LNV)	0.40	0.38	0.41	0.35	0.32	0.37

None of the fishery vessel classes returned more calories than were consumed in the act of fishing. The vessel category with the lowest general energetic return was SIV. The five year average was 0.19, less than a fifth of a calorie is returned in the pursuit of fishing. This vessel class returns ranged from a high of 0.23 for 1982 to a low of 0.15 in 1986. The vessel class with the highest energetic return was LIV, which averaged 0.63 for the five year period. In this category, the energetic return ranged from a high of 0.75 in 1982 with a steady downward trend to 0.48 in 1986. The SNV vessel class had the second highest energetic return, averaging 0.43 for the five year period. The largest vessel class, LNV had the second lowest energetic return over the five year period with a value of 0.37.

When using the five year average for each vessel class, it appears they can be grouped into three different levels. The first level, having the least yield, is the SIV. The second level has twice the energetic yield of the first group, and contains the two largest vessel classes, SNV and LNV. The third level is LIV which has the highest yield, a little over three times the lowest yield.

Observed in three of the four vessel categories was a general trend of decreasing energetic return over time. The exception is the vessel category of SNV. Here the values increased in the middle years of the five year time span.

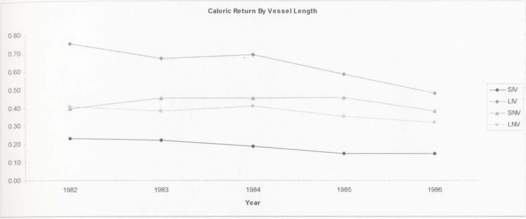


Figure 2. Graph of the Energetic Return for the Four Vessel Classes from 1982-1986

3.1.1 Small Inshore Vessel (SIV)

The energetic return values for the less than twenty-five feet class results are shown in the Table 2. The five year average was 0.19. The highest value was 0.23 and the lowest found in the final two years was 0.15. During the five year period a general decreasing energetic return trend was observed.

Table 2 Energy (Gigajoules) from Cod and Energy Expended in Inputs for Vessel Class SIV

	82	83	84	85	86	Average
Energy $_{Fish}$	454	601	1,192	1,012	1,132	
Energy $_{Fuel}$	1,419	1,943	4,696	5,058	5,922	
Energy $_{People}$	41	71	138	153	129	
Energy $_{Vessel}$	507	691	1,500	1,594	1,672	
Total Energy	1,967	2,706	6,334	6,805	7,723	
Energetic Return	0.23	0.22	0.19	0.15	0.15	0.19

The percentage of energy expended by input type is given in Table 3. The energy from fuel constitutes over seventy percent of the energy expended for fishing in all years. Energy from human effort is very low, two percent or less for all years.

Table 3 Energy from Cod and Energy Required by Inputs for Vessel Class SIV

Input	**82**	**83**	**84**	**85**	**86**	**Average**
Fuel $_{Energy}$	72%	72%	74%	74%	77%	74%
People $_{Energy}$	2%	3%	2%	2%	2%	2%
Vessel $_{Energy}$	26%	26%	24%	23%	22%	24%

3.1.2 Large Inshore Vessels (LIV)

The five year energetic return average was 0.64 (Table 4). For the first three years the value hovered around 0.7. In the final two years the energetic return decreases, reaching the low of 0.48 in the final year.

Table 4. Energy (Gigajoules) from Cod and Energy Expended in Inputs for Vessel Class LIV

	82	83	84	85	86	Average
Energy Fish	3,111	3,075	2,983	2,629	2,854	
Energy Fuel	2,741	3,010	3,033	3,021	4,717	
Energy People	133	176	174	148	169	
Energy Vessel	1,269	1,416	1,129	1,345	1,081	
Total Energy	4,143	4,602	4,335	4,514	5,966	
Energetic Return	0.75	0.67	0.69	0.58	0.48	0.63

The energy from fuel is the dominant input, with the 5 year average at 71% (Table 5). The highest observed in the final year at 80%. Second is the energy from vessel construction and maintenance and then finally energy expended by people. The energy expended by people represents from one to three percent, a small fraction of the total energy expended.

Table 5. Percentage Energy Expended by Input Type for Vessel Class LIV

Input	82	83	84	85	86	Average
Fuel Energy	66%	65%	70%	67%	79%	71%
People Energy	3%	4%	4%	3%	3%	3%
Vessel Energy	31%	31%	26%	30%	18%	27%

3.1.3 Vessel Class Small Nearshore Vessel (SNV)

The five year average was 0.43 (Table 6). A slight increase in energetic return for the middle three years was observed, followed by a drop in energetic return to approximately the same level as was observed in the first year.

Table 6. Energy (Gigajoules) from Cod and Energy required by Inputs for Vessel Class SNV

	82	83	84	85	86	Average
Energy $_{\text{Fish}}$	1,243	1,841	2,865	1,763	1,617	
Energy $_{\text{Fuel}}$	2,608	3,392	5,328	3,086	3,476	
Energy $_{\text{People}}$	47	69	102	67	77	
Energy $_{\text{Vessel}}$	489	614	931	709	670	
Total Energy	3,145	4,0745	6,361	3,861	4,223	
Energetic Return	0.40	0.45	0.45	0.46	0.38	0.43

The 35 to 44 feet vessel class has fuel input accounting for over 80 % of energy expended in pursuit of fishing (Table 7). The energy from the vessel is in the mid to high teens. With the energy expended from people at one percent, again a very small fraction of the energy expended in landing cod.

Table 7. Percentage Energy Expended by Input Type for Vessel Class SNV

	82	83	84	85	86	Average
Fuel $_{\text{Energy}}$	83%	83%	84%	80%	82%	82%
People $_{\text{Energy}}$	2%	2%	2%	2%	2%	2%
Vessel $_{\text{Energy}}$	16%	15%	15%	18%	16%	16%

3.1.4 Vessel Class Large Nearshore Vessel (LNV)

The five year average was 0.37 (Table 8). The LNV class had energetic returns hovering at the 0.4 level for the first three years and then dropped off in the final two years. This was the second lowest energetic return of the four vessel classes.

Table 8. Energy (Gigajoules) from Cod and Energy Expended in Inputs for Vessel Class LNV

	82	83	84	85	86	Average
Energy $_{Fish}$	2,704	1,640	4,445	2,450	2,034	
Energy $_{Fuel}$	6,041	3,888	9,625	6,046	5,418	
Energy $_{People}$	62	35	116	82	74	
Energy $_{Vessel}$	586	355	1,125	826	874	
Total Energy	6,689	4,279	10,866	6,954	6,367	
Energetic Return	0.40	0.38	0.41	0.35	0.32	0.37

The LNV class had the highest observed energy expenditure from fuel (Table 9). The energy from people was again a small fraction of the energy expended in pursuing fish. The energy from the vessel over the five years was at eleven percent.

Table 9. Percentage Energy Expended by Input Type for LNV

	82	83	84	85	86	Average
Fuel $_{Energy}$	90%	91%	89%	87%	85%	88%
People $_{Energy}$	1%	1%	1%	1%	1%	1%
Vessel $_{Energy}$	9%	8%	10%	12%	14%	11%

The figures 3 - 6 indicate the five-year average percentage energy by Input type. The percentage attributable to human effort is very small. Fuel is the largest input type by almost a magnitude of three greater than next highest being the vessel and gear construction and maintenance.

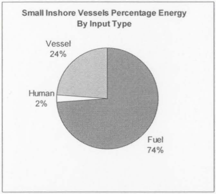


Figure 3. Percentage Energy Expended (Five Year Average) by Input Type for SIV

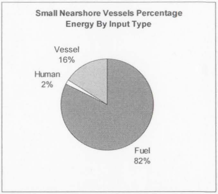


Figure 5. Percentage Energy Expended (Five Year Average) by Input Type for LIV

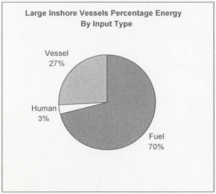


Figure 4. Percentage Energy Expended (Five Year Average) by Input Type for SNV

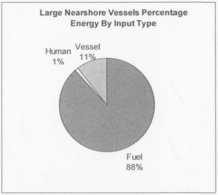


Figure 6. Percentage Energy Expended (Five Year Average) by Input Type for LNV

3.2 EF Results

The EF_M did not fluctuate much between the four vessel categories. The EF_M is almost entirely the result of the foraging area required for cod to grow. The component from human effort in pursuing fishing is so small that it is insignificant when compared to the foraging area. Table 10 summarizes the results of the total marine EF.

Table 10. EF_M (hectares/tonne) by Year and Vessel Class

	1982	1983	1984	1985	1986
SIV	14.09	14.10	14.10	14.11	14.10
LIV	14.08	14.09	14.09	14.09	14.09
SNV	14.08	14.08	14.08	14.08	14.08
LNV	14.08	14.08	14.08	14.08	14.08

For the EF_M 14.07 ha of total was the result of the forage area for cod in the northwest Atlantic. The balance of the EF was the result of human effort from actively fishing. EF_M from human effort per tonne was very small and ranging from 0.01 per tonne to 0.03. The highest EF_M values were found in the category of vessels SIV. LIV commenced at 14.08 and rose and remained at 14.09. The other two vessel category lengths remained at 14.08.

The EF_M is not a metric that can be used to distinguish the ecological efficiencies of the different vessel classes. However, the EF_T values for the four vessel classes varied. The EF_T is a metric that can be used to distinguish ecological efficiencies. Table 11 summarizes the terrestrial EF_T by vessel length and year.

Table 11. EF_T (hectares/tonne) by Year and Vessel Class

	1982	1983	1984	1985	1986	Average
SIV	0.36	0.39	0.45	0.57	0.56	0.47
LIV	0.12	0.14	0.13	0.15	0.18	0.15
SNV	0.21	0.18	0.18	0.18	0.22	0.20
LNV	0.20	0.21	0.20	0.23	0.25	0.22

With respect to fishing vessel length the category of SIV had the highest EF_T values, with an average of 0.47 ha per tonne. The next highest was vessel class LNV with 0.22 hectares per tonne. The second lowest was the SNV class with 0.20 hectares per tonne. The lowest EF_T values were the vessel category of LIV with a five year average of 0.15 hectares per tonne.

Similar to the energetic return it would appear that amongst the four vessel classes there were three orders of EF_T. The lowest order is the LIV, followed by the two largest vessel classes, SNV and LNV, which had approximately one and third to one and a half times greater EF_T values than the lowest class. The highest level was SIV, which was over three times greater than the lowest order.

For three of the four vessel classes increased EF_T over the five year period was observed. The SNV class remained relatively stable. It appears to have dipped in the middle years.

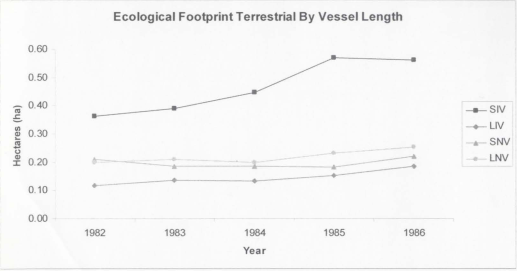


Figure 7. Graph of the EF_T for the Four Vessel Classes from 1982-1986

The EF_M Ancient has the same trends as does EF_T. This is not surprising as it represents the ancient NPP region required to create the fuel that was used in the pursuit of the fishery. The SIV has the greatest five-year average, followed by LNV, SNV and lastly LIV with the smallest region of ancient NPP required.

Table 12. EF_M (hectares/tonne) Ancient by year and vessel class

EF Ancient	1982	1983	1984	1985	1986	Average
SIV (LT 25')	126	130	159	202	211	166
LIV (25'-34')	36	39	41	46	67	46
SNV (35'-44')	85	74	75	71	87	78
LNV (45'-64')	90	96	87	100	107	96

3.2.1 Small Inshore Vessel (SIV)

The five-year average for SIV was 0.47 hectares per tonne (Table 13). The EF_T value for the vessel class had a general increasing trend between the first and last year. The increase was effectively due to the result of an increase in EF_T for fuel.

Table 13. EF_T, EF_M and EF_M Ancient (hectares/tonne) for Cod by Input Type and Total for Small Inshore Vessels1982 - 1986

	82	83	84	85	86	Average
Fuel $_{EF (T)}$	0.24	0.25	0.31	0.39	0.41	0.32
Human Effort $_{EF(T)}$	0.05	0.07	0.06	0.08	0.06	0.07
Vessel EF $_{(T)}$	0.07	0.07	0.08	0.10	0.09	0.08
EF Terrestrial	**0.36**	**0.39**	**0.45**	**0.57**	**0.56**	**0.47**
Human Effort $_{EF(M)}$	0.02	0.03	0.03	0.03	0.03	0.03
Forage $_{EF(M)}$	14.07	14.07	14.07	14.07	14.07	14.07
EF Marine	**14.09**	**14.10**	**14.10**	**14.11**	**14.10**	**14.10**
EF_M Ancient	**126**	**130**	**159**	**202**	**211**	**166**

The input of fuel represents sixty-eight percent of the EF_T for cod caught in this vessel category. The vessel construction and maintenance represent a little less than twenty percent of the EF_T and human effort is a smaller fraction at fourteen percent.

Table 14. Percentage EF_T by Input Type for Vessel Class SIV

Input	82	83	84	85	86	Average
Fuel $_{EF (T)}$	67%	65%	69%	68%	73%	68%
Human Effort $_{EF(T)}$	14%	17%	14%	15%	11%	14%
Vessel EF $_{(T)}$	19%	18%	17%	17%	16%	17%

3.2.2 Large Inshore Vessel (LIV)

The five year average EF_T was 0.15 hectares per tonne (Table 15). A general increasing EF_T trend was observed. The EF_T increase was effectively the result of the increased fuel used to catch one tonne of fish. EF_T attributable to human effort and from vessel construction and maintenance was more or less unchanged.

Table 15. EF_T, EF_M and EF_M Ancient (hectares/tonne) for Cod by Input Type and Total for LIV: 1982 - 1986

	82	83	84	85	86	Average
Fuel $_{EF(T)}$	0.07	0.08	0.08	0.09	0.13	0.09
Human Effort $_{EF(T)}$	0.02	0.03	0.03	0.03	0.03	0.03
Vessel EF $_{(T)}$	0.02	0.03	0.02	0.03	0.02	0.03
EF Terrestrial	**0.12**	**0.14**	**0.13**	**0.15**	**0.18**	**0.15**
Human Effort $_{EF(M)}$	0.01	0.01	0.01	0.01	0.01	0.01
Forage $_{EF(M)}$	14.07	14.07	14.07	14.07	14.07	14.07
EF Marine	**14.08**	**14.09**	**14.09**	**14.09**	**14.09**	**14.09**
EF_M Ancient	**36**	**39**	**41**	**46**	**67**	**46**

Over the five year period the EF_T due to fuel represented sixty percent of the EF_T (Table 16). The EF_T for the vessel construction and maintenance was twenty-one percent and human effort at eighteen percent.

Table 16. Percentage EF_T by Input Type for LIV

Input	82	83	84	85	86	Average
Fuel $_{EF(T)}$	59%	56%	59%	59%	70%	60%
Human Effort $_{EF(T)}$	20%	24%	24%	21%	18%	21%
Vessel EF $_{(T)}$	21%	21%	17%	20%	12%	18%

3.2.3 Small Nearshore Vessel (SNV)

The five year average was 0.20 hectares per tonne (Table 17). A decrease in the EF_T for the middle three years was observed. The first and last years were very similar at 0.21 and 0.22 hectares per tonne. The middle three years were at the same level of 0.18 hectares per tonne. The decrease during the three year period was due to decreased EF_T for fuel.

Table 17. EF_T, EF_M and EF_M Ancient (hectares/tonne) for Cod by Input Type and Total for Vessel Class SNV: 1982 - 1986

	82	83	84	85	86	Average
Fuel $_{EF\,(T)}$	0.16	0.14	0.15	0.14	0.17	0.15
Human Effort $_{EF(T)}$	0.02	0.02	0.02	0.02	0.03	0.02
Vessel EF $_{(T)}$	0.02	0.02	0.02	0.02	0.03	0.02
EF Terrestrial	0.21	0.18	0.18	0.18	0.22	0.20
Human Effort $_{EF(M)}$	0.01	0.01	0.01	0.01	0.01	0.01
Forage $_{EF(M)}$	14.07	14.07	14.07	14.07	14.07	14.07
EF Marine	14.08	14.08	14.08	14.08	14.08	14.08
EF_M Ancient	85	74	75	71	87	78

For this vessel length the EF_T due to fuel represents almost eighty percent. The levels due to the vessel and human effort are twelve and eleven percent respectively.

Table 18. Percentage EF_T by Input Type for SNV

Input	82	83	84	85	86	Average
Fuel $_{EF\,(T)}$	78%	78%	79%	75%	76%	77%
Human Effort $_{EF(T)}$	10%	11%	11%	12%	12%	11%
Vessel EF $_{(T)}$	11%	11%	11%	13%	11%	12%

3.2.4 Large Nearshore Vessel (LNV)

LNV class had a five year average of 0.22 hectares per tonne (Table 19). A general increasing EF_T trend was observed. Of the five years observed, the middle year had a slight dip in the EF_T value. The dip was the result of lower EF_T attributable to fuel. This vessel length category had the second highest average EF_T.

Table 19. EF_T, EF_M and EF_M Ancient (hectares/tonne) for Cod by Input Type and Total for LN V: 1982 - 1986

	82	83	84	85	86	Average
Fuel $_{EF\ (T)}$	0.17	0.18	0.17	0.19	0.21	0.19
Human Effort $_{EF(T)}$	0.01	0.01	0.01	0.02	0.02	0.02
Vessel EF $_{(T)}$	0.01	0.01	0.02	0.02	0.03	0.02
EF Terrestrial	0.20	0.21	0.20	0.23	0.25	0.22
Human Effort $_{EF(M)}$	0.01	0.00	0.01	0.01	0.01	0.01
Forage $_{EF(M)}$	14.07	14.07	14.07	14.07	14.07	14.07
EF Marine	14.08	14.08	14.08	14.08	14.08	14.08
EF_M Ancient	90	96	87	100	107	96

For the five-year average, the input of fuel accounts for eighty-five percent of the EF_T. The vessel construction and maintenance accounts for eight percent and the EF_T due to humans is at seven percent.

Table 20. Percentage EF_T by Input Type for LNV

Input	82	83	84	85	86	Average
Fuel $_{EF\ (T)}$	87%	88%	85%	83%	82%	85%
Human Effort $_{EF(T)}$	6%	6%	7%	8%	8%	7%
Vessel EF $_{(T)}$	7%	6%	8%	9%	10%	8%

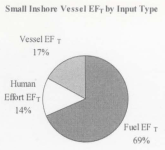


Figure 8. Percentage EF$_T$ (Five Year Average) by Input Type for SIV

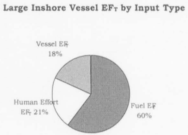


Figure 9. Percentage EF$_T$ (Five Year Average) by Input Type for LIV

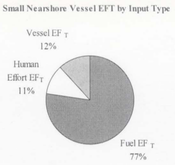


Figure 10. Percentage EF$_T$ (Five Year Average) by Input Type for SNV

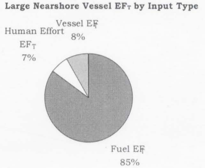


Figure 11. Percentage EF$_T$ (Five Year Average) by Input Type for LNV

3.3 Cod Effort

As indicated in earlier chapters the method used for determining the level of effort attributable to cod was by taking the percentage round weight of cod landed versus total round weight of all species landed by the vessel. Table 21 indicates the percentage effort by vessel class by year.

Table 21. Effort Attributable to Cod by Year and Vessel Class

	1982	1983	1984	1985	1986	Average
SIV	79%	90%	83%	79%	66%	80%
LIV	83%	86%	83%	75%	65%	78%
SNV	51%	61%	63%	49%	45%	54%
LNV	66%	66%	46%	47%	70%	59%

The vessel class with the highest effort for cod (cod representing the greatest percentage of catch) was the SIV, with the five-year average at 80 percent. The next vessel class was LIV with a five-year average of 78 percent. The third is the LNV at 59 percent and finally the SNV class at 54 percent.

Cod represented almost four-fifths of the landings for the inshore vessel classes. The percentage effort attributed to inshore vessels decreased from the second to the fifth year. The nearshore vessel classes did not appear to have a common trend. The SNV saw an increase in the middle two years and then a decline in the last two. The LNV class saw a dip in the 1984 and 1985 and then a rise in 1986.

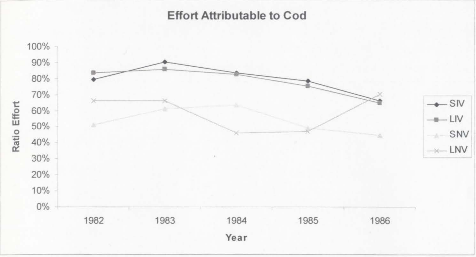


Figure 12. Graph of the Effort Attributable to Cod for the Four Vessel Classes from 1982-1986

4. Discussion

Restating the hypothesis, given that the inshore and nearshore fisheries off the coast of Newfoundland have been pursued for several hundred years, optimal techniques and methodology would have been developed during the pre-industrial period leading to maximal energetic return. With the advent of the industrial age, engines powered by fossil fuels were introduced reducing the requirement for human, wind and current power in a fishery. Currently all fishery vessel types involved in the cod fishery use engines and fossil fuels. Larger vessels can hold larger harvests therefore theoretically may be economically cheaper. However, as the scale is greater, because they may consume more fuel per tonne harvested. The overall energy required through the increased mechanization will be great. It might therefore be hypothesized that the smallest vessel class will have the optimal energetic return and lowest Ecological Footprint (EF). It might also be hypothesized that with an increase vessel size, energetic return would diminish and EF increase.

Table 22 Five Year Average Results by Vessel Class

Vessel Class	Energetic Return	EF_T (ha)	EF_M (ha)	EF_M Ancient (ha)
SIV (LT 25')	0.19	0.47	14.1	166
LIV (25'-34')	0.63	0.15	14.1	46
SNV (35'-44')	0.43	0.20	14.1	78
LNV (45'-64')	0.37	0.22	14.1	96

As seen in Table 22 above, the best energetic return, lowest EF_T and lowest EF_M Ancient observed were for the large inshore vessel class (LIV) 25-34 feet, followed by small nearshore vessel class (SNV) 35-44 feet, then by the large nearshore vessel class (LNV) 45-64 feet. The worst were for the small inshore vessel class (SIV) less than 25 feet. Contrary to my hypothesis, the smallest fishing vessel class SIV had the lowest energetic returns and highest EFs. However, in accordance with the predictions, a trend of decreasing energetic return and increasing EFs was observed with increasing vessel size commencing with the second smallest vessel class, LIV, as opposed to the smallest vessel class.

None of the four vessel classes returned an energetic surplus. Even the best energetic return ratio was less than one-to-one. Considering that these calculations do not include the energy for cod processing, transport to market and purchase, the energetic return for northwest Atlantic cod procurement is actually lower than estimated here. Industrial fish foraging for the northwest Atlantic cod is a strategy that requires a considerable amount of external energy.

Three of the four vessel classes had a diminishing energetic return and increasing EF_T over the period under study. The ratio decreased between the first and last year for all vessel classes except SNV, 35 to 44 feet. The SNV class energetic return remained relatively the same over the five-year period. For the other three vessel classes, the first year had the best energetic return and the last year the worst energetic return during the five-year period. The percentage change can be seen in Table 23.

Table 23. Energetic Return Percent Change From First to Fifth Year

Vessel Class	First Year Energetic Return	Fifth Year Energetic Return	Percentage Change	Average	Magnitude
SIV	23 %	15 %	-36.6 %	19 %	n
LIV	75 %	48 %	-36.4 %	64 %	~3n
SNV	40 %	38 %	-3.0 %	43 %	~2n
LNV	40 %	32 %	-20.9 %	37 %	~2n

The percentage increase in EF_T between the first year and the last year for the different vessel classes is shown in Table 24.

Table 24. EF Terrestrial Per Tonne Percent Change From First to Fifth Year

Vessel Class	First Year EF_T	Fifth Year EF_T	Percentage Change	Average	Magnitude
SIV	0.36	0.56	55.3	0.47	~ 3n
LIV	0.12	0.18	57.6	0.15	n
SNV	0.21	0.22	5.1	0.20	~ 1.3n
LNV	0.20	0.25	27.0	0.22	~ 1.5n

The four fishing vessel classes can be categorized into three different groups or levels of magnitudes for energetic return (Table 23) and EF_T (Table 24). The highest energetic returns were for the 25 – 34 feet class (LIV), approximately one and one half times greater than the next 35-44 feet (SNV) class and the 45-64 feet class (LNV). This level is three times greater than the lowest energetic return found with the less than 25 feet class (SIV). With respect to EF_T, the four vessel classes fall into the same three groups. The LIV has the lowest EF_T, approximately two thirds the value of the next two vessel classes, SNV and LNV, and is a third the value of the SIV which has the largest EF_T. It would appear that the vessel class LIV was the optimal vessel length for maximizing energetic return and minimizing EF.

My results indicate that the LIV was the most efficient vessel length, followed by the SNV, LNV and SIV. The better returns may be the result of several factors. It could be that amongst these vessel classes the LIV had the most fuel efficient engines, therefore resulting in less fuel being consumed per tonne harvested. Another possibility is that this vessel class size may result in optimal strategy for making trips between the shore and fishing area to catch fish and back to shore for processing.

There are several possible explanations for why the SIV had the lowest energetic returns and highest EFs. The SIV engines may have low fuel efficiencies, therefore leading to poorer energetic returns and increased EF. The profit motivation may be higher for the larger vessel classes, resulting in them returning to shore only when the hold is full. For the SIV class, economic factors might be a greater driving force and other duties may result in vessels returning to shore even without filling the hold. This would increase the number of trips between shore and fishing grounds, resulting in decreased energetic return and ecological efficiency. The model may be more sensitive to measuring the effort and energy of the SIV class versus the others. It is also possible that the cod stocks fished by the SIV class were lower than the fish stocks fished by the larger vessel classes contributing to decreased catch per unit of effort energy expenditure.

It should be noted that if any processing of the fish is done on board, it will increase fuel consumption leading to diminishing energetic returns and higher EF_Ts as compared with vessels that do not do any processing on board. Therefore if there is any processing on board vessels it will negatively skew results for energetic return and EF. This may explain a portion of the difference between the two largest vessel classes and the large inshore vessel class.

Given that the energetic returns were decreasing and EFs increasing with time for three of the four vessel classes it would be logical to infer that more effort was required to catch each unit of cod. This means that either the method of fishing was becoming more inefficient or more effort was required to catch one tonne of cod. It is very unlikely that the method of fishing was becoming less efficient with time. Therefore this leads to the scenario of more effort required to catch a tonne of cod as the likely explanation. Given that the cod stocks decreased dramatically by the early 1990s leading to a moratorium on fishing these cod stocks, the trend of diminishing cod stocks was reflected in the data used in this study.

4.1 Addressing Some Assumptions & Data Limitations

The method used for determining the cost (energy and EF_T) of constructing a vessel was based on a per foot value taken from a 32.81 foot vessel (Tyedmers 2000). However, the beam of a vessel increases with increasing length. Therefore, the per foot value will undervalue the construction cost for larger vessels and overestimate it for shorter vessels. However, the per foot energy and EF_T used for the calculations was derived from a ten-metre fiberglass vessel type. This was the most conservative value of the three available for comparison, almost half the value of the ten-metre aluminum hull vessel and 1/8th the value of an eighteen-metre aluminum hull vessel (Appendix B). As the fleets fishing in 3K and 3L consisted of vessels of mixed construction types, the potential for overestimation has been compensated for by the use of a low per foot result. Therefore the calculations are still expected to give a conservative result. Tyedmers (2005) indicated that the vessel construction and maintenance accounts for 10 to 25 percent of the input energy. Only LIV had a value above this range, with a percentage energy contribution of twenty-seven percent. All other calculations had the contribution within or below the range. One of the goals for this study was to ensure that that calculations be as conservative as possible. This was achieved with the per foot values used for energy and EF_T.

Table 25. Percentage of Energy by Input Type by Vessel Class

Vessel Class	Fuel $_{Energy}$	People $_{Energy}$	Vessel $_{Energy}$
SIV	74%	2%	24%
LIV	70%	3%	27%
SNV	82%	2%	16%
LNV	88%	1%	11%

In this study, effort attributable the cod fishery was calculated as the percentage of cod landed versus total landings. For SIV, LIV and for the last three years of the LNV cod effort diminished with time, which means the percentage of cod landed relative to total catch landed was decreasing. As well, for these three vessel classes, the general trend was a decreasing energetic return and increasing EF_T. The vessels's catch rate (Table 21) for other species increased while those for cod decreased, and still the energetic return for cod diminished (Table 1). It would thus appear to be unlikely that the energetic returns were overvalued or the EFs undervalued due to cod being "subsidized" by another fishery.

4.2 Comparing Northwest Atlantic Cod Fisheries to Other Food Production Systems

Table 26 contains the EFs for a variety of aquatic food procurement systems. The EF_M required for the growth of cod is higher than for many commercially caught or aquaculture raised salmon fisheries found on the west coast of Canada. Part of the reason could be that cod growth rates are lower than those for the Pacific Salmon species. As well, this is compounded by lower NPP rates off of the coast of Newfoundland versus the coast of British Columbia, therefore requiring a larger foraging area.

The EF_T for the cod fisheries in the northwest Atlantic was lower than for any of the BC salmon fisheries. It should be noted that the evaluation was performed on the 1980s cod fishery, where as the salmon fisheries studied were in the 1990s. Both fisheries were being studied after a lengthy period of industrial human predation. The additional years can have a significant effect on the fish populations and their associated EFs. This is especially illustrated as the commercial cod fishery was placed in a moratorium in 1992. In addition, some of the salmon fisheries in British Columbia raise and release smolts into the natural fishery. This increases the EF_T for those fisheries. This practice is not performed in the cod fishery in the northwest Atlantic. The cod fishery's entire recruitment was supplied by nature. The EF_T for the cod fisheries, regardless of vessel class were lower than for any of the aquaculture methods. It would appear that aquaculture for aquatic piscivorous species will have higher EF_Ts, as compared with natural fisheries, as a component of the input for aquaculture is fishmeal, a product of another natural fishery.

Table 26. Ecological Footprints of Aquatic Food Production Types

Production System	Ecological Footprint Aquatic (ha/tonne)	Terrestrial (ha/tonne)	Analysis Includes Ecosystem Support to	Source
Semi-intensive pond culture of Tilapia in	0.28	0	O_2 production, P assimilation	Berg *et al.* 1996[c]
Commercially caught pink salmon in B.C.	4.5	0.53	feed, energy, materials, labour	Tyedmers 2000[d]
Commercially caught chum salmon in B.C.	4.6	0.59	feed, energy, materials, labour	Tyedmers 2000[d]
Commercially caught sockeye salmon in B.C.	5	0.68	feed, energy, materials, labour	Tyedmers 2000[d]
Semi-intensive shrimp culture in Colombia	5.4	3.8 to 42	feed, energy, water and	Larsson *et al.*
Commercially caught coho salmon in B.C.	9.3	0.87	feed, energy, materials, labour	Tyedmers 2000[d]
Farmed Atlantic salmon in B.C.	9.9	2.8	feed, energy, materials, labour	Tyedmers 2000[d]
Commercially caught chinook salmon in B.C.	10.1	0.87	feed, energy, materials, labour	Tyedmers 2000[d]
Farmed chinook salmon in B.C.	12.4	3.6	feed, energy, materials, labour	Tyedmers 2000[d]
Commercial Cod Fishery northwest Atlantic – twenty-thirty four feet vessel Class (LIV)	**14.1**	**0.15**	**None**	**This study**
Commercial Cod Fishery northwest Atlantic – Thirty-five to Forty-four feet vessel Class (SNV)	**14.1**	**0.20**	**None**	**This study**
Commercial Cod Fishery northwest Atlantic – forty-five to sixty four feet vessel Class (LNV)	**14.1**	**0.22**	**None**	**This study**
Commercial Cod Fishery northwest Atlantic – Less than twenty-feet vessel Class (SIV)	**14.1**	**0.47**	**None**	**This study**
Intensive net-pen culture of Tilapia in Zimbabwe	17	0.3	feed, O_2 production, P	Berg *et al.* 1996[b].
Farmed Atlantic salmon in Sweden	100	7.5	feed	Folke 1988
Atlantic salmon ranching in Sweden - all interception fishing is stopped so that ranched fish are harvested exclusively in the vicinity of the hatchery	125	< 0.08	feed	Folke 1988
Atlantic salmon ranching in Sweden - interception fisheries continue so that returns to the hatchery are reduced	525	<0.08	feed	Folke 1988

Original table taken from Tyedmers (2000,181)

a) Ecosystem support areas re-calculated based on an average shrimp production rate of 4 tonne/ha/year (Larsson *et al.* 1994).
b) Ecosystem support areas re-calculated based on an average Tilapia production rate of 125 kg/m2 of net-pen/year (Berg *et al.* 1996).
c) Ecosystem support areas re-calculated based on an average Tilapia production rate of 0.5 kg/m2 of pond/year (Berg *et al.* 1996).
d) Tyedmers 2000.

Tyedmers (2004) indicated that vessel construction and maintenance generally contributes between 10% and 25% of the total energy input of an industrial fishery. Given this it may be worthwhile to compare fuel requirements per tonne of fish landed. Table 27 lists different fishery types and the amount of fuel per tonne required, and also includes the edible protein return on investment (EROI).

Table 27. Energy Performance From Industrial Fisheries For Human Consumption

	Main Fishery Targets	Gear	Time Frame	Location of Fishery	Fuel Use Intensity (L / tonne)	Edible Protein EROI
Demersal Fisheries	**Cod**	**Mixed -Vessels LIV (25'-34')**	**Early to Mid 1980's**	**NW Atlantic**	**36[A]**	**0.64**
	Cod	**Mixed – Vessels SNV (35'-44')**	**Early to Mid 1980's**	**NW Atlantic**	**62[A]**	**0.43**
	Cod	**Mixed - Vessels LNV (45'-64')**	**Early to Mid 1980's**	**NW Atlantic**	**76[A]**	**0.37**
	Cod	**Mixed - Vessels SIV (LT 25')**	**Early to Mid 1980's**	**NW Atlantic**	**131[A]**	**0.19**
	Redfish spp.	Trawl	Late 1990's	North Atlantic	420[B]	0.11
	Cod/Flatfish spp.	Danish seine	Late 1990's	North Atlantic	440[B]	0.1
	Cod/Haddock	Longline	Late 1990's	North Atlantic	490[B]	0.091
	Cod/Saithe	Trawl	Late 1990's	North Atlantic	530[B]	0.084
	Alaskan pollock	Trawl	Early 1980's	North Pacific	600[C]	0.052
	Flatfish spp.	Trawl	Early 1980's	NW Pacific	750[C]	0.066
	Croakers	Trawl	Early 1980's	NW Pacific	1,500[C]	0.029
	Flatfish spp.	Trawl	Late 1990's	NE Atlantic	2,300[B]	0.019
Pelagic Fisheries	Herring/Mackerel	Purse seine	Late 1990's	NE Atlantic	100[B]	0.56
	Herring	Purse seine	Early 1980's	NE Pacific	140[D]	0.36
	Herring/Saithe	Danish Seine	Late 1990's	NE Atlantic	140[B]	0.35
	Salmon spp.	Purse seine	1990's	NE Pacific	360[D]	0.15
	Salmon spp.	Trap	Early 1980's	NW Pacific	780[C]	0.072
	Salmon spp.	Gillnet	1990's	NE Pacific	810[D]	0.068
	Salmon spp.	Troll	1990's	NE Pacific	830[D]	0.067
	Herring	Purse seine	Early 1980's	NW Pacific	1,000[C]	0.051

	Skipjack/Tuna	Poll and line	Early 1980's	Pacific	1,400[C]	0.053
	Skipjack/Tuna	Purse seine	Early 1980's	Pacific	1,500[C]	0.049
	Swordfish/Tuna	Longline	Late 1990's	NW Atlantic	1,740[B]	0.042
	Salmon spp.	Gillnet	Early 1980's	NW Pacific	1,800[C]	0.031
	Swordfish/Tuna	Longline	Early 1990's	Central Pacific	2,200[E]	0.027
	Tuna/Billfish	Longline	Early 1980's	Pacific	3,400[C]	0.022
Shellfish Fisheries	Abalone/Clams	Hand gathering	Early 1980's	NW Pacific	300[C]	0.11
	Crab	Trap	Late 1990's	NW Atlantic	330[B]	0.057
	Scallop	Dredge	Late 1990's	North Atlantic	350[B]	0.027
	Shrimp	Trawl	Late 1990's	North Atlantic	920[B]	0.058
	Shrimp	Trawl	Early 1980's	North Pacific	960[C]	0.056
	Norway Lobster	Trawl	Late 1990's	NE Atlantic	1,030[B]	0.026
	Crab	Trap	Early 1980's	NW Pacific	1,300[C]	0.014
	Spiny Lobster	Trawl	Early 1980's	NW Pacific	1,600[C]	0.017
	Squid	Jig	Early 1980's	NW Pacific	1,700[C]	0.033
	Shrimp	Trawl	Late 1990's	SW Pacific	3,000[E]	0.019

Note: Sources A. Current Study B. Tyedmers, 2001; C. Wantanabe and Okubo, 1989; D. Tyedmers, 2000; E. Unpublished data;– original table taken from Tyedmers (2004,12).

Comparatively speaking, the cod fisheries in the northwest Atlantic in the early eighties, regardless of vessel class, had relatively low fuel per tonne ratios. Four of the five lowest fuel per tonne values were from the early eighties northwest Atlantic cod fisheries. The exception was the herring/mackerel fisheries of the late 1990s in the northeast Atlantic which had the fourth lowest fuel per tonne value. The magnitude in difference between the results for cod and other fisheries might be the result of the following or a combination of the following: the cod stocks were still healthy with respect to harvesting, but were moving towards an equilibrium where the biomass would decrease dramatically; the other demersal fish stocks being pursued are also in decline and therefore their fuel use intensity values are high; the species being harvested in the shell and pelagic fisheries inherently require greater fuel consumption as effectively humans are fishing down the food web.

Looking at the edible return on protein investment (EROI), the cod fisheries based on the different vessel lengths had the first (LIV), third (SNV), fourth (LNV) and seventh (SIV) highest returns as found in the Table 27. The fisheries with comparable EROI were the Herring/Mackerel in the late 1990s in the Northeast Atlantic which was second highest at 0.56, Herring in the Northeast Pacific in the early 1980s, the Herring/Saithe in the Northeast Atlantic in the early 1990s, which were fifth and sixth highest with 0.36 and 0.35 EROI respectively. It is surprising that the returns on investment are so low given that less than two hundred years ago most of these food procurement methods would have had to have been performed without the aid of fossil fuels. The scale and methodology in the pre-industrial period must have been different, as such low energetic returns would have made these forms of food procurement too inefficient energetically.

The return on investment for industrial fishing is low. These foraging strategies are currently reliant on large amounts of external energy supplied principally from fossil fuels. Dukes (2003) indicates that one gallon US (3.8 L) is derived from ninety metric tonnes of ancient plant matter. Table 28 shows the results of the four vessel classes and a conservative estimate of the amount of ancient and current NPP that is required to catch a tonne of cod in the northwest Atlantic in the 1980s.

Table 28. NPP Required per tonne of Cod – Ancient and Current

Vessel Type	Litres Per Tonne	Ancient Tonnes of Plant Matter	g C of NPP (Ancient)	EF Marine (Ancient)[a]	EF_{Marine} (Current)	$EF_{Terrestrial}$ (Current)
SIV (LT 25')	131	3,094	849,147,434	166	14.1	0.45
LIV (25'-34')	36	856	247,323,121	46	14.1	0.15
SNV (35'-44')	62	1462	422,506,203	78	14.1	0.20
LNV (45'-64')	76	1,794	518,398,981	96	14.1	0.22

a. calculated using the current NPP for the waters off of the coast of Newfoundland.

The results indicate that a tonne of fish caught today requires not only NPP from current time, but an even larger region of ancient net primary production is required to catch a tonne of cod. (Petroleum is the result of ancient aquatic NPP trapped in the crust and that is why it appears as EF Marine). The NPP required per tonne of fish has increased with an industrial fishery. Due to Ancient NPP requirements, the region of NPP required increased by 5 to 10 times depending on the vessel length class.

This result indicates that human reliance on NPP is increasing with the use of fossil fuels. If humans move away from using fossil fuels towards using ethanol from grains, this will increase human demands for current NPP. As indicated, humans were appropriating 40% of the world's NPP by 1986 (Vitisouek et al 1986). Considering the widespread use of fossil fuels, any large scale move to grain-based ethanol will only increase pressure from human demand for NPP on the other organisms occupying the planet.

The model does give an indication of the energetic return and ecological costs for a fishery. Using the model on a yearly basis could give a general trend for a fishery with respect to efficiency of the foraging strategy (energetic return) or the ecological cost, EF. The model can be useful for other types of fisheries.

4.3 Concluding Remarks

Both types of fisheries are powered by the sun, pre-industrial by solar energy converted into wind and currents and the industrial fishery by ancient sunlight converted into fossil fuels. The method of fishing for all vessel classes has changed with the availability of motors, technology and petroleum. With regard to human effort, the industrial fish foraging strategy is an improvement. As well, an industrial fishery can be performed with less influence of seasonal conditions. However, taking into account all the NPP that is required, the energetic return on investments is low and has diminished with time; the ecological costs represented by EFs have increased with time.

The pre-industrial fish foraging method had limitations resulting in periods where it was either too risky or not worthwhile to fish, i.e. winter or during storms. The pre-industrial fishery could not operate all year round in the northwest Atlantic. Technology has reduced the limitations on when and how much fishing is possible. Humans can predate on cod all year long. In the case of the northwest Atlantic cod fishery, predation of cod was greater than the recruitment rate, leading to gradual reduction in energetic returns and higher EF_T per tonne, and ultimately to the collapse of cod stocks in the northwest Atlantic in 1992. Using a term coined by Ronald Wright (2004) the industrial fish foraging strategy may be a "progress trap". If not focused on conservation, the new foraging strategy is more efficient and convenient relative to the pre-industrial fisheries by allowing a fishery to be performed in more difficult weather conditions and all year round. However, the absence of limitations can lead to the decimation of a fish population. In the case of cod in the Northwest Atlantic, it did.

Another detriment of an industrial fishery is that its ecological demands are greater than those of a pre-industrial fishery in that it requires forests to sequester the re-introduced carbon, the result of the combustion of fossil fuels. This was not the case with the pre-industrial fishery. As well, industrial fisheries require more NPP, in the form of fossil fuels.

Another concern is that the industrial foraging strategy is based on a finite external energy source. Pre-industrial societies using ecologically safe paradigms can exist for millennia, as has been the case with several civilizations (e.g., Egypt and China). Egypt and China have been blessed with a constant inflow of nutrient enriching waters that flood the land via the Nile and Yangtze respectively. By not urbanizing heavily on farm land, Egypt was able to sustain societies for millennia (Wilson 1960). Both societies ultimately had foraging strategies that allowed their societies to continue uninterrupted. Societies that did not possess foraging strategies that were energetic surplus in nature eventually faced crisis. Two of many examples are The Sumerian by 3,500 BC, the first to perform agriculture (Wright 2004) and the Mayan in the latter half of the ninth and tenth centuries AD (Diamond 2005). Crises of the environment and energetic returns often lead to a decrease in population and, if systemic, can lead to the eventual disbanding of the society. Neither scenario is necessarily a peaceful process.

In the case of the northwest Atlantic cod fishery, the people pursuing fishing in this region were not solely dependent on cod for calories. Food security was not an issue. There was, however, a decrease in human population because of the loss of jobs due to the collapse of the fisheries. The dispersal was non-violent in nature, but not without turmoil for those affected.

Overall the industrial method of fishing might be a progress trap because of its heavy reliance on NPP, whether ancient or current, and the predation levels possible on a fish stock. The model developed here and elsewhere has the potential to assist in identifying the types of fisheries that give the best returns and lower ecological impacts.

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Appendix A Percent Utilization by Fish Species Type

Table 29. Percentage Utilization By Species Type

Species	Percent Yield	Species	Percent Yield	Species	Percent Yield
Alewives	46	Grenadier	21	Redfish	31
Alfonsino	32	Greysole	29	Rockcod	32
Argetine	32	Groundfish	32	Salmon	32
Billfish	32	Grouper	32	Scallop	10
Capelin	50	Haddock	32	Sculpin	32
Cardinal	32	Hagfish	32	Sea Urchin	10
Catfish	30	Hake	32	Send eels	32
Char	32	Halibut	29	Shark	32
Chimera	32	Herring	46	Shrimp	25
Clams	10	Lobster	25	Skate	32
Cocules	10	Lumpfish roe	15	Smelt	70
Cod	32	Mackerel	49	Squid	60
Crab	25	Mahi Mahi	32	Swordfish	32
Crustaceans	25	Marlin	32	Tiapia	32
Cucumber	100	Monkfish	32	Trout	32
Cunners	32	Mussels	90	Tuna	32
Cusk	32	Ocean Pout	32	Turbot	36
Dogfish	32	Plaice	29	Whelks	10
Dollarfish	32	Pollock	36	Whitefish	32
Eels	32	Porbeagle	32	Winkles	10
Escolar	49	Quahaugs	90	Yellowtail	29
Flounder	29	Rainbow Trout	32		

Taken from Cull (2000) – Compiled from Tavel (1997)

Appendix B Primary Production Required by Fish Species Type

Table 30. Primary Production Required By Fish Species Type

FAO-codes	Species group	Catch (ww; t X 10^3)	n	k	Trophic Level Mean	s.e.	PPR g C x 10^{12}
Oceanic (gyre) systems							
36	Tunas, bonitos, billfishes	2,975	1	3	4.2	0.04	523.9
46	Krill	344	-	-	2.2	-	0.6
Upwelling systems							
35	Anchoviews, sardines	11,597	24	97	2.6	0.28	53.1
34	Jacks	4,785	8	28	3.2	0.06	86.7
37	Mackerels	1,096	10	44	3.3	0.1	22.8
57	Squids	248	6	31	3.2	0.14	6.9
Tropical shelves							
24,35	Small pelagics	7,127	5	20	2.8	0.27	59.9
31, 33, 39	Misc.teleosteans	5,342	22	16	3.5	0.26	204.3
34, 37	Jacks, mackerels	2,053	8	46	3.3	0.28	45.5
36	Tunas, bonitos, billfishes	1,275	8	44	4.0	0.12	141.7
57	Squids, cuttlefishes, octopuses	1,114	6	31	3.2	0.14	19.6
45	Shrimps, prawns	650	4	21	2.7	0.35	35.0
42-44, 47, 77	Lobster, crabs and other invertebrates	544	7	35	2.6	0.3	2.2
38	Sharks, rays, chimaeras	344	9	51	3.6	0.24	15.2
Non-tropical shelves							
32	Cods, hakes, haddocks	12,209	5	49	3.8	0.25	929.9
33	Redfishes, basses, congers	3,837	2	5	3.4	0.06	110.9
39	Miscellaneous marine fishes	3,362	1	5	3.2	0.11	52.8
34	Jacks, mullets, sauries	2,871	1	3	3.8	0.13	206.0
35	Herrings, sardines, anchovies	2,319	3	8	3.0	0.15	23.7

Table 30 Primary Production Required By Fish Species Type (continued)

FAO-codes	Species group	Catch (ww; t X 10^3)	n	k	Trophic Level Mean	s.e.	PPR g C x 10^{12}
Non-tropical shelves cont..							
42-45, 47, 75, 77	Shrimps and other crustaceans	1,195	3	10	2.3	0.24	2.6
57	Squids, cuttlefishes, octopuses	1,114	6	31	3.2	0.14	19.3
31	Flounders, halibuts, soles	1,098	3	10	2.9	0.12	9.8
37	Mackerels, cutlassfishes	1,096	3	16	3.4	0.29	30.6
23-25	Diadromous fishes	819	14	49	2.4	0.25	2.3
38	Sharks, rays, chimaeras	344	2	15	3.7	0.28	19.2
Coastal and coral systems							
52-56, 58	Bivalves and other mollusks	5,150	4	12	2.1	0.13	7.6
31, 39	Miscellaneous marine fishes	3,424	15	86	2.8	0.41	24.0
35	Herrings, sardines, anchovies	2,319	9	52	3.2	0.2	40.8
9	Seaweeds	1,683	1	-	1.0	-	0.2
34, 37	Jancs and mackerels	1,322	17	97	3.3	0.22	29.3
23-25	Diadromous fishes	819	3	13	2.8	0.19	5.7
43-45, 47	Shrimps, prawns	748	8	42	2.6	0.33	3.3
42, 74-77	Crustaceans and other invertebrates	566	14	49	2.4	0.25	1.6
72	Turtles	2	2	7	2.4	0.37	0.0
Freshwater systems							
13	Misc. freshwater fishes	5,237	41	273	3.1	0.28	69.4
21-25	Misc. diadromous fishes	1,210	23	121	3.6	0.27	60.1
41, 45, 51, 54, 71, 77	Invertebrates and amphibians	896	14	54	2.2	0.23	1.6
11	Carp-like fish	632	15	79	2.7	0.34	3.7
12	Tilapias and other ciclids	579	24	11	2.5	0.18	2.0

Taken from Pauly & Christensen (1995, p 256)

Appendix C Ecological Footprint Of Nations

Table 31 Ecological Footprints of Nations

Country	Population in millions (1999)	Ecological Footprint in global hectares	Biocapacity in global hectares	Domestic *Ecological* Deficit/ Remainder in global hectares	**Ecological Footprint in global acres**	Biocapacity in global acres	Domestic *Ecological* Deficit/Remainder in global acres
WORLD	5,978.70	2.3	1.9	-0.4	**5.6**	4.7	-0.9
Afghanistan	21.2	0.9	0.8	-0.2	**2.3**	1.9	-0.4
Albania	3.1	1	0.8	-0.2	**2.4**	1.9	-0.5
Algeria	29.8	1.6	0.5	-1	**3.8**	1.3	-2.5
Angola	12.8	0.9	5.9	5	**2.2**	14.5	12.4
Argentina	36.6	3	6.7	3.6	**7.5**	16.5	9
Armenia	3.8	0.9	0.5	-0.4	**2.2**	1.2	-0.9
Australia	18.9	7.6	14.6	7	**18.7**	36.1	17.4
Austria	8.1	4.7	2.8	-2	**11.7**	6.9	-4.8
Azerbaijan	8	1.7	0.9	-0.8	**4.3**	2.2	-2
Bangladesh	134.6	0.5	0.3	-0.2	**1.3**	0.7	-0.6
Belarus	10.2	3.3	2.6	-0.7	**8.1**	6.3	-1.7
Belgium & Luxembourg	10.2	6.7	1.1	-5.6	**16.6**	2.8	-13.8
Benin	6.1	1.1	1	-0.1	**2.8**	2.6	-0.2
Bolivia	8.1	1	6.4	5.4	**2.4**	15.8	13.4
Bosnia and Herzegovina	3.8	1.1	1.1	0.1	**2.6**	2.8	0.2
Botswana	1.5	1.5	3.9	2.4	**3.7**	9.7	6
Brazil	168.2	2.4	6	3.6	**5.9**	14.9	9
Bulgaria	8	2.4	1.8	-0.5	**5.8**	4.5	-1.3
Burkina Faso	11.2	1.2	0.9	-0.2	**2.9**	2.3	-0.6
Burundi	6.3	0.5	0.5	0	**1.2**	1.3	0.1
Cambodia	12.8	0.8	1.4	0.5	**2**	3.4	1.3
Cameroon	14.6	1.1	3.9	2.8	**2.7**	9.7	6.9
Canada	30.5	8.8	14.2	5.4	**21.8**	35.2	13.3
Central African Rep	3.6	1.3	6.2	4.9	**3.1**	15.3	12.2

Table 31 Ecological Footprint of Nations (continued)

Country	Population in millions (1999)	Ecological Footprint in global hectares	Biocapacity in global hectares	Domestic *Ecological* Deficit/ Remainder in global hectares	**Ecological Footprint in global acres**	Biocapacity in global acres	Domestic *Ecological* Deficit/Remainder in global acres
Chad	7.6	1	1.7	0.7	**2.5**	4.1	1.6
Chile	15	3.1	4.2	1.1	**7.7**	10.5	2.8
China	1,272.00	1.5	1	-0.5	**3.8**	2.6	-1.2
Colombia	41.4	1.3	2.5	1.2	**3.3**	6.2	2.9
Congo	2.9	0.9	9	8.1	**2.3**	22.3	20.1
Congo, Dem. Rep.	49.6	0.8	3.4	2.6	**2**	8.3	6.3
Costa Rica	3.9	2	2.3	0.4	**4.8**	5.7	0.9
Cote d'Ivoire	15.7	0.9	2	1.1	**2.3**	4.9	2.7
Croatia	4.7	2.7	2.1	-0.6	**6.6**	5.3	-1.4
Cuba	11.2	1.5	1.1	-0.4	**3.7**	2.7	-1
Czech Republic	10.3	4.8	2.3	-2.5	**11.9**	5.7	-6.2
Denmark	5.3	6.6	3.2	-3.3	**16.2**	8	-8.2
Dominican Republic	8.2	1.5	0.7	-0.8	**3.8**	1.8	-1.9
Ecuador	12.4	1.5	2.6	1.1	**3.8**	6.5	2.6
Egypt	66.7	1.5	0.8	-0.7	**3.7**	1.9	-1.8
El Salvador	6.2	1.2	0.5	-0.7	**2.9**	1.3	-1.6
Eritrea	3.5	0.8	0.8	0	**1.9**	1.9	-0.1
Estonia	1.4	4.9	4.1	-0.8	**12.2**	10.2	-2
Ethiopia	64.9	0.8	0.5	-0.3	**1.9**	1.1	-0.8
Finland	5.2	8.4	8.6	0.2	**20.8**	21.3	0.5
France	59	5.3	2.9	-2.4	**13**	7.1	-5.9
Gabon	1.2	2.1	28.7	26.6	**5.2**	70.9	65.6
Gambia	1.3	1	0.9	-0.1	**2.5**	2.3	-0.2
Georgia	5.3	0.9	0.9	0	**2.2**	2.3	0
Germany	82	4.7	1.7	-3	**11.6**	4.3	-7.3

Table 31 Ecological Footprint of Nations (continued)

Country	Population in millions (1999)	Ecological Footprint in global hectares	Biocapacity in global hectares	Domestic *Ecological* Deficit/ Remainder in global hectares	**Ecological Footprint in global acres**	Biocapacity in global acres	Domestic *Ecological* Deficit/Remainder in global acres
Ghana	18.9	1.1	0.9	-0.2	**2.6**	2.2	-0.4
Greece	10.6	5.1	2.3	-2.8	**12.6**	5.8	-6.8
Guatemala	11.1	1.4	1.2	-0.2	**3.5**	3	-0.5
Guinea	8	1.2	2	0.8	**3**	5	2
Guinea-Bissau	1.2	0.7	4.2	3.5	**1.7**	10.3	8.6
Haiti	8	0.8	0.3	-0.6	**2**	0.6	-1.4
Honduras	6.3	1.3	1.6	0.2	**3.3**	3.8	0.5
Hungary	10	3.1	1.7	-1.3	**7.6**	4.3	-3.3
India	992.7	0.8	0.7	-0.1	**1.9**	1.7	-0.2
Iran	69.2	2	0.9	-1.1	**4.9**	2.2	-2.7
Iraq	22.3	1.4	0.2	-1.2	**3.4**	0.6	-2.8
Ireland	3.8	5.3	6.1	0.8	**13.2**	15.2	2
Israel	5.9	4.4	0.6	-3.9	**11**	1.4	-9.5
Italy	57.5	3.8	1.2	-2.7	**9.5**	2.9	-6.6
Jamaica	2.6	2.1	0.6	-1.5	**5.1**	1.5	-3.7
Japan	126.8	4.8	0.7	-4.1	**11.8**	1.7	-10
Jordan	4.8	1.5	0.2	-1.4	**3.8**	0.4	-3.4
Kazakhstan	16.3	3.6	3.3	-0.2	**8.9**	8.2	-0.6
Kenya	30	1.1	1.1	0	**2.7**	2.6	-0.1
Korea, Dem People's Rep	22.1	3	0.8	-2.2	**7.5**	2	-5.5
Korea, Rep	46.4	3.3	0.7	-2.6	**8.2**	1.8	-6.4
Kuwait	1.8	7.7	0.4	-7.4	**19.1**	1	-18.2
Kyrgyz Republic	4.8	1.1	1	-0.1	**2.8**	2.4	-0.4
Laos	5.2	0.8	4.5	3.7	**2**	11.1	9.1
Latvia	2.4	3.4	4.6	1.1	**8.5**	11.3	2.8

Table 31 Ecological Footprint of Nations (continued)

Country	Population in millions (1999)	Ecological Footprint in global hectares	Biocapacity in global hectares	Domestic *Ecological* Deficit/ Remainder in global hectares	**Ecological Footprint in global acres**	Biocapacity in global acres	Domestic *Ecological* Deficit/Remainder in global acres
Lebanon	3.4	2.6	0.5	-2.1	**6.4**	1.2	-5.2
Lesotho	2	0.9	0.7	-0.1	**2.1**	1.8	-0.4
Liberia	2.7	0.9	3.3	2.3	**2.3**	8	5.8
Libya	5.2	3.3	0.9	-2.3	**8.1**	2.3	-5.8
Lithuania	3.7	3.1	3	-0.1	**7.6**	7.5	-0.1
Macedonia	2	3.3	1.5	-1.8	**8**	3.6	-4.4
Madagascar	15.5	0.9	1.9	1	**2.2**	4.6	2.4
Malawi	11	0.9	0.8	0	**2.2**	2	-0.1
Malaysia	21.8	3.2	3.4	0.2	**7.8**	8.4	0.6
Mali	11	1.1	1.4	0.3	**2.8**	3.5	0.7
Mauritania	2.6	1.3	2.6	1.3	**3.3**	6.5	3.3
Mauritius	1.2	1.5	1.3	-0.2	**3.7**	3.2	-0.6
Mexico	97.4	2.5	1.7	-0.8	**6.2**	4.2	-2.1
Moldova Republic	4.3	1.4	0.8	-0.6	**3.4**	2	-1.4
Mongolia	2.5	2.6	6.4	3.9	**6.4**	15.9	9.5
Morocco	29.3	1.1	0.9	-0.2	**2.7**	2.1	-0.6
Mozambique	17.9	0.5	1.9	1.4	**1.2**	4.6	3.5
Myanmar	47.1	0.7	1.6	0.9	**1.7**	4	2.3
Namibia	1.7	1.5	5	3.6	**3.6**	12.4	8.8
Nepal	22.5	0.8	0.6	-0.3	**2.1**	1.4	-0.6
Netherlands	15.8	4.8	0.8	-4	**11.9**	2	-9.9
New Zealand	3.7	8.7	23	14.3	**21.4**	56.7	35.3
Nicaragua	4.9	1.5	3.1	1.6	**3.8**	7.6	3.8
Niger	10.5	1.1	0.9	-0.2	**2.8**	2.2	-0.6
Nigeria	110.8	1.3	0.9	-0.4	**3.3**	2.2	-1.1

Table 31 Ecological Footprint of Nations (continued)

Country	Population in millions (1999)	Ecological Footprint in global hectares	Biocapacity in global hectares	Domestic *Ecological* Deficit/ Remainder in global hectares	**Ecological Footprint in global acres**	Biocapacity in global acres	Domestic *Ecological* Deficit/Remainder in global acres
Norway	4.4	7.9	5.9	-2	**19.6**	14.7	-4.9
Pakistan	137.6	0.6	0.4	-0.2	**1.6**	1	-0.6
Panama	2.8	1.7	3.1	1.4	**4.2**	7.6	3.4
Papua New Guinea	4.7	1.4	14	12.6	**3.5**	34.6	31.1
Paraguay	5.4	2.5	6.7	4.2	**6.2**	16.5	10.3
Peru	25.2	1.2	5.3	4.2	**2.8**	13.1	10.3
Philippines	74.2	1.2	0.6	-0.6	**2.9**	1.4	-1.5
Poland	38.6	3.7	1.6	-2.1	**9.1**	4	-5.1
Portugal	10	4.5	1.6	-2.9	**11**	3.9	-7.1
Romania	22.5	2.5	1.4	-1.1	**6.2**	3.4	-2.8
Russian Federation	146.2	4.5	4.8	0.4	**11.1**	12	0.9
Rwanda	7.1	1.1	0.9	-0.1	**2.6**	2.3	-0.3
Saudi Arabia	19.6	4.1	1	-3.1	**10**	2.4	-7.6
Senegal	9.2	1.3	1.5	0.2	**3.2**	3.7	0.5
Sierra Leone	4.3	0.5	1.1	0.5	**1.3**	2.6	1.3
Slovak Republic	5.4	3.4	2.4	-1.1	**8.5**	5.8	-2.7
Slovenia	2	3.6	2.2	-1.3	**8.8**	5.5	-3.3
Somalia	8.4	1	1.1	0	**2.6**	2.6	0
South Africa	42.8	4	2.4	-1.6	**9.9**	6	-3.9
Spain	39.9	4.7	1.8	-2.9	**11.5**	4.4	-7.1
Sri Lanka	18.7	1	0.5	-0.5	**2.5**	1.3	-1.2
Sudan	30.4	1.1	2	1	**2.6**	5.1	2.4
Sweden	8.9	6.7	7.3	0.6	**16.6**	18.1	1.5
Switzerland	7.2	4.1	1.8	-2.3	**10.2**	4.5	-5.7
Syria	15.8	1.6	0.6	-1	**4**	1.5	-2.5

Table 31 Ecological Footprint of Nations (continued)

Country	Population in millions (1999)	Ecological Footprint in global hectares	Biocapacity in global hectares	Domestic *Ecological* Deficit/ Remainder in global hectares	**Ecological Footprint in global acres**	Biocapacity in global acres	Domestic *Ecological* Deficit/Remainder in global acres
Tajikistan	6	0.7	0.3	-0.4	**1.6**	0.8	-0.9
Tanzania	34.3	1	1.3	0.3	**2.5**	3.2	0.6
Thailand	62	1.5	1.4	-0.2	**3.8**	3.4	-0.4
Togo	4.4	0.9	0.8	0	**2.1**	2	-0.1
Trinidad and Tobago	1.3	3.3	0.8	-2.5	**8.2**	2	-6.2
Tunisia	9.4	1.7	1	-0.7	**4.2**	2.5	-1.7
Turkey	65.7	2	1.2	-0.7	**4.9**	3	-1.8
Turkmenistan	4.6	3.2	2	-1.2	**7.9**	5	-2.9
Uganda	22.6	1.1	0.9	-0.2	**2.6**	2.2	-0.4
Ukraine	50	3.4	1.5	-1.9	**8.3**	3.6	-4.7
United Arab Emirates	2.6	10.1	1.3	-8.9	**25**	3.1	-21.9
United Kingdom	59.5	5.3	1.6	-3.7	**13.2**	4.1	-9.1
United States of America	280.4	9.7	5.3	-4.4	**24**	13	-10.9
Uruguay	3.3	3.8	4.6	0.8	**9.4**	11.3	1.9
Uzbekistan	24.5	1.9	0.7	-1.2	**4.7**	1.7	-3
Venezuela	23.7	2.3	3.3	0.9	**5.8**	8.1	2.3
Vietnam	77.1	0.8	0.8	0.1	**1.9**	2.1	0.2
Yemen	17.6	0.7	0.5	-0.2	**1.7**	1.3	-0.5
Yugoslavia	21.1	2.1	1.2	-0.9	**5.3**	3	-2.3
Zambia	10.2	1.3	2.7	1.4	**3.1**	6.6	3.5

Taken from Wakernagel et al. 2002

Appendix D Sequestration Rate by Forest Type

Table 32 Sequestration Rate by Forest Type

Forest Type	Sequestration Rate tonnes of C Ha^{-1}	Sequestration Rate tonnes CO_2 Ha^{-1}
Canadian Boreal Forests	0.33[a]	1.209[a]
Canadian Temperate Forests	0.40[a]	1.466[a]
Canadian Grasslands	0.27[a]	0.989[a]
British Columbian Forests	1.0[b]	3.664[b]

a. Essa Technologies (1996)
b. Tyedmers (2000)

Appendix E Fuel Indices

Table 33. Fossil Fuel Energy Equivalence

Gasoline	Energy
Lower Heating Value (LHV)	32 MJ/liter [a]
HHV including condensation of combustion products	35 MJ/liter [a]
Petro-diesel	36.4 MJ/liter [a]
Natural gas:	
Lower Heating Value (LHV)	38.3 MJ/m^3 [a]
HHV including condensation of combustion products	34.6 MJ/m^3 [a]
Carbon Content	
Gasoline	639 g/L [a]

a. Oak Ridge National Laboratory http://bioenergy.ornl.gov/papers/misc/energy_conv.html

Appendix F Human Effort Indices

Table 34 Dietary Reference Intakes (DRIs): Estimated Energy Requirements (EER) for Men and Women 30 Years of Age[a]

Height (m [in])	PAL[b]	Weight for BMI[c] of 18.5 kg/m2 (kg [lb])	Weight for BMI[c] of 24.99 kg/m2 (kg [lb])	EER, Men [d] (kcal/day)		EER, Women [d] (kcal/day)	
				BMI of 18.5 kg m^{-2}	BMI of 24.99 kg m^{-2}	BMI of 18.5 kg m^{-2}	BMI of 18.5 kg m^{-2}
1.5 (59)	Sedentary	41.6 (92)	56.2 (124)	1,848	2,080	1,625	1,762
	Low active			2,009	2,267	1,803	1,956
	Active			2,215	2,506	2,025	2,198
	Very active			2,554	2,898	2,291	2,489
1.65 (65)	Sedentary	50.4 (111)	68 (150)	2,068	2,349	1,816	1,982
	Low active			2,254	2,566	2,016	2,202
	Active			2,490	2,842	2,267	2,477
	Very active			2,880	3,296	2,567	2,807
1.8 (71)	Sedentary	59.9 (132)	81(178)	2,301	2,635	2,015	2,211
	Low active			2,513	2,884	2,239	2,459
	Active			2,782	3,200	2,519	2,769
	Very active			3,225	3,720	2,855	3,141

Taken from Dietary Reference Intakes for Energy, Carbohydrate, Fibre, Fat, Fatty Acids, Cholesterol, Protein and Amino Acids (2002).

a For each year below 30, add 7 kcal/day for women and 10 kcal /day for men. For each year above 30, subtract 7 kcal/day for women and 10 kcal/day for men.
b PAL = physical activity level.
c BMI = body mass index.
d Derived from the following regression equations based on doubly labeled water data:
Adult man: EER = 662 – 9.53 × age (y) + PA × (15.91 × wt [kg] + 539.6 × ht [m])
Adult woman: EER = 354 – 6.91 × age (y) + PA × (9.36 × wt [kg] + 726 × ht [m])
Where PA refers to coefficient for PAL
PAL = total energy expenditure ÷ basal energy expenditure
PA = 1.0 if PAL, 1.0 < 1.4 (sedentary)
PA = 1.12 if PAL1.4 < 1.6 (low active)
PA = 1.27 if PAL1.6 < 1.9 (active)
PA = 1.45 if PAL, 1.9 < 2.5 (very active)

Appendix G Primary Production Rate (PPR) by Ocean Region

Table 35 Primary Production Required Oceans

Domain	Ocean	Province	Area (10^6 km^2)	Primary Production Rate g C m^{-2} day^{-1}	g C m^{-2} year^{-1}	Gt C year^{-1}	Case 2 * 0.5	Case 2 * 0.25
Coastal	Atlantic	NECS	1.36	2	730	1.00	0.5	0.25
Coastal	Atlantic	NWCS	2.00	1.48	540	1.08	0.54	0.27
Coastal	Atlantic	CNRY	0.81	2.01	732	0.60	0.6	0.6
Coastal	Atlantic	GUIN	1.42	1.36	495	0.70	0.35	0.18
Coastal	Atlantic	GUIA	1.23	1.92	699	0.86	0.43	0.22
Coastal	Atlantic	BRAZ	1.20	0.83	302	0.36	0.18	0.09
Coastal	Atlantic	FKLD	0.14	1.3	474	0.67	0.67	0.67
Coastal	Atlantic	BENG	1.13	0.88	323	0.37	0.37	0.37
Coastal	Indian	REDS	0.56	1.69	617	0.34	0.34	0.34
Coastal	Indian	ARAB	2.93	1.24	454	1.33	1.33	1.33
Coastal	Indian	EAFR	3.72	0.52	190	0.71	0.71	0.71
Coastal	Indian	INDE	0.97	0.97	354	0.34	0.17	0.09
Coastal	Indian	INDW	0.80	1.01	369	0.29	0.15	0.07
Coastal	Indian	AUSW	2.94	0.55	199	0.59	0.59	0.59
Coastal	Pacific	ALSK	0.59	1.81	661	0.39	0.39	0.39
Coastal	Pacific	CCAL	0.96	1.06	388	0.37	0.37	0.37
Coastal	Pacific	CAMR	1.26	0.92	334	0.42	0.42	0.42
Coastal	Pacific	CHIL	2.61	0.74	269	0.70	0.7	0.7
Coastal	Pacific	CHIN	0.97	1.7	619	0.60	0.3	0.15
Coastal	Pacific	SUND	6.33	0.9	328	2.08	1.04	0.52
Coastal	Pacific	AUSE	1.14	0.64	232	0.27	0.27	0.27
Coastal	Pacific	NEWZ	1.04	0.85	312	0.32	0.32	0.32
Polar	Artic	BPLR	1.66	1.77	645	1.07	1.07	1.07
Polar	Atlantic	ARCT	2.10	1.33	484	1.02	1.02	1.02
Polar	Atlantic	SARC	2.33	0.83	302	0.70	0.70	0.70
Polar	Pacific	BERS	3.89	0.99	363	1.41	1.41	1.41
Polar	Southern	ANTA	8.87	0.45	165	1.47	1.47	1.47
Polar	Southern	APLR	1.93	1.09	398	0.77	0.77	0.77
Westerlies	Atlantic	NADR	3.50	0.66	240	0.84	0.84	0.84
Westerlies	Atlantic	GFST	1.10	0.49	178	0.20	0.20	0.20
Westerlies	Atlantic	NASW	5.80	0.26	95	0.55	0.55	0.55
Westerlies	Atlantic	MEDI	3.08	0.59	216	0.67	0.67	0.67
Westerlies	Atlantic	NASE	4.45	0.33	122	0.54	0.54	0.54
Westerlies	Pacific	PSAE	3.20	0.55	199	0.64	0.64	0.64
Westerlies	Pacific	PSAW	2.90	0.72	264	0.77	0.77	0.77
Westerlies	Pacific	KURO	3.70	0.53	193	0.72	0.72	0.72
Westerlies	Pacific	NPPF	3.02	0.47	172	0.52	0.52	0.52
Westerlies	Pacific	NPSE	6.83	0.3	111	0.76	0.76	0.76
Westerlies	Pacific	NPSW	3.93	0.3	109	0.43	0.43	0.43

Table 35 continued Primary Production Required Oceans (continued)

Domain	Ocean	Province	Area (10 km^2)	Primary Production Rate g C m^{-2} day^{-1}	g C m^{-2} year^{-1}	Gt C year^{-1}	Case 2 * 0.5	Case 2 * 0.25
Westerlies	Pacific	OCAL	2.39	0.32	117	0.28	0.28	0.28
Westerlies	Pacific	TASM	1.65	0.45	163	0.27	0.27	0.27
Westerlies	Pacific	SPSG	37.29	0.24	87	3.23	3.23	3.23
Westerlies	Southern	SSTC	16.84	0.37	136	2.29	2.29	2.29
Westerlies	Southern	SANT	30.25	0.33	120	3.63	3.63	3.63
Trades	Atlantic	NATR	8.27	0.29	106	0.88	0.88	0.88
Trades	Atlantic	WTRA	5.36	0.36	130	0.70	0.70	0.70
Trades	Atlantic	ETRA	5.34	0.43	157	0.84	0.84	0.84
Trades	Atlantic	SATL	17.77	0.21	75	1.33	1.33	1.33
Trades	Atlantic	CARB	4.48	0.52	190	0.85	0.85	0.85
Trades	Indian	MONS	14.21	0.29	105	1.49	1.49	1.49
Trades	Indian	ISSG	19.25	0.19	71	1.37	1.37	1.37
Trades	Pacific	NPTG	21.09	0.16	59	1.24	1.24	1.24
Trades	Pacific	PNEC	8.17	0.29	107	0.87	0.87	0.87
Trades	Pacific	PEQD	10.34	0.31	113	1.17	1.17	1.17
Trades	Pacific	WARM	16.78	0.2	82	1.38	1.38	1.38
Trades	Pacific	ARCH	8.84	0.27	100	0.88	0.88	0.88
			328.00	0.77	282	50.17	46.52	44.70
Geographical subsets								
Coastal domain			37.4	1.1	385	14.40	10.7	8.9
Polar domain			20.8	0.8	310	6.40	6.4	6.4
Westerlies domain			129.9	0.3	126	16.30	16.3	16.3
Trades domain			139.9	0.3	93	13.00	13	13
Arctic Ocean			1.7	1.8	645	1.10	1.1	1.1
Atlantic Ocean			74	0.5	199	14.80	12.8	11.8
Pacific Ocean			148.9	0.4	132	19.70	18.4	17.7
Indian Ocean			45.4	0.4	143	6.50	6.2	6
Southern Ocean			57.9	0.4	141	8.20	8.2	8.2
Upwelling provinces			8.4	1.1	398	3.40	3.4	3.4
Atlantic westerlies			17.9	0.4	156	2.80	2.8	2.8
Pacific westerlies			64.9	0.3	117	7.60	7.6	7.6
Atlantic trades			41.2	0.3	112	4.60	4.6	4.6
Pacific trades			65.2	0.2	85	5.50	5.5	5.5
Indian trades			33.5	0.2	86	2.90	2.9	2.9

Taken from Longhurst et al. (1995, p1262)

Appendix H Caloric and Nutrional Content by Fish Species Type

Table 36 Composition by Fish Species Type - Calories, Protein, fat, etc.

Common Name	Scientific Name	Water	Energy	Energy	Protein	Total lipid (fat)	Ash	Carbohydrate	Fiber total dietary	Sugars total
		g	kcal	kj	g	g	g	g	g	g
abalone, mixed species, raw	*Haliotis spp.*	745.6	1050	4390	171	7.6	15.7	60.1	0	0
anchovy, european, raw	*Engraulis encrasicholus (L.)*	733.7	1310	5480	203.5	48.4	14.4	0	0	0
sea bass, mixed species, raw	*Centropristes striata L. and Lateolabrax japonicus (Cuvier)*	782.7	970	4060	184.3	20	10.9	0	0	0
blueraw	*Pomatomus saltatrix (L.)*	708.6	1240	5190	200.4	42.4	10.4	0	0	0
burbot, raw	*Lota lota (L.)*	792.6	900	3770	193.1	8.1	11.6	0	0	0
butterraw	*Peprilus triacanthus (Peck)*	741.3	1460	6110	172.8	80.2	12	0	0	0
carp, raw	*Cyprinus carpio (L.)*	763.1	1270	5310	178.3	56	14.6	0	0	0
catchannel, farmed, raw	*Ictalurus punctatus (Rafinesque)*	753.8	1350	5650	155.5	75.9	10	0	0	0
catchannel, wild, raw	*Ictalurus punctatus (Rafinesque)*	803.6	950	3970	163.8	28.2	9.6	0	0	0
cisco, raw	*Coregonus artedi Lesueur*	789.3	980	4100	189.9	19.1	12	0	0	0
cod, Atlantic, raw [a]	*Gadus morhua*	760	760		174	7				

Table 36 Composition of by Fish Species Type – Calories, Protein, Fat, etc. (continued)

Common Name	Scientific Name	Water	Energy	Energy	Protein	Total lipid (fat)	Ash	Carbohydrate	Fiber total dietary	Sugars total
		g	kcal	kj	g	g	g	g	g	g
cod, Atlantic, raw	*Gadus morhua*	812.2	820	3430	178.1	6.7	11.6	0	0	0
cod, Pacific, raw	*Gadus macrocephalus Tilesius*	812.8	820	3430	179	6.3	12	0	0	0
crab, alaska king, raw	*Paralithodes camtschatica (Tilesius)*	795.7	840	3510	182.9	6	18	0	0	0
crab, blue, raw	*Callinectes sapidus Rathbun*	790.2	870	3640	180.6	10.8	18.1	0.4	0	0
crab, dungeness, raw	*Cancer magister Dana*	791.8	860	3600	174.1	9.7	17	7.4	0	0
crab, queen, raw	*Chionoectes opilio (O. Fabricius)*	805.8	900	3770	185	11.8	20	0	0	0
craymixed species, farmed, raw	*Astacus, Orconectes, and Procambarus spp.*	840.5	720	3010	148.5	9.7	10	0	0	0
craymixed species, wild, raw	*Astacus, Orconectes, and Procambarus spp.*	822.4	770	3220	159.7	9.5	13.4	0	0	0
cuttlemixed species, raw	*Sepiidae*	805.6	790	3310	162.4	7	16.8	8.2	0	0
dolphinraw	*Coryphaena hippurus (L.)*	775.5	850	3560	185	7	21	0	0	0
drum, freshwater, raw	*Aplodinotus grunniens Rafinesque*	773.3	1190	4980	175.4	49.3	10.8	0	0	0
flatfish (flounder and sole species), raw	*Bothidae and Pleuronectidae*	790.6	910	3810	188.4	11.9	12	0	0	0

Table 36 Composition of by Fish Species Type – Calories, Protein, Fat, etc. (continued)

Common Name	Scientific Name	Water	Energy	Energy	Protein	Total lipid (fat)	Ash	Carbohydrate	Fiber total dietary	Sugars total
		g	kcal	kj	g	g	g	g	g	g
grouper, mixed species, raw	*Epinephelus spp.*	792.2	920	3850	193.8	10.2	11.7	0	0	0
haddock, raw	*Melanogrammus aeglefinus (L.)*	799.2	870	3640	189.1	7.2	12.1	0	0	0
halibut, Atlantic and Pacific, raw	*Hippoglossus hippoglossus (L.) and H. stenolepis Schmidt*	779.2	1100	4600	208.1	22.9	13.6	0	0	0
halibut, Greenland, raw	*Reinhardtius hippoglossoides (Walbaum)*	702.7	1860	7780	143.7	138.4	10	0	0	0
herring, Atlantic, raw	*Clupea harengus harengus (L.)*	720.5	1580	6610	179.6	90.4	14.6	0	0	0
herring, Pacific, raw	*Clupea harengus pallasi Valenciennes*	715.2	1950	8160	163.9	138.8	23.7	0	0	0
ling, raw	*Molva molva (L.)*	796.3	870	3640	189.9	6.4	14	0	0	0
lingcod, raw	*Ophiodon elongatus Girard*	810.3	850	3560	176.6	10.6	12.1	0	0	0
lobster, northern, raw	*Homarus americanus Milne-Edwards*	767.6	900	3770	188	9	22	5	0	0
spiny lobster, mixed species, raw	*Jasus spp. and Panulirus spp.*	740.7	1120	4690	206	15.1	13.9	24.3	0	0
mackerel, Atlantic, raw	*Scomber scombrus L.*	635.5	2050	8580	186	138.9	13.5	0	0	0
mackerel, king, raw	*Scombermorus cavalla (Cuvier)*	758.5	1050	4390	202.8	20	12.8	0	0	0

Table 36 Composition of by Fish Species Type – Calories, Protein, Fat, etc. (continued)

Common Name	Scientific Name	Water	Energy	Energy	Protein	Total lipid (fat)	Ash	Carbohydrate	Fiber total dietary	Sugars total
		g	kcal	kj	g	g	g	g	g	g
mackerel, Pacific and jack, mixed species, raw	*Scomber spp. and Trachurus spp.*	701.5	1580	6610	200.7	78.9	16.2	0	0	0
mackerel, spanish, raw	*Scombermorus maculatus (Mitchill)*	716.7	1390	5820	192.9	63	12.7	0	0	0
milkraw	*Chanos chanos (Forskaal)*	708.5	1480	6190	205.3	67.3	11.4	0	0	0
monkraw	*Lophius piscatorius L.*	832.4	760	3180	144.8	15.2	12.1	0	0	0
mullet, striped, raw	*Mugil cephalus L.*	770.1	1170	4900	193.5	37.9	12	0	0	0
ocean perch, Atlantic, raw	*Sebastes marinus L.*	787	940	3930	186.2	16.3	12	0	0	0
octopus, common, raw	*Octopus vulgaris Lamarck*	802.5	820	3430	149.1	10.4	16	22	0	0
roughy, orange, raw	*Hoplostethus atlanticus*	756.7	760	3200	164.1	7	10.8	0	0	0
perch, mixed species, raw	*Morone americana Gmelin and Perca flavescens (Mitchill)*	791.3	910	3810	193.9	9.2	12.4	0	0	0
pike, northern, raw	*Esox lucius L.*	789.2	880	3680	192.6	6.9	12	0	0	0
pike, walleye, raw	*Stizostedion vitreum vitreum (Mitchill)*	793.1	930	3890	191.4	12.2	12	0	0	0
pollock, Atlantic, raw	*Pollachius virens L.*	781.8	920	3850	194.4	9.8	14.1	0	0	0

Table 36 Composition of by Fish Species Type – Calories, Protein, Fat, etc. (continued)

Common Name	Scientific Name	Water	Energy	Energy	Protein	Total lipid (fat)	Ash	Carbohydrate	Fiber total dietary	Sugars total
		g	kcal	kj	g	g	g	g	g	g
pollock, walleye, raw	*Theragra chalcogramma (Pallas)*	815.6	810	3390	171.8	8	12.1	0	0	0
pompano, florida, raw	*Trachinotus carolinus (L.)*	711.2	1640	6860	184.8	94.7	11	0	0	0
pout, ocean, raw	*Macrozoarces americanus (Schneider)*	813.6	790	3310	166.4	9.1	11.3	0	0	0
rockPacific, mixed species, raw	*Sebastes spp.*	792.6	940	3930	187.5	15.7	12	0	0	0
sableraw	*Anoplopoma fimbria (Pallas)*	710.2	1950	8160	134.1	153	10.5	0	0	0
salmon, Atlantic, farmed, raw	*Salmo salar L.*	689	1830	7660	199	108.5	10.5	0	0	0
salmon, Atlantic, wild, raw	*Salmo salar L.*	685	1420	5940	198.4	63.4	25.4	0	0	0
salmon, chinook, raw	*Oncorhynchus tshawytscha (Walbaum)*	716.4	1790	7500	199.3	104.3	13.3	0	0	0
salmon, chum, raw	*Oncorhynchus keta (Walbaum)*	753.8	1200	5020	201.4	37.7	11.8	0	0	0
salmon, coho, farmed, raw	*Oncorhynchus kisutch (Walbaum)*	704.7	1600	6690	212.7	76.7	13	0	0	0
salmon, coho, wild, raw	*Oncorhynchus kisutch (Walbaum)*	726.6	1460	6110	216.2	59.3	12.1	0	0	0
salmon, pink, raw	*Oncorhynchus gorbuscha (Walbaum)*	763.5	1160	4850	199.4	34.5	12.2	0	0	0

Table 36 Composition of by Fish Species Type – Calories, Protein, Fat, etc. (continued)

Common Name	Scientific Name	Water	Energy	Energy	Protein	Total lipid (fat)	Ash	Carbohydrate	Fiber total dietary	Sugars total
		g	kcal	kj	g	g	g	g	g	g
salmon, sockeye, raw	*Oncorhynchus nerka (Walbaum)*	702.4	1680	7030	213	85.6	11.8	0	0	0
scallop, mixed species, raw	*Pectinidae*	785.7	880	3680	167.8	7.6	15.3	23.6	0	0
scup, raw	*Stenotomus chrysops L.*	753.7	1050	4390	188.8	27.3	12.1	0	0	0
sea bass, mixed species, raw	*Centropristes striata L. and Lateolabrax japonicus (Cuvier)*	782.7	970	4060	184.3	20	10.9	0	0	0
seatrout, mixed species, raw	*Cynoscion spp.*	780.9	1040	4350	167.4	36.1	12.6	0	0	0
shad, american, raw	*Alosa sapidissima (Wilson)*	681.9	1970	8240	169.3	137.7	13.2	0	0	0
shark, mixed species, raw	*Squaliformes*	735.8	1300	5440	209.8	45.1	13.9	0	0	0
shrimp, mixed species, raw	*Penaeidae and Pandalidae*	758.6	1060	4440	203.1	17.3	12	9.1	0	0
smelt, rainbow, raw	*Osmerus mordax (Mitchill)*	787.7	970	4060	176.3	24.2	14	0	0	0
snapper, mixed species, raw	*Lutjanidae*	768.7	1000	4180	205.1	13.4	13.1	0	0	0
spot, raw	*Leiostomus xanthuras Lacepede*	759.5	1230	5150	185.1	49	10.6	0	0	0
squid, mixed species, raw	*Loligoidae and Ommastrephidae*	785.5	920	3850	155.8	13.8	14.1	30.8	0	0

Table 36 Composition of by Fish Species Type – Calories, Protein, Fat, etc. (continued)

Common Name	Scientific Name	Water	Energy	Energy	Protein	Total lipid (fat)	Ash	Carbohydrate	Fiber total dietary	Sugars total
		g	kcal	kj	g	g	g	g	g	g
sturgeon, mixed species, raw	*Acipenser spp.*	765.5	1050	4390	161.4	40.4	11	0	0	0
sucker, white, raw	*Catostomus commersoni (Lacepede)*	797.1	920	3850	167.6	23.2	14.6	0	0	0
sunpumpkin seed, raw	*Lepomis gibbosus (L.)*	795	890	3720	194	7	11	0	0	0
surimi		763.4	990	4140	151.8	9	7.2	68.5	0	0
swordraw	*Xiphias gladius L.*	756.2	1210	5060	198	40.1	14.8	0	0	0
tileraw	*Lopholatilus chamaeleonticeps Goode and Bean*	789	960	4020	175	23.1	11.4	0	0	0
trout, mixed species, raw	*Salmonidae*	714.2	1480	6190	207.7	66.1	11.7	0	0	0
trout, rainbow, farmed, raw	*Salmo gairdneri Richardson*	727.3	1380	5770	208.7	54	14.3	0	0	0
trout, rainbow, wild, raw	*Salmo gairdneri Richardson*	718.7	1190	4980	204.8	34.6	13.1	0	0	0
tuna, fresh, bluefin, raw	*Thunnus thynnus (L.)*	680.9	1440	6020	233.3	49	11.8	0	0	0
tuna, fresh, skipjack, raw	*Euthynnus pelamis (L.)*	705.8	1030	4310	220	10.1	13	0	0	0
tuna, fresh, yellowfin, raw	*Thunnus albacares (Bonnaterre)*	709.9	1080	4520	233.8	9.5	13.4	0	0	0

Appendix H continued

Table 36 Composition of by Fish Species Type – Calories, Protein, Fat, etc. (continued)

Common Name	Scientific Name	Water	Energy	Energy	Protein	Total lipid (fat)	Ash	Carbohydrate	Fiber total dietary	Sugars total
		g	kcal	kj	g	g	g	g	g	g
turbot, european, raw	*Scophthalmus maximus (L.)*	769.5	950	3970	160.5	29.5	21	0	0	0
whelk, unspecified, raw	*Buccinidae*	660	1370	5730	238.4	4	20	77.6	0	0
whitemixed species, raw	*Coregonus spp.*	727.7	1340	5610	190.9	58.6	11.2	0	0	0
whiting, mixed species, raw	*Gadidae*	802.7	900	3770	183.1	13.1	13	0	0	0
wolfAtlantic, raw	*Anarhichas lupus (L.)*	799	960	4020	175	23.9	11.6	0	0	0
yellowtail, mixed species, raw	*Seriola spp.*	745.2	1460	6110	231.4	52.4	10.9	0	0	0

All values in the table are from USDA National Nutrient Database for Standard Reference (2005) except
a. Holland et al. (1991)

Appendix I Ecological Equivalence by Vessel Type

Table 37 Vessel Construction and Gear Maintenance

Material Input	Energy Intensity (MJ/kg)	Greenhouse Gas Emissions (Tonne CO2 eq./kg)	Conversion Factors	
Aluminum	140	0.008	1 metre	3.28 ft
Steel	25	0.0025	GasolineTotal GHG Emission Intensity tonnes of CO_2 / MJ	9.26E-05
Other Metals	25	0.0025		
Glass	10	0.001	Diesel Total GHG Emission Intensity tonnes CO_2 / MJ	8.79E-05
Concrete	1	0.00015		
Plastics	75	0.003		
Fibreglass Hulled Vessel				
Inputs	**10 m (32.81 feet) Gillnetter**	**Per Foot**	**Energy Equivalent Per Foot (MJ)**	**GHG Emission Tonne CO_2**
Aluminum (kg)	77	2.35	328.6	1.88E-02
Steel and/or iron (kg)	306	9.33	233.2	2.33E-02
Lead (kg)	10	0.30	7.6	7.62E-04
Mixed metals and other materials (kg)	59	1.80	45.0	4.50E-03
Glass (kg)	68	2.07	20.7	2.07E-03
Fibreglass resin (kg)	50	1.52	114.3	4.57E-03
Wood (m^3)	0.21	0.01		
Electricity (MJ)		0.00		
Total			**749.3**	**5.40E-02**
Aluminum Hulled Seiner				
Inputs	**18 m (59.04 ft)**	**Per Foot**	**Energy Equivalent Per Foot (MJ)**	**GHG Emission Tonne CO_2**
Aluminum (kg)	1,725	29.22	4090	0.23374
Steel and/or iron (kg)	1,380	23.37	584	0.058435
Lead (kg)				
Mixed metals and other materials (kg)	180	3.05	76	0.007622
Glass (kg)				
Fibreglass resin (kg)				
Wood (m^3)				
Electricity (MJ)	54,000	914.63	914.63	0.084695
Total			**5,665.65**	**3.84E-01**

Appendix I continued

Table 37 Vessel Construction and Gear Maintenance (continued)

Aluminum Hulled Gillnetter				
Inputs	**10 m (32.81 ft)**	**Per Foot**	**Energy Equivalent Per Foot (MJ)**	**GHG Emission Tonne CO_2**
Aluminum (kg)	166	5.06	708	4.05E-02
Steel and/or iron (kg)	285	8.69	217	2.17E-02
Lead (kg)	10	0.30	8	7.62E-04
Mixed metals and other materials (kg)	59	1.80	45	4.50E-03
Glass (kg)	4	0.12	1	1.22E-04
Fibreglass resin (kg)				
Wood (m^3)				
Electricity (MJ)	13500	411.46	411	3.81E-02
Total			**1390**	**1.06E-01**

Data taken from Tyedmers (2000).