BLUE FRONTIERS

Managing the environmental costs of aquaculture

POLICY BRIEF

Policy Recommendations

- IMPROVE POLICY WHERE IT MATTERS MOST: The level of environmental impact is strongly correlated with overall levels of aquaculture production. China and the rest of Asia account for 91% of global aquaculture production. Focused support to Asian producers is required to mitigate the current and future environmental impacts of aquaculture.
- IMPROVE EFFICIENCY BY LEARNING FROM OTHERS: Aquaculture systems vary markedly in their environmental performance, both within and across countries, offering great potential for improvement. Shared learning of best practice across the industry would close efficiency gaps.
- REDUCE USE OF FISHMEAL AND FISH OILS THROUGH LEARNING AND INNOVATION: Use of fishmeal and fish oils is widespread. Promoting best practices and stimulating innovation in the feed sector would have environmental benefits.
- CONDUCT ENERGY AND WATER AUDITS TO IDENTIFY OPPORTUNITIES FOR EFFICIENCY GAINS: Improvements in energy efficiency throughout the aquaculture value chain would reduce the sector's impact on climate change and acidification. Significant reductions in the impact of energy use however, may require changes in the way that energy is generated at the national level. Policy makers and industry professionals are recommended to support development of productive technologies that make best use of land, water and feed resources and that minimize demands on environmental services.
- PROMOTE SUSTAINABLE AQUACULTURE TO EXPAND ANIMAL FOOD PRODUCTION: Because fish are highly efficient at converting feed into protein, fish farming offers an ecologically competitive option for producing animal source foods. Aquaculture also contributes less to global emissions of nitrogen and phosphorus than pork or beef production.
- DEVELOP SUSTAINABLE AQUACULTURE TO IMPROVE FOOD SECURITY: Aquaculture is poised to be an increasingly important contributor to food and nutrition security in developing countries with a culture of fish consumption.
- AVOID SITING AQUACULTURE OPERATIONS IN SENSITIVE HABITATS: Climate change cannot be ignored. New aquaculture enterprises should not be located in areas that are high in sequestered carbon.
- SUPPORT AQUACULTURE INNOVATION, REGULATION, CAPACITY DEVELOPMENT AND MONITORING: It is important that the policy and regulatory environment keeps pace with and support sector development and that the aquaculture industry internalizes the costs of its environmental impacts.

Understanding and quantifying the environmental impacts of aquaculture is essential for sound decision making. Using information about environmental impact, policy-makers can establish evidence-based and fair environmental regulations. Fish farmers can understand and comply with environmental regulations while implementing good management practices. Development and environmental organizations need it to guide their strategies and actions while retailers and consumers need it to make informed choices and drive appropriate policy and farming practices.

Blue Frontiers: ***Managing the environmental costs of aquaculture*** is a new publication from The WorldFish Center and Conservation International. The report analyzes how the global aquaculture industry uses natural resources and its impacts on the environment. It makes a broad-brush comparison of aquaculture with other animal food production systems and extrapolates from past history to look forward and identify potential future impacts. The paper also proposes important recommendations for policy makers and scientists engaged in debate on the future of food production and nutrition security.

This brief provides a summary of the report and its conclusions, and highlights policy implications and the research agenda necessary to more effectively manage the environmental costs so that aquaculture can contribute to food security and environmental sustainability.

Background

Aquaculture is one of the fastest growing food production sectors in the world. It has grown at an average annual rate of 8.4% since 1970 and total production reached 65.8 million tonnes in 2008. China and the rest of Asia supply 91% of global production. Despite the overall dominance of Asia, however, aquaculture is an important economic activity on most continents and its importance is growing almost everywhere.

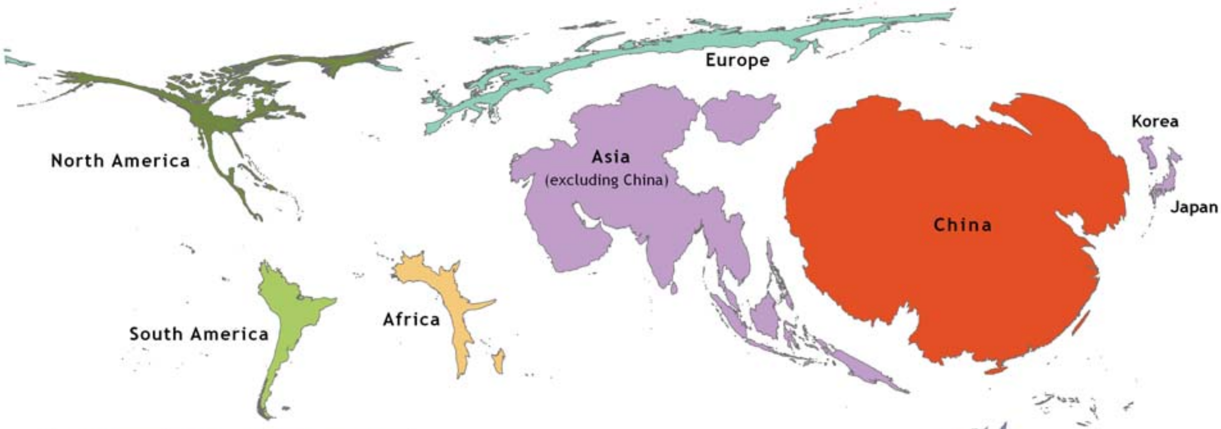
Carp production dominates in both China and the rest of Asia while in Europe and South America it is salmonids. African aquaculture production is almost exclusively of finfish, of which tilapias are the most important. Shrimps and prawns dominate in Oceania, while North American production is more evenly distributed among species with shrimps and prawns, catfish, bivalves and salmonids accounting for the majority of production.

The worldwide growth in aquaculture production is variable from one area to another. Over the last five years growth has been high in China and the rest of Asia at 30% and 56%, respectively. It is also high in Oceania at 37% and South America at 39%. The highest growth rate over this period, however, was in Africa at 81%, albeit from a very low baseline. Growth of catfish culture in Asia (307%) and Africa (496%) has been explosive.

Also, and of increasing significance, is the trend in the proportion of fish provided by aquaculture as opposed to the more conventional capture fisheries. Supply from aquaculture is now dominant for seaweeds (99.5%) carps (89.9%) and salmonids (72.8%). Cultured tilapia, catfish, mollusks, crabs and lobsters are currently 50% of total supply.

The rapid growth of aquaculture has raised questions concerning the environmental sustainability of industry growth. Central to these concerns are the demands that aquaculture places on biophysical resources (inputs) and the demands placed on the environment from wastes (outputs). Unsustainable consumption of resources will ultimately undermine productivity and bring it into competition for resources with other sectors, while the externalities arising from the discharge of waste materials need to be factored into environmental impact analyses.

Logically associated with this topic is the need to understand how aquaculture, with its many different production systems, compares with other animal protein production practices (such as that of poultry, pork or beef) in terms of efficiency and the relative degree of environmental impact, and what the likely future impacts of aquaculture will be.



Continent	Production 2008	Proportion
China	40,508,119	61.5
Asia	19,401,808	29.5
Europe	2,341,646	3.6
South America	1,461,061	2.2
North America	965,792	1.5
Africa	952,133	1.4
Oceania	176,181	0.3

Figure 1
World aquaculture production by continent in 2008 (China treated separately). Land areas are adjusted proportionally to reflect production volumes.

Life Cycle Analysis of Environmental Impacts

The report clearly identifies how environmental impact compares across systems and geographies, the species groups or production systems that are especially demanding on biophysical resources, and how environmental performance for similar systems differs among countries.

Absolute impact levels correlate well with overall levels of production. Globally inland pond culture is the predominant production system and contributes the greatest impact across all 6 impact categories. From a global perspective, the impacts of Chinese aquaculture, and carp culture in particular, stand out. Marine cage and pen fish farming are notable for biotic depletion due to their demand for wild fish. So is the production of shrimp, prawn and salmon due to the quantity of wild fish needed to produce acceptable fish food containing the necessary quantity and variety of oils and fats. Eel farming was shown to be particularly demanding in its energy requirements. In contrast, bivalve and seaweed production placed low demands on biotic resources and actually reduced eutrophication by absorbing nutrients from the water.

The results show the relative efficiencies in production by species, system and country. Of particular significance are the comparisons between species cultured in the same system in different countries. Here we find considerable variance. For more than half of the comparisons, the best performing nations showed more than 50% lower impact levels than the worst performing nations. This is due to differences in production practices where farm level choices and management exert significant influence on impacts, and in systemic country-specific conditions (such as method of energy production) over which fish farmers often have little or no control.

Implications and policy recommendations

Policy reform and research are essential to reduce the overall environmental impact in regions suffering the most, i.e., Asia and particularly China.

Given the observed differences in species, system choices and management practices, there is potential for large improvements in efficiency. Shared learning of best practices across the industry offers significant opportunities to increase efficiencies. It is not surprising that the salmon industry showed least variation across both countries and impact categories. This is almost certainly due to the greater investments in salmon farming research, the global nature and competitiveness of the industry and the fact that the sector is dominated by a few large companies. Similar investment in research, combined with the right institutional, policy and market drivers, could lead to a dramatic improvement in performance in many other aquaculture systems.

New innovations are required to reduce the dependency of some aquaculture production systems on fishmeal and fish oil. This may be achieved by management changes that limit supply of fishmeal and oil to selected growth periods, or by the production of alternative vegetable based feeds that provide the necessary ingredients. Alternatively, through artificial selection, fish may be bred that have lower requirements for fishmeal and fish oils.

In most production systems electricity generation was shown to be the main contributor to acidification, energy demand and climate. Although energy use can be reduced by increases in efficiency, the method of production is largely a national policy issue and out of the direct control of farmers. The use of water and energy audits is recommended to encourage practices that reduce resource demands.

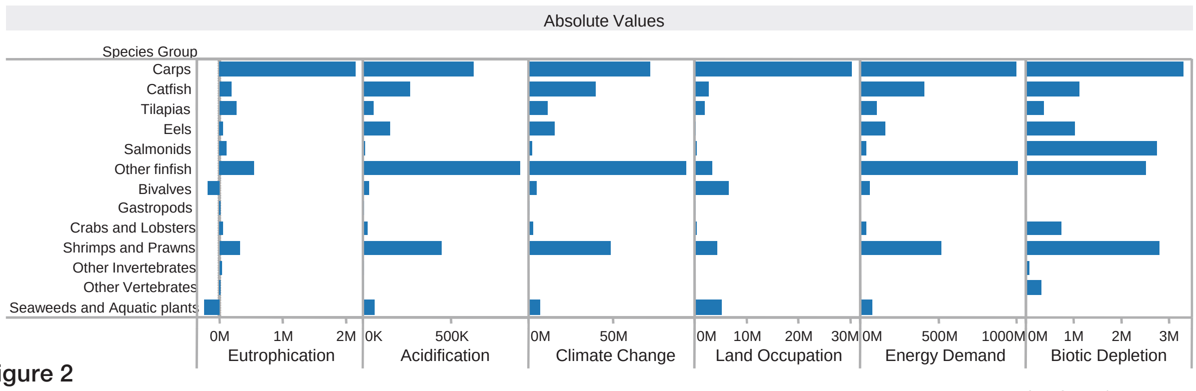


Figure 2

The absolute environmental impact of 2008 aquaculture production categorized by species group; Eutrophication (t PO_4 eq); Acidification (t SO_2 eq); Climate Change (t CO_2 eq); Land Occupation (ha eq); Cumulative Energy Demand (Gj); Biotic Depletion.

Comparing Aquaculture with Other Animal Food Production

Comparisons of the environmental costs of aquaculture with those of livestock are important to ensure that the animal food production sector develops in ways that use available resources wisely. Drawing extensively on the work of FAO, similar biophysical resource inputs and emissions were reviewed and environmental impacts were determined for dairy, poultry, pork and beef production.

Fish score well in terms of food conversion efficiencies (Figure 3). They convert a higher percentage of the food they eat into consumable protein. This efficiency is partly a reflection of the fact that fish being cold blooded, do not use energy to maintain a high body temperature. As fish live in an aquatic environment they do not need as extensive a skeleton as terrestrial livestock and so there are more portions available as food. Efficiencies are most notable for fish species that feed low in the food chain, primarily on vegetable-based feeds. However, not all fish can be grown on this diet alone. Shrimp, prawns and salmonids, for example, require feeds with fishmeal and fish oil. Replacing fishmeal with land-based crops leads to increases in the use of land and water. It also produces a nutritionally inferior end product in which total lipid levels rise and lipid profiles shift to become dominated by less desirable omega-6 fatty acids. Concerns of overfishing of marine ecosystems arise with a growing demand for fishmeal and fish oil from capture fisheries.

On average, fish have a lower potential to cause eutrophication than pork or beef (Figure 4).

The land area required to produce equivalent quantities of fish or meat were found to be broadly similar, but research from other authors has yielded contradictory results. This illustrates the complexity of comparative analysis between different animal production systems.

Aquaculture use of water is variable and can, in fact be lower than other animal production systems (Figure 5). For example, coastal aquaculture makes use of sea water rather than fresh. Inland aquaculture ponds are drained and filled on a periodic basis but the water is often a form of water storage and seepage losses from ponds represent an ecosystem service, serving to recharge groundwater reserves.

Implications and policy recommendations

An important advantage of fish production is the greater efficiency of fish in converting feed to biomass. Evidence also suggests that aquaculture contributes less to global emissions of nitrogen and phosphorus than production of pork and beef. Aquaculture thus has clear advantages over other types of animal source food production for human consumption. Where resources are stretched, policies that promote fish farming over other forms of livestock production should be considered.

It is important to remember that there is trade-offs between different production systems and in the level of environmental impact from the various species groups.

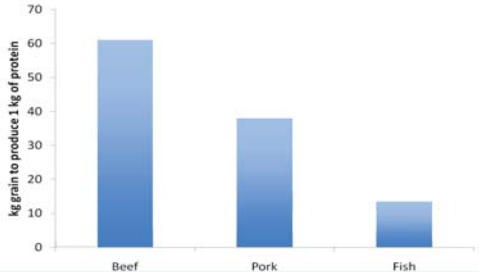


Figure 3
Conversion efficiency for animal food production.

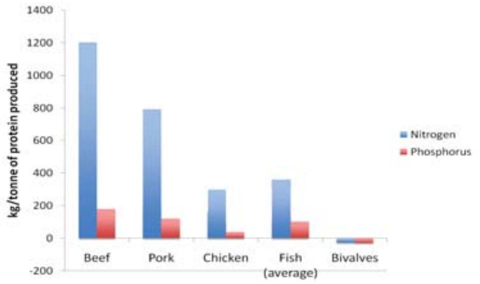


Figure 4
Emissions for animal food production.

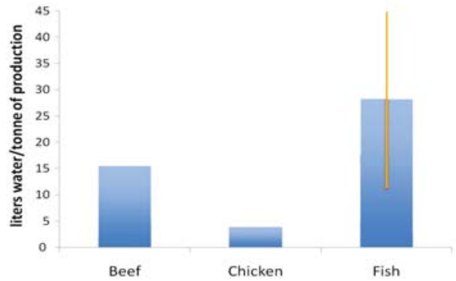


Figure 5
Water use for animal food production.

Projecting the Future of Aquaculture

Studies suggest that increasing prosperity and urbanization are the key factors driving demand for animal protein, including fish. Relative price of other protein sources and increased awareness of health benefits are relevant, but secondary elements. As incomes rise, demand for fish follows suit. Evidence also suggests that moving from a rural to an urban environment is associated with an increase in consumption of animal source foods. By 2025, almost six out of ten people on Earth will live in urban centers, and over half of these will live in the cities of developing countries. China, India and the rest of Asia with their growing middle classes are where we can expect demand for fish to rise most significantly. The contribution of fish to food and nutrition security will become increasingly important in developing countries. This is particularly true for Asian and African countries where there is growing domestic and regional demand for fish, especially from the growing urban populations, including the urban poor.

There is a general consensus among published studies that the growth of global aquaculture production will continue along a trajectory similar to that of the recent past for at least the next five years. This results in an "uncertainty envelope" for production in 2020 estimated at between 65 and 85 million tonnes. Estimates that extend to 2030 have a wider margin of error, yielding a conservative range of 79 to 110 million tonnes.

The current distribution of production is likely to remain unchanged to at least 2015: Asia will account for more than 90% of production; Europe for around 3–4%; Latin America, North America and Africa for 2% each and Oceania for only a fraction of a percentage point. Projecting regional distribution beyond this period is more problematic due to a variety of interrelated factors such as competition for resources and markets and changes in government policies that favor or obstruct growth. Production in Europe and North America, which has remained largely static over the past decade, will probably not grow substantially due to lack of suitable new sites and competition from other producing countries. Growth in Africa is likely to be patchy. Private investment is driving rapid growth in Uganda, Nigeria and Ghana, but the very low production base and inefficient and poorly developed value chains indicate that at least a decade will pass before substantial increases in production are realized there.

Current trends indicate that the majority of the increase in global production to 2030 will come from South and Southeast Asia where India, Indonesia and Thailand will become increasingly larger producers. Major producer countries such as China and Vietnam will continue their drive towards export to European and North American markets. Other than markets, the principal constraint to production growth in the Asian region is likely to be availability of resources (land, water) and environmental change.

Life Cycle Analysis (LCA) models have been used to predict change in overall environmental impact (assuming that environmental production from aquaculture in 2030 reaches 100 million tons) for each of the six impact categories listed in Table 1. The largest projected change (+168%) is for eutrophication. Meeting the demands for fish production in the future will therefore require particular attention to issues of waste disposal.

The geographical distribution of each impact category broadly corresponds to production levels, re-affirming the importance of focused support to Asian producers

Table 1

*Projected change in total environmental impact between 2008 and 2030 for the systems modeled in this study**

Year	Eutrophication (Mt PO_4 eq)	Acidification (Mt SO_2 eq)	Climate Change (Mt CO_2 eq)	Land Occupation (Mha)	Energy Demand (Tj eq)	Biotic Depletion (Mt)
2008	3.57	2.54	291.2	50.61	3,358,468	15.11
2030	9.55	5.05	674. 6	113.63	7,622,647	37.88
% Change	+168%	+99%	+132%	+125%	+127%	+151%

**data exclude seaweeds, and assumes current production practices* for mitigation of current and future environmental impacts of aquaculture.

How the rise in production can be achieved in an environmentally sustainable manner raises important issues. Environmental constraints to increased production will need to be met through a combination of science and technology and with an enabling but environmentally sensitive set of policies and procedures. These will be driven by three actors, the industry itself, driven to maintain ecological integrity and ensure that any environmental degradation does not lead to decreases in production; by governments who will need to regulate impacts such as the quantity and quality of effluent discharge, and the retail consumer through awareness (such as from certification schemes) and purchasing preferences.

The current dominant systems will undoubtedly continue to intensify. Intensification has historically been accompanied by serious environmental issues that include disease outbreaks, habitat loss, overuse of antibiotics leading to resistant strains of pathogens, and pollution of local populations caused by genetic escapes. Fortunately, evidence suggests that some of these issues characterize the early stages of industry development and that lessons have been learnt that can prevent or reduce the occurrence of similar future scenarios. Policy makers will need to establish operating environments in which regulators can ensure that best industry standards and FAO guidelines for aquaculture are followed.

As aquaculture production methods intensify and farms get larger and more spatially concentrated, there is increased risk from the spread of pathogens. Disease prevention can prove difficult and increased use of antimicrobials as prophylactics and growth promoters is likely. This will increase the likelihood that new, drug-resistant strains of pathogens will develop and also raises concerns for human health.

Several approaches will be needed to overcome these obstacles. Developing vaccines is one means of reducing use of medicines, but research in this area is currently restricted to relatively few species (e.g., salmon, trout, and grouper) and vaccines are only effective against certain types of disease. Improved welfare standards will minimize stress on fish and reduce the incidence of disease. Well-enforced application of the environmental standards developed for many medicines will reduce the spread of pathogens. Food safety standards, designed to protect consumers from exposure to potentially harmful medicinal and other chemical residues, will force producers to stop using more persistent and harmful compounds and to use only approved compounds with due care and attention. These standards are currently more widely used in developed countries and applied to products from developing countries for export. Developing countries will need to apply similar regulations to protect their domestic consumers. While industry codes of practice may help, legislation and legislation implementation, combined with capacity building, are also needed.

The majority of aquaculture production is currently from extensive and semi-intensive systems. Feed is predominantly crop based. However, the inevitable increase in intensification, coupled with growth in the current systems, will place increased demand on both crop-based and fishmeal resources. Increased demand for crop-based feeds will intensify competition with crops grown for human consumption. The use of 'trash fish' (usually small pelagic species) in shrimp and carnivorous fish production has already been flagged as problematic because it exploits other marine resources, as reflected by the now stagnant rate of increase in capture fisheries. Reducing the fishmeal and fish oil component in aquaculture feeds is a high priority for intensive and semi-intensive systems. Some recommendations for addressing this issue include the increased use of locally sourced agricultural by-products such as oil cakes and rice bran, and the development of pre-treatment methods that increase the digestibility and nutrient availability of the food source. Development of alternative sources of high quality feed from plants or microorganisms may offer another method of solving the problem. Better use of the high quality fishmeal and fish oil supplies may be made by restricting their inclusion in the diet to only those periods when they are essential, or by use only as finishing diets to improve the nutritional value of the product for the consumer. Future research may yield new feeding technologies and management systems that optimize the conversion of feeds into aquatic animal biomass, thus reducing the need to rely on fishmeal and fish oils.

Aquaculture will increasingly compete with other animal production sectors for use of feedstuff crops and agricultural by-products. The sector will continue to secure access only if it can afford the going rate and if the role of aquaculture in food security and economic development is sufficiently recognized to motivate an enabling policy environment.

Some increase in production is likely to result from use of fish strains selectively bred for increased growth rate, disease resistance and other traits. Results from selective breeding programs can be impressive: the selectively bred Jayanti strain of Labeo rohita ('rohu') that is widely used by Indian farmers has shown the ability to grow (across a range of production environments) up to 17% faster per generation over five generations compared with local strains. Though improved strains may reduce the level of impact on land and water use, they are unlikely to make a significant dent in the other impact categories: faster growing fish may simply eat more, rather than show any improvement in conversion efficiencies.

The incentives for use of non-native species in aquaculture remain high, particularly for developing countries. Future efforts will need to be directed towards improving risk assessment and mitigation measures. Based on the FAO Code of Conduct for Responsible Fisheries (1995) and the ICES Code of Practice on the Introductions and Transfers of Marine Organisms (2005), IUCN provides useful recommendations for national governments to implement responsible use of alien species in aquaculture.

The implications of climate change cannot be ignored. While aquaculture is a relatively small contributor to greenhouse gas generation, climate change will affect the industry. Rises in temperature are likely to cause changes to the physico-chemical environment that effect ecosystem processes. Productivity may rise to a point where temperature becomes a stress factor and production subsequently decreases. The most likely outcome is that the there will be a shift in the location of aquaculture from areas that have become unsuitable to new areas that will become more suitable.

Implications and policy recommendations

Aquaculture is likely to be an increasingly important contributor to food and nutrition security in developing countries where there is a culture of fish consumption. Governments and industry will need to stimulate investments in aquaculture where there is strong demand in domestic and regional markets; evaluate research and policy development needs along the entire value chain from inputs to consumer markets; support development of aquaculture that delivers sustained supplies at affordable prices for poor consumers and support aquaculture both as a household livelihood and as a food and nutrition security strategy in areas where production is feasible but markets are weak.

To reduce their carbon footprint, new aquaculture enterprises should not be located in areas that are high in sequestered carbon, such as mangroves, areas of seagrass, or forests. The industry needs to review on-farm energy use to inform efforts to decrease carbon dioxide emissions. Energy consumption associated with pumping and post-harvest processing, transport and marketing must be minimized. Organically enriched fish pond sediments, which are a potential source of methane, should be used for producing other foods.

General Conclusions and Core Recommendations

The demand for aquaculture products will continue to grow. The sector has the capacity to meet this increased demand by expanding to new areas and through intensification. The environmental impacts of such growth can be managed through innovation, strengthened policy, capacity building and monitoring. These core recommendations are offered to policy makers, development and environmental organizations, and industry professionals:

1. Support innovation in the aquaculture sector, especially the development of technologies that make best use of land, water and feed resources and that minimize demands on environmental services.

2. Ensure that the regulatory environment keeps pace with sector development and support policy analysis and development that internalize the costs of environmental impacts into aquaculture enterprises.

3. Develop capacity in national agencies for sector regulation and for monitoring and compliance.

4. Monitor carefully how supply and demand for fish is evolving to ensure that support and investment are appropriate to the market opportunity.

These core recommendations apply globally, but there are regional differences in their relative importance over the next three to five years, as shown in Figure 6.

Focus	Core Recommendation
1. Innovation	Continue to support innovation in the aquaculture sector, especially the development of productive technologies that make best use of land and water and feed resources and that minimize demands on environmental services.
2. Regulation	Ensure the regulatory environment keeps pace with sector development and support policy analysis and development that internalizes into aquaculture enterprises costs of environmental impacts
3. Monitoring and compliance	Develop capacity in national agencies for supporting the development of sector regulation and for monitoring and compliance.
4. Supply and demand analysis	Monitor carefully how supply and demand for fish is evolving to ensure that support and investment is appropriate to the market opportunity.

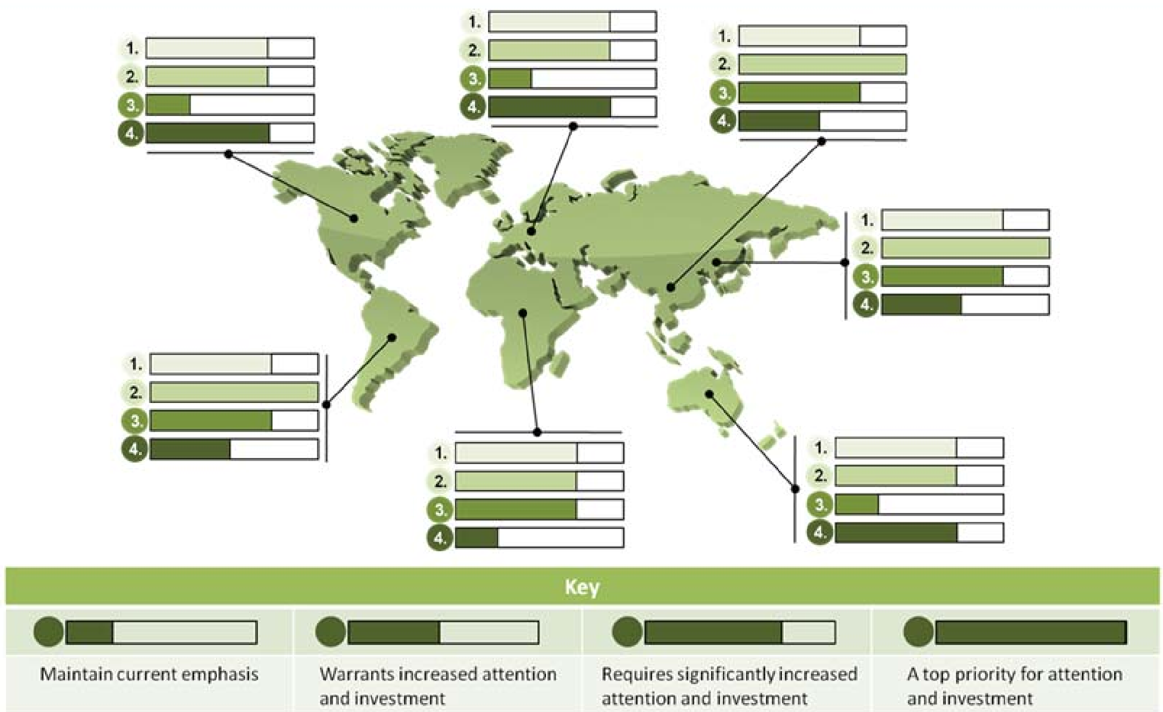


Figure 6
Core recommendations for government and industry in all producer countries and their relative importance for each region.

Analysis Methods

Using data from 2008, the study compared aquaculture's global and regional demands for a range of biophysical resources across the entire suite of species and production systems in use today. The units of analysis included 13 species groups, 18 countries, 3 production intensities, 4 production systems, 2 habitats and 5 feed types. This selection produced 75 species-production systems that accounted for 88% of estimated total world aquaculture production. Life Cycle Analysis (LCA) was used to analyze each of these 75 combinations.

The input resources estimated included the amount of land, water, feed, fertilizers and energy required on-farm. The outputs (emissions) considered were nitrogen, phosphorus and carbon dioxide. Environmental costs associated with building infrastructure, seed production, packaging and processing of produce, transport and other factors were excluded from the analysis.

For some production systems, particular processes become irrelevant or are reversed. With seaweed or bivalve culture, for example, nutrients are taken up from the environment rather than released. Similarly, with bivalves (which extract food from the environment), the feed production process makes no demands on energy, crop meal, fishmeal or fish oil.

Six impact categories were estimated for each of the 75 species-production systems: eutrophication, acidification, climate change, cumulative energy demand, land occupation and biotic depletion. Eutrophication includes all impacts due to excessive levels of macronutrients released to the environment. Acidification includes all the acidifying substances causing impact on the functioning of ecosystems and human well-being. Climate change results are expressed in t CO2 equivalents. Cumulative energy demand is a measure of the total direct and indirect industrial energy required throughout the aquaculture production process. Land occupation was calculated as the sum of direct and indirect land occupation, using equivalence factors to adjust for different types of land and for relative levels of bio-productivity. Finally, biotic depletion is a measure of the amount of wild fish (usually small pelagic fish species) required for fishmeal and fish oil to support aquaculture production. A completed description of the analysis is available in the full report.

Implications for the Research Agenda

The LCA demonstrated significant differences in the resource demands and outputs for similar production processes in different geographical locations. Where the industry is not performing well further research is needed to identify the technological and management factors required to improve ecological performance.

Further work is required to improve the comparability of data across the aquaculture sector. This will involve research to improve LCA. It will include the development of cost-effective LCA-based indicators for measuring ecological performance status, indicators for use with integrated farming systems and the identification of incentives (e.g., economic, policy, markets) to improve the ecological performance of integrated aquaculture and agriculture. Determining the environmental benefits of certification using LCA tools and identifying improvements in certification standards, plus more in-depth LCA studies on trends in intensification, choice of farmed species and system design and management practices will provide a better understanding of entry points for improvement.

Policy makers, producers and retailers need to understand the drivers of fish consumption. This can be realized through better modeling. Research is needed to ensure that policies designed to help meet demand for aquaculture products are consistent with policy objectives for other sectors, such as environment, energy, food and nutrition security, and poverty reduction.

This analysis has identified the species groups (carp, shrimp and prawn aquaculture) and production processes that have the greatest environmental impact (pond and cage production systems) and the geographical areas most affected (China, the rest of Asia and Latin America). Research should be directed at both technological and management interventions, and at the incentives (e.g., policies, legislation, taxation, market) that produce the greatest environmental benefits.

Further nutrition research is needed to reduce the dependency on wild capture fisheries used in aquaculture feeds. Replacement with alternatives from crops, however, will lead to further competition with agriculture for human consumption and bio-fuels. Additional research is needed to identify optimal feed strategies with minimum environmental demands.

The potential impact of climate change on aquaculture production and distribution and the consequent effects on food and nutrition security are currently poorly understood. Further research and modeling will help to clarify this situation.

Summary of Recommendations for Key Stakeholders

Stakeholder Group	Recommendations
Policy makers	• Use audits of energy and other ecological resources across aquaculture value chains as a guide for management decisions. • Make information on energy and other ecological resource impacts and efficiency measures accessible to producers. • Review and improve certification standards, Good Aquaculture Practice, Codes of Practices and other industry management codes and guidance documents to ensure they reflect ecologically efficient approaches to farm management and value chains. • Facilitate cross-sectoral comparisons and dialogue on best practices in food production within the livestock, fisheries and agriculture sectors. • Examine thoroughly the relative benefits of the various animal production sectors and consider policy drivers that can shift towards a more ecologically efficient production portfolio. • Avoid locating aquaculture farms in those wetland or coastal ecosystems with high values as sinks for sequestration of carbon, other greenhouse gases or nutrients.
Development and environmental organizations	• Encourage and support China and other Asian and Latin American countries to better manage the sector towards improved environmental performance. • Continue to encourage adoption in practice and policy of the Ecosystem Approach to Aquaculture. • Monitor performance of certification in the aquaculture sector, and seek ways to support and improve systems to deliver environmental improvements at scale. • Support development of regional knowledge sharing and learning networks for both policies and technologies. • Invest now in improvements in aquaculture technologies in Africa that will help set an ecologically sound foundation for future aquaculture growth. • Pay particular attention to carps, shrimps and prawns. • Pay particular attention to pond culture systems and to pen and cage systems in freshwater; focus on improving inland pond aquaculture. • Continue to engage and seek to partner with key retail chains to improve the ecological performance of the sector.
Private sector operators and investors	• Make better use of scarce and costly fishmeal and fish oil supplies. • Avoid using areas high in sequestered carbon for aquaculture. • Use locally sourced feedstuffs and develop pre-treatment and processing methods to increase digestibility and nutrient availability and reduce anti-nutrients. • Breed fish that have more limited demand for high quality marine lipids and protein. • Deal carefully with organically enriched fish pond sediments. • Minimize energy consumption on-farm and in the following value chain.

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The full report can be downloaded at *www.worldfishcenter.org/global_aquaculture/*

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