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Life Cycle Considerations for Improving Sustainability Assessments in Seafood Awareness Campaigns

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Abstract It is widely accepted that improving the sustainability of seafood production requires efforts to reverse declines in global fisheries due to overfishing and to reduce the impacts to host ecosystems from fishing and aquaculture production technologies. Reflective of on-going dialogue amongst participants in an international research project applying Life Cycle Assessment to better understand and manage global salmon production systems, we argue here that such efforts must also address the wider range of biophysical, ecological, and socioeconomic impacts stemming from the material and energetic throughput associated with these industries. This is of particular relevance given the interconnectivity of global environmental change, ocean health, and the viability of seafood production in both fisheries and aquaculture. Although the growing popularity of numerous ecolabeling, certification, and consumer education programs may be making headway in influencing Western consumer perceptions of the relative sustainability of alternative seafood products, we also posit that the efficacy of these initiatives in furthering sustainability objectives is compromised by the use of incomplete criteria. An emerging body of Life Cycle Assessment research of fisheries and aquaculture provides valuable insights into the biophysical dimensions of environmental performance in alternative seafood production and consumption systems, and should be used to inform a more holistic approach to labeling, certifying, and educating for sustainability in seafood production. More research, however, must be undertaken to develop novel techniques for incorporating other critical dimensions, in particular, socioeconomic considerations, into our sustainability decision-making.

Keywords Life Cycle Assessment · Seafood · Fisheries · Aquaculture · Ecolabel · Organic · Sustainability

Introduction

Growing human populations and maladaptive patterns of production and consumption exert synergistic pressures on planetary ecosystems. During the last century, the cumulative impacts of industrial activities have become of sufficient magnitude to overwhelm the homeostatic capacity of biogeochemical cycles at multiple scales. Ozone depletion resulting from the release of chlorofluorocarbons and other ozone-depleting substances has compromised the capacity of the atmosphere to filter damaging UV radiation (Crutzen 1992; Madronich and others 1995). Anthropogenic emissions of greenhouse gases are altering climatic conditions by contributing to radiative forcing of the atmosphere (Hughes 2000; Robertson and others 2000; Levitus and others 2001; Walther and others 2002). Flows of biologically available reactive nitrogen have doubled since 1960, resulting in local eutrophication impacts and raising concerns regarding potential broad-scale ecosystem effects (Smil 1999; Galloway and others 2004). Acid precipitation linked to nitrogen- and sulfur-based atmospheric emissions is similarly generating both local and regional impacts (Likens and others 1996; Bouwman and others 2002), and depletion of biotic and abiotic resources is of increasing concern (Vitousek and others 1986; Haberl and others 2007). Inarguably, addressing these issues is of paramount importance and will necessarily involve implementing a range of tools to assess and improve the

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sustainability of a diverse range of human activities (van Berkel and others 1997, 1999).

A broadly accepted definition of sustainable development is development that improves the quality of human life within the context of earth's carrying capacity (IUCN 1991). In other words, sustainable development must simultaneously address the scale and consequences of directing substantial flows of living and nonliving matter and energy through the human economy, together with how and to whom the benefits of these flows are directed. Although the concept of sustainability is gaining increasing currency in both business and government circles, the extent to which it is meaningfully applied to regulating human activities remains limited (MEA 2005). In part, this failure reflects a lack of consensus regarding how to best evaluate the relative sustainability of disparate human activities. Such an endeavor requires not only rigorous criteria for the multiple facets of sustainability, but also workable analytical instruments. To this end, contributions from numerous traditional and interdisciplinary fields have begun to map out possible approaches to understanding and assessing sustainability [for an example of multicriteria sustainability assessments in fisheries, see Utne (2006, 2007) and Standal and Utne (2007)].

Life Cycle Assessment (LCA) is an International Organization for Standardization (ISO)-standardized accounting framework used to develop "cradle-to-grave" life history profiles of the potential environmental impacts associated with the energetic and material intensity of products or processes. It has emerged as the leading tool for identifying and comparing the environmental impacts of industrial production systems (ISO 2003; Baumann and Tillmann 2004). LCA is particularly well suited to evaluating the biophysical performance of industrial activities because of the high degree of resolution it can provide with respect to the relative importance of distinct life cycle stages to specific areas of macroscale environmental concern such as contributions to climate change, acid precipitation, ozone depletion, eutrophication, ecotoxicity, and resource use. Considerable research is currently under way to include measures of socioeconomic criteria within the LCA framework as well, although, in practice, this work has seen limited application (O'Brien and others 1996; Dreyer and others 2005).

Marketing for Sustainability

Although the formulation of testable criteria and tools for assessing sustainability is clearly prerequisite to meaningfully operationalizing sustainable development goals, it is equally important to create an enabling environment for such development. One popular approach has been to develop market incentives for socially and environmentally responsible behaviors (Deere 1999; Borregaard and Dufey 2005).

Product certification and ecolabeling are processes used to identify and distinguish specific consumer products within product categories based on their relative environmental performance (Preiss 1997; Borregaard and Dufey 2005). Both have been employed by government and nongovernment bodies to encourage sustainable production and consumption, and to create opportunities for businesses to capitalize on niche market incentives for environmentally preferable practices. In principle, the efficacy of product certification and ecolabeling is a function of the relevance of the criteria employed, the market share that the labeled products command, consumer confidence in and recognition of specific labels, and consumer preference (Preiss 1997).

Numerous certification and ecolabeling schemes currently exist for a broad array of products and services. This is increasingly true of food industries, where rising consumer sensitivity to the environmental consequences of food production, as well as health and social equity issues, has fueled a proliferation of labeling and certification initiatives. At present, certified and ecolabeled food products represent one of the fasted growing food markets. Global sales of certified organic products are increasing at 20%–25% per annum (El Hage-Scialabba and Hattam 2002) and markets for fair trade foods increased by 221% between 1997 and 2003 (Borregaard and Dufey 2005). Since the 1992 inauguration of the Marine Stewardship Council (MSC), more than 155 product lines have been certified. Overall, "green products" account for approximately 3% of world trade (Borregaard and Dufey 2005).

Development of certification and ecolabeling programs has been widespread for seafood products (Lambrecht Haland and Esmark 2002; Gardiner and Viswanathan 2004), where the combination of increasing demand for seafood, declines in traditional fisheries, and the rapid rise of aquaculture has generated significant concerns regarding the sustainability of production practices in this sector (Naylor and Burke 2005). The majority of these programs are driven by nongovernmental organizations or NGO/business partnerships, and include the MSC, the Global Aquaculture Alliance, and various organic seafood certification initiatives such as those of the U.K. Soil Association (2005) and German-based Naturland (2005). In addition, numerous consumer awareness programs within the United States (Blue Ocean Institute's "MiniGuide to Ocean Friendly Seafood," the Monterey Bay Aquarium's "Seafood Watch" program, and "The Audubon Guide to Seafood"), Europe (WWF produces "Seafood Guides" in at least seven European countries), Canada (the "SeaChoice Guide," produced by a partnership of five nongovernmental organizations), Australia (the "Sustainable Seafood Guide," from the Australian Marine Conservation Society), and others have helped popularize the concept of sustainable seafood consumption. The recent commitment by retail giant Wal-Mart to source only MSC-certified fishery products (Chaffee 2006) further indicates that labeled and certified products now compete in mainstream rather than niche markets.

The rapid development of certification and ecolabeling programs has been accompanied by increasing recognition of the need to standardize criteria and evaluation mechanisms to reduce potential consumer confusion and frustration. This challenge is not unique to sustainable seafood initiatives, however. In response to the more general need for standardization, ISO has produced a series of standards for the development of ecolabeling and environmental certification schemes. Various other international bodies, including the International Federation of Organic Agriculture Movements (IFOAM 2005) and the Global Ecolabeling Network (GEN 2004), have similarly standardized the principles, practices, and key characteristics of ecolabeling/certification initiatives. A common element of many such "umbrella standards" is the recommendation that the criteria used be informed by full product life cycle considerations. To date, several published studies report the use of LCA to inform ecolabeling criteria (Llorenc and others 2002; Baldo and others 2002). However, a U.S. Environmental Protection Agency (EPA) review of national and international ecolabeling schemes, and the methods used by the labeling bodies to evaluate and measure the environmental impacts of a product, reported that only 21 of 53 used full LCA, while a further four used modified LCAs. Of the remaining 28, most employed only single attributes as labeling criteria (EPA 1998). While it is unclear how prevalent the inclusion of life cycle considerations within certification schemes generally has become over the last decade, it is noteworthy that none of the current sustainable seafood programs employ such considerations.

Moreover, in the case of seafood ecolabeling/certification and consumer awareness programs, peer-reviewed research regarding the efficacy of the criteria used in assessing and promoting sustainability is limited or nonexistent. This lack of information implies the possibility that current programs may be inappropriate, incomplete, or simply ineffectual. A systematic assessment of the criteria employed by these programs, with reference to the multiple dimensions of sustainability, is important in order to determine their strengths and weaknesses in driving performance improvements in the seafood sector.

The Seafood Sector: Current Status and Future Prospects

The global production of seafood from fisheries and aquaculture reached 133 million tons, and provided direct employment to an estimated 38 million people, in 2002 (FAO 2004). In total, seafood contributes almost one-fifth of the animal protein consumed globally. With the doubling of seafood consumption since 1970, increased awareness of the health benefits of seafood, growing populations, wealth, and demand for luxury seafood products in the developed world (Naylor and Burke 2005), this trend is likely to continue into the foreseeable future. Less certain is the capacity of contemporary seafood production systems to meet this burgeoning demand.

Stagnation and declines in many of the world's most lucrative and productive fisheries are well documented (Watson and Pauly 2001; Pauly and others 2002; Worm and Myers 2004). With many traditional fisheries fully exploited, overexploited, or depleted, it appears that the global carrying capacity for fisheries production has been reached and, in many cases, exceeded (Worm and Myers 2004). An emerging consensus regarding the need for improved management and conservation of global fisheries is evident in international conventions and agreements such as the 1993 FAO Agreement to Promote Compliance with International Conservation and Management Measures by Fishing Vessels on the High Seas, the 1995 U.N. Agreement on the Conservation and Management of Straddling Fish Stocks and Highly Migratory Fish Stocks, and the 1995 FAO Code of Conduct for Responsible Fisheries.

Stagnation in global fisheries landings has been countered by the rapid development of industrial aquaculture production. With an average growth rate of 9.2% per year since 1970, aquaculture is one of the most rapidly expanding food industries (FAO 2004). At present, almost half of seafood products consumed globally are farmed (FAO 2006). This share is predicted to reach 70% by 2030 (FAO 2004).

Production systems within fisheries and aquaculture are highly diverse, and numerous environmental and social impacts have been attributed to a variety of harvest and culture technologies (Naylor and Burke 2005). Fisheries have been variously implicated in direct impacts to targeted stocks through overfishing (Pauly and others 1998, 2002, Christensen and others 2003; Myers and Worm 2003), by-catch of nontarget organisms (Alverson and others 1994; Glass 2000), disturbance of the benthos and benthic communities (Johnson 2002; Chuenpagdee and others 2003), and ecosystem-level effects including the alteration of trophic dynamics due to excessive biomass extraction or the extraction of keystone species (Jackson and others 2001).

Controversial environmental issues in aquaculture have largely been associated with the intensive cultivation of high-value species such as shrimp and salmon (Paez-Ozuna 2001; Naylor and others 1998; Naylor and Burke 2005). These include the net loss of fish protein through the use of fish-based feeds to raise cultured species (Naylor and others 2000; Naylor and Burke 2005), eutrophication of local water bodies (Folke and others 1992), deterioration of the benthos (Findlay and others 1995; Paez-Azuna 2001), discharge of pharmaceuticals and other chemicals (Hastein 1995), depletion of wild stocks through broodstock or seed harvesting (Mungkung and others 2006), introduction of genetic material into compromised conspecific populations (Fleming and others 2000), and amplification and retransmission of diseases and parasites to the wild (Krkosek and others 2006, 2007).

In addition to these proximate effects, which typically dominate discourse regarding the environmental repercussions of seafood production, other research indicates that the impacts stemming from the material and energetic demands of both industrial fisheries and aquaculture can also be substantial. For fisheries, these secondary impacts include the energetic and material inputs and emissions related to fishing vessel and gear construction and maintenance, (Watanabe and Okubo 1989; Hayman and others 2000; Ziegler and others 2003), fuel use for fishing (Ziegler and Hansson 2003; Thrane 2004a; Tyedmers 2004; Hospido and Tyedmers 2005), transport and processing of landings (Karlsen and Angelfoos 2000; Andersen 2002), and discharge of wastes and loss of fishing gear at sea (Derraik 2002). In aquaculture, the provision of concentrate feed for intensive production systems and the maintenance of water quality in closed containment systems have been found to appropriate high levels of both primary production and industrial energy, and generate significant greenhouse gas emissions (Folke 1988; Tyedmers 2000; Troell and others 2004; Papatryphon and others 2004; Pelletier and Tyedmers 2007; Ayer and Tyedmers 2008).

Obviously, the provision of seafood products by either traditional fisheries or emerging intensive aquaculture technologies generates a diverse range of impacts. If ecolabeling and certification schemes for seafood are to meaningfully influence more sustainable practices in these industries, then the criteria they employ should endeavor to address the full spectrum of significant ecological, biophysical, and socioeconomic consequences of seafood production. However, as the following review of several high-profile programs indicates, the scope of sustainability criteria considered by current initiatives appears to be seriously limited.

Current Criteria for Sustainable Seafood Production

Marine Stewardship Council

The MSC was established in 1997 through a partnership between Unilever, then the world's largest seafood buyer, and the World Wildlife Fund. Largely concerned with curtailing overexploitation of targeted and by-caught species, the MSC program licenses its label to fisheries that have been independently certified according to its standard for sustainable and well-managed fisheries (MSC 2006). At the core of the MSC certification program is a set of Principles and Criteria for Sustainable Fishing, which stipulate that a sustainable fishery must maintain or reestablish healthy populations of target species, ensure the integrity of ecosystems, develop and maintain effective management systems, and comply with all relevant laws, standards, understandings, and agreements. Each of these principles is embodied in a suite of criteria against which fisheries seeking certification are assessed (Table 1). In short, the MSC criteria for sustainable fisheries speak largely to proximate ecological concerns, make minor mention of limited socioeconomic criteria, and overlook the full range of broader biophysical sustainability considerations that flow from the diverse range of industrial activities associated with the provision of wild-caught seafood products to consumers.

Global Aquaculture Alliance (GAA) and the Aquaculture Certification Council

The GAA, which operates under the motto "Feeding the world through responsible aquaculture," is an international nonprofit trade association representing the shrimp industry. GAA has established voluntary, quantitative "Best Aquaculture Practices" standards for shrimp farming that are intended to promote environmental, economic, and social sustainability (GAA 2006). Specifically, the standards address mangrove, soil and water conservation, postlarval sources, drug and chemical use, effluent and sediment management, sanitation, harvest and transport practices, property rights, regulatory compliance, and employee and community relations (Table 2). The Aquaculture Certification Council is an international certifying body established by the GAA to administer a certification program based on the GAA standards.

Similar to the MSC criteria, the GAA standards for sustainable shrimp farming are largely concerned with localized ecological impacts. The criteria for socioeconomic sustainability are limited to prescribing adherence to existing laws and labor standards. As with the MSC, nonecological biophysical dimensions are not included.

Organic Aquaculture Standards

Organic standards regulate the materials and practices used in food production. A central goal of organic certification is to verify, and communicate to consumers, the ecological efficiency of a certified production system (IFOAM 2005).

Table 1 Marine Stewardship Council (2006) principles and criteria

Principles/Criteria
The fishery must:
1. Avoid over-fishing or take actions to recover depleted fishery.
• Maintain high productivity of target population(s) and associated ecosystems; execute fishery such that depleted populations recover within a specified time; not impair reproductive capacity.
2. Allow for the maintenance of the structure/productivity/function/diversity of the ecosystem.
• Maintain functional relationships among species; not cause trophic cascades or ecosystem state changes; not threaten biological diversity; recovery of depleted populations is assured.
3. Have an effective management system that respects relevant laws/standards and incorporates institutional and operational frameworks that require use of the resource to be responsible and sustainable.
• Fishery not conducted under a unilateral exemption to an international agreement; demonstrate clear long-term objectives consistent with MSC Principles and Criteria and contain a consultative process involving all impacted parties; be appropriate to the cultural context, scale and intensity of the fishery.
The management system must:
4. Observe the legal and customary rights and long term interests of people dependent on fishing for food and livelihood, in a manner consistent with ecological sustainability.
5. Incorporate an appropriate mechanism for the resolution of disputes arising within the system.
6. Provide economic and social incentives that contribute to sustainable fishing and not operate with subsidies that contribute to unsustainable fishing.
7. Act in a timely fashion using best available information and a precautionary approach.
8. Incorporate an appropriate research plan.
9. Management plan requires assessments of biological status/impacts.
10. Specify measures and strategies to control the degree of exploitation of the resource, including:
• Setting catch levels that maintain productivity of target population and ecological community; identifying appropriate fishing methods that minimize adverse impacts on habitat; provide for the recovery of depleted fish populations within specified time frames; mechanisms in place to limit or close fisheries when designated catch limits are reached; establishing no-take zones where appropriate.
11. Contains procedures for effective compliance/monitoring/control surveillance/enforcement.
The fishing operation must:
12. Use gear/practices that minimize by-catch, by-catch mortality, and discards.
13. Implement appropriate fishing methods designed to minimize adverse impacts on habitat.
14. Not use destructive fishing practices such as fishing with poisons or explosives.
15. Minimize loss of fishing gear, oil spills, onboard spoilage of catch, etc.
16. Be in compliance with fishery management system and all legal and administrative requirements.
17. Facilitate collection of data important to effective management.

In recent years, standards for organic aquaculture have been developed in several jurisdictions throughout the world, although many are still in draft form. Albeit presently catering to a niche market, the United Nations Food and Agriculture Organization predicts a 240-fold increase in certified organic aquaculture production by 2030 (El Hage-Scialabba and Hattam 2002). The relative contribution to total aquaculture production will remain small, but the majority of this increase will occur in the shrimp and carnivorous finfish aquaculture sectors, which have traditionally attracted the majority of concern regarding their environmental impacts.

Organic aquaculture standards typically include criteria for stock density, chemical inputs, production materials, benthic impacts, and siting considerations. The standards also prescribe restrictions on aquafeeds, including specifications for resources of marine origin, agricultural ingredients, feed additives, and production technologies (Pelletier 2003) (Table 3). Although the basic organic aquaculture standards prescribed by the International Federation of Organic Agriculture Movements suggest that species-specific standards should address matters of eco-efficiency and social sustainability, a review of existing standards reveals that, for the most part, these are limited to proximate, ecologically oriented considerations (Pelletier 2003).

Consumer Guides: Seafood Watch

As indicated previously, there are numerous programs providing direct guidance to consumers around the world regarding the relative sustainability of seafood product

Table 2 Global Aquaculture Alliance best aquaculture practices standards for shrimp farms

Community

1. Property rights and regulatory compliance
   - Comply with local and national laws and environmental regulations.
2. Community relations
   - Must not deny local communities access to public resources.
3. Worker safety and employee relations
   - Comply with labor laws to assure worker safety, compensation and living conditions at the facility.

Environment

4. Mangrove conservation and biodiversity protection
   - Must not be located in mangrove areas, seagrass beds or other coastal wetlands. Farm operations shall not damage wetlands or reduce the biodiversity of coastal ecosystems. Mangroves removed for allowable purposes shall be replaced by replanting an area three times as large.
5. Effluent management
   - Monitor effluents to confirm that water quality complies with BAP criteria.
6. Sediment management
   - Farms shall contain sediment from ponds, canals and settling basins and not cause salinization or other ecological nuisance in surrounding land and water.
7. Soil/Water conservation
   - Farms must not cause soil and water salinization or depletion of ground water.
8. Post-larvae sources
   - Certified farms shall not use wild post-larvae and shall comply with governmental regulations regarding the importation of native and non-native shrimp seedstock.
9. Storage and disposal of farm supplies
   - All materials shall be stored and disposed of in a safe and responsible manner.

Food safety

10. Drug and chemical management
    - Banned chemical compounds shall not be used. Other therapeutic agents shall be used as directed on product labels for control of diagnosed diseases or required pond management, not prophylactic purposes. Shrimp shall be periodically monitored for residues of suspect pesticides, PCBs and heavy metals that are confirmed in the vicinity.
11. Microbial sanitation
    - Human waste and untreated animal manure shall be excluded from shrimp grow-out ponds.
12. Harvest and transport
    - Shrimp shall be harvested and transported in a manner that maintains temperature control and minimizes physical damage and contamination. Shrimp treated with sulfites or other allergens shall be labeled accordingly.

Traceability

13. Record-keeping requirement
    - To establish product traceability, specified information shall be recorded for each pond and each production cycle.

Source: Aquaculture Certification Council (2006)

choices. Although all of these initiatives differ in terms of their geographic and substantive focus, along with the evaluative criteria that they employ, for simplicity, we have chosen to focus our discussion on the Seafood Watch program of the Monterey Bay Aquarium. Seafood Watch evaluates the performance of farmed and wild-caught seafood products against a detailed set of criteria using publicly available data and publishes a variety of pocket and online guides to sustainable seafood consumption (Seafood Watch 2006a). The mission of the program is to empower seafood consumers to influence more sustainable aquaculture and fisheries practices by providing clear and easily accessible signals regarding the relative sustainability of specific products.

Seafood Watch follows a six-step framework for developing seafood recommendations. First, regional U.S. market information is analyzed to determine the most popular seafood items within those markets. Information is then gathered for each of these products, including species name, life history and distribution, market information, capture/culture technologies, and management regimes. Next, a detailed Seafood Report is created for each species in which this information is evaluated against a suite of sustainability criteria (Table 4). The results of this

Table 3 Selected criteria from organic salmon aquaculture standards compared to conventional practices

Criterion	Organic production	Conventional production
Stock density	5–10 kg/m^3	15–35 kg/m^3
Antibiotics	Restricted or not allowed	Usually regulated
Antifouling compounds	Not allowed	Usually regulated
Feed restrictions		
Marine resources	By-products of food fisheries, or from "sustainable" reduction fisheries (FAO Code of Conduct)	No restrictions
Crop ingredients	Certified organic	No restrictions
Animal by-products	Certified organic or not allowed	May be allowed
Disease/parasite interactions	May have action levels for sea lice	Usually regulated
Benthic impacts	May have action levels for remediation	Usually regulated

Source: Pelletier (2003)

assessment are used to assign each product one of three potential recommendations: Best Choices, Good Alternatives, or Avoid. Recommendations are published on-line and in the form of pocket guides.

A review of the major criteria used by Seafood Watch (Table 4) indicates that proximate ecological considerations are once again the primary focus, with socioeconomic and broader-scale biophysical criteria notable only by their absence. This is perhaps not surprising given that the Seafood Watch criteria for sustainable fisheries were initially developed from those employed by the MSC.

A comparison of the criteria employed in these varied approaches to labeling, certifying, or communicating for sustainable seafood production and consumption outlined above indicates that precedence has been given to addressing those proximate environmental impacts that stem directly from the extractive or production stages of fisheries and aquaculture (Table 5). For fisheries, this typically encompasses the direct impacts on target and nontarget stocks via overfishing, by-catch, and physical damage to benthic communities. In aquaculture, key areas of concern appear to be local environmental impacts such as the conversion of aquatic ecosystems, degradation of the benthos, disease/parasite transfer to wild stocks, escapes, chemical emissions, and, more broadly, the use of wild fish for feed production.

Table 4 Seafood Watch (2006) sustainability criteria for fisheries and aquaculture

Capture fishery criteria

- Inherent vulnerability to fishing pressure
- Status of wild stocks
- Nature and extent of discarded by-catch
- Effect of fishing practices on habitats and ecosystems
- Effectiveness of the management regime

Aquaculture criteria

- Use of marine resources
- Risk of escaped fish to wild stocks
- Risk of disease and parasite transfer to wild stocks
- Risk of pollution and habitat impacts
- Effectiveness of the management regime

Inarguably, such ecological criteria speak to important considerations for sustainable seafood production. Maintaining the productivity of target populations/culture organisms and their host ecosystems is prerequisite to ensuring the viability of the resource base. However, these criteria alone do not adequately reflect the breadth of sustainability concerns associated with alternative seafood production systems because they pay little, if any. attention to socioeconomic considerations, and largely ignore the broad-scale biophysical impacts that result from the myriad material and energy resource flows underpinning fisheries and aquaculture production technologies. The importance of the latter, which directly influence the stability of the biogeochemical cycles that cumulatively provide the implicate order for resilient ecosystems, bears particular consideration.

As suggested by numerous authors (see Roessig and others 2004; Brander 2007; Ficke and others 2007, etc.), the interrelationships between the macroscale environmental changes resulting from the cumulative impacts of

Table 5 Presence and strength of measures of ecological, socioeconomic, and biophysical sustainability in seafood ecolabeling, certification, and consumer education programs

	Sustainability criteria		
	Ecological	Socioeconomic	Biophysical
MSC	Strong	Limited	None
GAA	Limited	Limited	None
Organic	Limited	Limited	None
Seafood Watch	Strong	None	None

Note: MSC, Marine Stewardship Council; GAA, Global Aquaculture Alliance industrial activities, ocean and freshwater ecosystem health, and fishery viability should not be understated. For example, Hoegh-Guldberg and others (2008) discuss how climate change exacerbates local stresses in reef ecosystems, driving reefs increasingly toward the tipping point for functional collapse. They further suggest that warming and ocean acidification will compromise carbonate accretion, with corals becoming increasingly rare on reef systems. As fisheries are biodiversity hot spots important in the life cycles of many commercially exploited species, the implications are grave.

In short, it is readily apparent that none of the schemes reviewed have seriously considered the full range of environmental and social costs generated in the delivery to market of the products they refer to. The implication, then, is that seafood products currently marketed as sustainable, based on a limited, albeit important, set of ecological criteria, may, in fact, be profoundly unsustainable on other counts. LCA studies of seafood production provide a means of assessing and understanding a number of these often overlooked, but critically important, considerations for evaluating sustainability in the seafood sector.

Lessons from Life Cycle Assessment Research of Seafood Production Systems

The limited but increasing volume of LCA research of industrial fisheries and aquaculture indicates a growing interest in the use of LCA methodology to better understand and manage the biophysical sustainability of seafood production systems (Pelletier and others 2007). The LCA framework can be used to evaluate many of the macroscale environmental impacts associated with individual energetic and material inputs and outputs at each stage of the seafood product life cycle. This includes inputs and emissions related to the extraction and processing of raw materials, transportation and distribution, storage, consumption, and final disposal. Moreover, because these inputs and emissions are expressed according to their relative contributions to specified impact categories (Table 6), such analyses facilitate the identification of environmental "hot spots" in production systems, which can be used to inform criteria for product or process improvements (Consoli and others 1993). The results also facilitate comparisons of the relative ecoefficiency of competing production technologies.

To date, published LCA research on aquaculture production systems includes French land-based turbot production (Aubin and others 2006), Norwegian net-cage farmed salmon (Ellingsen and Aanondsen 2006), Thai shrimp products (Mungkung 2005), French recirculating trout farms and feeds (Papatryphon and others 2003, 2004), conventional and organic salmon feed production (Pelletier and Tyedmers 2007), Finnish trout production (Gronroos and others 2006), and alternative salmon production technologies (Ayer and Tyedmers 2008). LCA research on fisheries has been conducted for Spanish tuna fisheries (Hospido and Tyedmers 2005), Danish fish products (Thrane 2004a, b, 2006), Swedish cod products (Zeigler and others 2003), and Norwegian cod (Ellingsen and Aanondsen 2006). A comparison of life-cycle impacts between these diverse production scenarios indicates a number of key trends and similarities between systems.

Life Cycle Impacts of Aquaculture Production

Encompassing numerous technologies and culture organisms, aquaculture is a highly diverse activity. Worldwide, more than 220 different species of finfish, shellfish, and seaweeds are farmed. Production systems are also diverse, ranging from traditional, low-intensity subsistence aquaculture to highly intensive industrial production facilities in a variety of freshwater, brackish, and marine environments. The continuum between these extremes is populated with a plethora of farming technologies, including monoculture and polyculture systems, freshwater pond farming, land-based tanks, and open water culture systems such as cages and pens for finfish, and poles, rafts, or longlines for seaweed and mussel culture (Troell and others 2004).

Aquaculture involves the redirection and concentration of matter and energy from the environment to facilitate the growth of specific organisms (Troell and others 2004). Given the diversity of culture systems in use, it is to be anticipated that different kinds of aquaculture consume varied forms and amounts of resources and generate different quantities and qualities of waste products. In some cases, such as the culture of photosynthetic seaweeds or filter-feeding bivalves, all energy directly required by the culture organisms is derived from the immediate environment. More commonly, auxiliary feed energy inputs from off-farm sources are used to enhance productivity. In addition, the energetic, material, labor, capital, and technology inputs required to provide both feed and an appropriate culture environment vary widely (Troell and others 2004). Most LCA research on aquaculture has dealt with intensive culture systems for high-trophic-level organisms, which are characterized by considerable energy and material throughput.

In general, life cycle research suggests that feed provision for the culture organisms often accounts for the majority of the associated macroscale environmental impacts. Papatryphon and others (2003) found that feed production for closed-containment rainbow trout aquaculture in France accounted for 52% of the overall energy use, 82% of the acidifying emissions, 83% of greenhouse gas emissions, and 100% of biotic resource use. Gronroos and others (2006) reported that the production of raw feed materials and the manufacturing of feed were responsible for most of the atmospheric emissions associated with net-cage rainbow trout aquaculture in Finland. Ellingsen and Aanondsen (2006) found that feed provision for net-cage salmon aquaculture contributed the majority of environmental burdens in all impact categories considered, and an LCA of Danish closed-containment trout production showed that feed production and use on the farm accounted for the greatest share of environmental impacts in 6 of the 10 impact categories analyzed (DAAS 2000). Closely related to feed provision, eutrophication impacts linked to nitrogen and phosphorous emissions from fish farms may also be significant (Gronroos and others 2006).

More recently, as part of an on-going international research project using Life Cycle Assessment to evaluate global salmon production systems, Pelletier and Tyedmers (2007) compared the life cycle industrial energy use, global warming potential, acidification, eutrophication, marine aquatic ecotoxicity, and biotic resource use associated with feed production for conventional and organic salmon aquaculture in the Northeast Pacific. The environmental performance of each feed component (delivered to the mill gate) was evaluated on an individual basis and several feed formulations were compared. It was found that the production of animal-derived ingredients (i.e., fishmeals/oil and poultry by-product meal) generated substantially greater life cycle impacts than crop-based ingredients. Although the production of organic crop ingredients had much lower impacts than equivalent conventionally produced ingredients, substituting organic for conventional ingredients in feeds resulted in only minor improvements to the overall environmental performance in feed production because the benefits of this substitution were overwhelmed by the much larger impacts associated with the fish- and poultry-based ingredients. Feeds in which fishmeals and oils from dedicated reduction fisheries were replaced with fishery by-product meals and oils performed poorest, largely due to the higher energy intensity of fisheries for human consumption relative to reduction fisheries (Tyedmers 2004) and the low meal/oil yield rates from fishery by-products. Feeds containing reduced proportions of animal-derived ingredients (25% of fishmeal replaced with soy meal and all fish oil replaced with canola oil) demonstrated significant improvements over all other scenarios, generating on average 54% of the impacts associated with the conventional feed (Pelletier and Tyedmers 2007).

The consistency of these results is not surprising considering the high energy and material demands of the reduction fisheries, fishmeal and oil reduction plants, agricultural production systems, fish feed plants, and transportation infrastructure that underpin concentrate feed production for intensive aquaculture (Tyedmers 2000; Troell and others 2004; Papatryphon and others 2004; Pelletier and Tyedmers 2007). Accordingly, efforts to mitigate the environmental impacts of intensive aquaculture must pay close attention to improving the ecoefficiency of feed production and use by maximizing feed conversion efficiency and employing low-trophic-level inputs. The use of synthetic amino acids in place of animal proteins may prove efficacious in this sense.

Table 6 Impact categories commonly employed in published Life Cycle Assessment research

Impact category	Description of impacts
Global warming	Contributes to atmospheric absorption of infrared radiation
Acidification	Contributes to acid deposition
Eutrophication	Provision of nutrients contributes to biological oxygen demand
Photochemical oxidant formation	Contributes to photochemical smog
Aquatic/terrestrial ecotoxicity	Creates conditions toxic to aquatic or terrestrial flora and fauna
Human toxicity	Creates conditions toxic to humans
Energy use	Depletes nonrenewable energy resources
Abiotic resource use	Depletes nonrenewable resources
Biotic resource use	Appropriates the products of primary production
Ozone depletion	Contributes to depletion of stratospheric ozone

Interestingly, at least one of the seafood consumer guide programs currently considers the ecoefficiency of feed production and use, but not out of concern for its associated energy and emission impacts. Among the criteria employed by Seafood Watch is the extent to which a cultured seafood system depends on wild-caught aquatic resources for fish meal and oil. Those systems in which ≥ 2 kg of wild-caught fish is needed to produce 1 kg live weight of farmed product are deemed to have an extensive dependence on marine resources and are flagged red. In contrast, those systems that require <1 kg of wild-caught fish per kilogram of farmed products are flagged green (Seafood Watch 2006b). This clearly places a premium on culture systems that are ecoefficient with respect to aquatic resources. However, although decreasing dependence on aquatic animal inputs may result in lower overall life cycle energy inputs and associated emissions as discussed above, it may not if those are replaced by equally energy-intensive terrestrial animal-derived feed inputs.

Open-water aquaculture relies on the surrounding environment to provide a constant supply of fresh, aerated water and to assimilate nutrient emissions generated by the culture organisms—in effect, making free use of these ecosystem services. Depending on the scale of the enterprise and the assimilative capacity of the receiving environment, the environmental impact of relying on these subsidies from nature may be benign or may lead to a deterioration of environmental quality. In contrast, intensive land-based aquaculture facilities typically internalize many of these costs by carefully maintaining a controlled, recirculating flow of water in which oxygen levels are artificially enhanced and wastes are removed and treated. This controlled environment may also minimize the potential for escapes and for disease and parasite transfer between wild and farmed stocks. Based on these fundamental differences between relatively open and controlled environment aquaculture systems, consumer guidance programs such as Seafood Watch promote the consumption of aquaculture products from intensive, controlled-environment farms (for example, farmed Arctic Char) and discourage consumers from purchasing products such as net-cage farmed salmon. In essence, because farming fish in highly controlled land-based facilities precludes the potential for many of the hot-button environmental impacts that receive considerable media currency, such systems are promoted as sustainable alternatives. However, this perspective discounts the broader environmental implications of the material and energy intensity often associated with such controlled-environment production technologies (Ayer and Tyedmers 2008).

LCA research of land-based aquaculture systems indicates that the environmental costs associated with the energy inputs required to maintain water quality and oxygen levels can be even greater than those linked to feed production. Papatryphon and others (2003) found that production intensity during the dry summer months, when higher levels of fuel and electricity use were required for water aeration and circulation, was an important indicator of overall environmental performance in land-based trout farming. In an LCA of Thai shrimp aquaculture, Mungkung (2005) reported that energy inputs for aeration contributed heavily to the environmental costs of production. An LCA study of turbot production in a land-based recirculating system (Aubin and others 2006) showed that energy use, global warming, and acidification impacts were environmental hot spots and were largely a function of both the quantity and the origin of the energy used to maintain water quality. Danish LCA research on trout production (DAAS 2000) similarly reported high global warming and toxicity impacts associated with on-farm energy inputs for aeration and recirculation.

As part of the aforementioned international research project applying LCA to global salmon production systems, Ayer and Tyedmers (2008) compared the life cycle impacts of four alternative salmonid culture technologies: the traditional open-water net-pen system, an in-water impermeable-bag system, a land-based flow-through tank system, and a land-based recirculating system. Feed production dominated impacts in both the net-pen and the seabag systems, but these were dwarfed by the considerable energy demands of both land-based systems. In other words, moving from sea-based to land-based culture environments addressed many of the proximate ecological concerns but replaced these with significantly higher contributions to broad-scale impacts such as global warming, acid precipitation, and resource depletion (Ayer and Tyedmers 2008). These results underscore the importance of considering a broader spectrum of environmental interactions—in particular, the energy dependencies and associated environmental impacts of alternative culture technologies—than those currently employed in many labeling/certification and consumer education programs.

To date, however, only one published study suggests using LCA specifically to inform ecolabeling criteria for seafood production. Mungkung and others (2006) identified abiotic depletion and global warming impacts due to energy use, and eutrophication caused by wastewater discharge as the environmental hot spots in shrimp aquaculture that could be quantified against relevant ecolabeling criteria. The depletion of broodstock, impacts of trawling on biodiversity, and choice of appropriate culture sites were also described as potential qualitative criteria.

Life Cycle Impacts of Fisheries Production

Thrane (2004b) used LCA to evaluate a suite of environmental impacts related to a Danish flatfish-derived product and reported that the fishery itself was the stage in the product life cycle with the greatest impacts in all impact categories measured. Reduction of fuel consumption through gear substitution was identified as an important means of decreasing impacts, and improvements in fuel efficiency also appeared consistent with reducing sea floor impacts and reducing overexploitation of fish stocks.

In a parallel study of energy consumption in the Danish fishing fleet as a whole, Thrane (2006) found a large variation in the energy intensity of various fisheries, depending, in particular, on the species targeted, vessel size, and gear type. Specifically, there was a 200-fold difference between the least and the most fuel-efficient fishery, with some products much more or much less energy intensive than typical meat products from agriculture. Several options for improving the fuel efficiency of the fisheries were provided. The suggestion that improvements in fuel efficiency may be consistent with objectives such as reducing discards and benthic impacts was also advanced. Zeigler and others (2003) reported similar findings in an LCA of Swedish cod products.

In an LCA of Spanish tuna fisheries Hospido and Tyedmers (2005) also found that the production and use of diesel fuel while fishing dominated impacts in six of seven categories evaluated. Fisheries located farther from the Spanish ports where tuna were to be processed resulted in higher impacts due to higher postharvest transport-related fuel inputs. These researchers also modeled scenarios characterized by higher tuna abundance and availability and concluded that management efforts to rebuild stocks could improve the overall environmental performance of the fisheries.

These studies consistently indicate the importance of fuel use efficiency to environmental performance in fisheries—in terms of both resource use and contributions to macroscale environmental problems such as climate change, ozone depletion, photo-oxidant formation, and ecotoxicity. From a perspective of biophysical sustainability, this is certainly an intuitive conclusion. Given the finite nature of available energy resources and assimilative capacity for waste emissions, the sustainability of alternative food production systems will, in part, depend on the caloric return derived in relation to the material and energy throughput. All else being equal, a fishery that consumes less fuel and generates fewer pollutants to deliver a specified quantity of fish protein to market is more sustainable than a fishery that consumes more fuel. Of course, all else is rarely equal, and for this reason, decisions of allocative efficiency must also be informed by considerations of comparative ecological and socioeconomic performance. However, the sustainability measures currently employed by ecolabeling, certification, and consumer awareness programs consistently fail to consider these factors in concert. Accordingly, it is conceivable that a program such as MSC could license its label for “sustainable” fishery products derived from the most energy- and greenhouse gas-intensive fishery in the world, and that consumer guidance programs such as Seafood Watch could encourage consumption of the products derived. This would appear somewhat akin to “not seeing the forest for the trees.”

The good news is that based on the limited data available, well-managed fisheries that exploit relatively abundant stocks generally have lower fuel intensities and result in lower emissions than they would otherwise. For example, unpublished data for at least some Alaskan-based fisheries for Pacific salmon (*Oncorhynchus* spp.) (derived from the same international salmon LCA project) and Alaskan pollock (*Theragra chalcogramma*), both of which are currently certified by the MSC, suggest that these fisheries typically burn <100 liters per ton of fish landed. This is far lower than the estimated average fuel use intensity for fisheries globally of 620 liters per ton (Tyedmers and others 2005). Similarly, historical data suggest that decades ago, fuel inputs were far lower than they are now, despite the constant improvements to engine efficiency and hull and gear design aimed at lowering fuel inputs and costs (Tyedmers 2004). This indicates that managing for more abundant stocks will have the simultaneous benefit of reducing fossil fuel consumption and the related environmental impacts.

Conclusion: Implications for Marketing Sustainability in the Seafood Sector

LCA studies of fisheries and aquaculture production systems generally consider a range of environmental impacts very different from those currently used in most ecolabeling, certification, and consumer awareness programs. Rather than focusing on the high-profile, largely proximate ecological impacts that such programs have traditionally sought to address, LCA research is more conducive to illuminating the material and energy flows related to alternative seafood production strategies and comparing how these biophysical flows contribute to macroscale environmental concerns.

For example, using energy intensity in seafood production as a crude proxy for macroscale biophysical impacts, it is possible to generalize which seafood products would be favored and which might be penalized were such considerations included in sustainability assessments, and to contrast these with the recommendations of existing sustainable seafood initiatives. In general, aquaculture production systems reliant on concentrate feed inputs containing substantial fractions of animal-derived ingredients and closed-containment technologies that require high energy inputs to maintain water quality are less sustainable in a macroscale, biophysical sense than those using low-trophic-level feeds and relying on ecosystem goods and services to maintain water quality. This contradicts the signals sent by sustainable seafood initiatives such as Seafood Watch, as well as the seeming focus of organic seafood certifying agencies—both of which speak largely to proximate, ecological considerations. Energy intensity in fisheries can similarly serve as a generic indicator, and could easily be incorporated in sustainable seafood initiatives such as those operated by both Seafood Watch and the MSC.

The most important insights emerging from LCA research should therefore be used in complement with measures of ecological and socioeconomic sustainability in seafood production since these measures are, by themselves, incomplete. If sustainability involves an optimum balance of ecological, broader biophysical, and socioeconomic conditions, then ecolabeling and certification criteria for sustainable seafood products should attempt to address all of these dimensions. Of course, it is to be expected that certain activities may be sustainable in some dimensions but unsustainable in others—necessitating informed value judgments of the tradeoffs associated with specific development pathways. This will certainly require considerable effort on the behalf of sustainable seafood programs—particularly where unidimensional indicators must be replaced with more nuanced signals that communicate these tradeoffs to consumers in a clear and accessible manner. This is a lesson for policy and management, generally. Reality will often prove more complex than our historically simplistic management paradigms imply. Yet the nature of our globalized, technological society necessitates that we embrace such complexity. The alternative is to risk promoting activities, products, or production systems as sustainable based on a narrow range of criteria when a more comprehensive suite of considerations would yield a very different result (Lavallee and Plouffe 2004).

At present, no one tool is adequate to the task of measuring and reporting on all aspects of sustainability. Thus, it may be necessary to call on a variety of tools from different disciplines in order to arrive at a comprehensive measure of the sustainability of a given enterprise. Current LCA research can usefully inform considerations of biophysical sustainability and may, in the future, similarly speak to certain ecological and socioeconomic considerations. Utne (2006, 2007) and Standal and Utne (2007) provide some interesting examples of the challenges and opportunities for simultaneously considering the multiple dimensions of sustainable seafood production in a management context.

At root, most environmental problems reflect a conflict between the scale of human activities and the limited nature of material/energy resources or the capacity of ecosystems to absorb wastes and respond to change. The precipitation of critical environmental problems such as ozone depletion, climate change, and biodiversity loss reflect this conflict, and the attendant necessity of instituting social policies that restructure human activities with respect to these limitations, while simultaneously ensuring the well-being of present and future generations. Efforts to improve the sustainability of fisheries and aquaculture production will therefore require attention to more than just the direct ecological impacts to target species and ecosystems. Rather, such endeavors must include considerations of how to most efficiently allocate resources between competing users in a manner that maximizes returns and minimizes impacts. This could include promoting fuel-efficient fisheries or forms of aquaculture that generate greater edible returns with respect to both industrial energy and primary production inputs while minimizing polluting emissions.

To this end, LCA research can be used to identify critical aspects of production systems that contribute disproportionately to specific kinds of environmental impacts and, thus, indicate important foci for ecolabeling and certification criteria. Furthermore, communicating this information in relation to both comparable performance in other production systems and biophysical limits in general will provide a solid foundation on which to preferentially promote or discourage the consumption of specific seafood products.

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