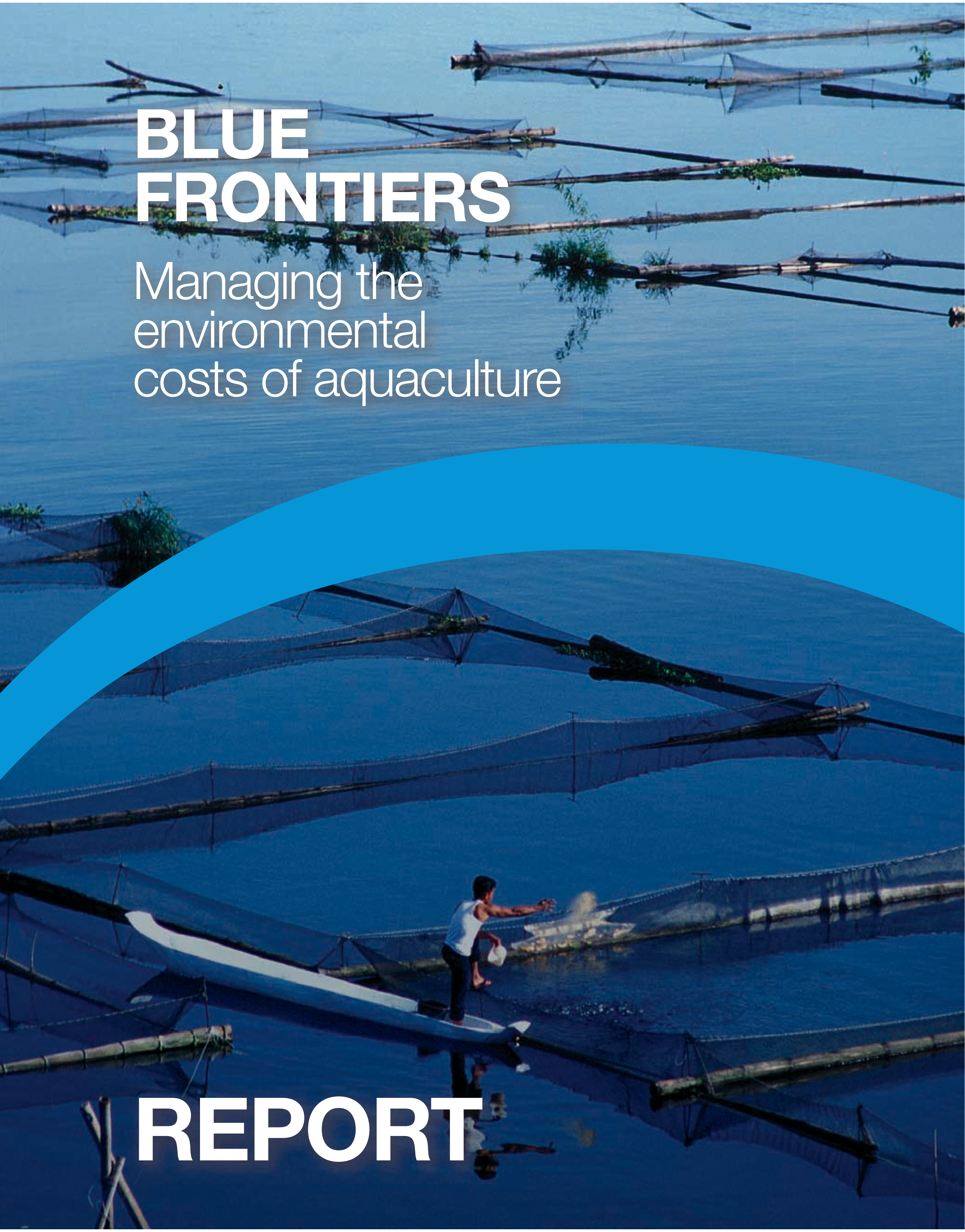
BLUE FRONTIERS

Managing the environmental costs of aquaculture



REPORT

Blue Frontiers

Managing the environmental costs of aquaculture

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About this Report

There is a pressing need to elevate the debate on the future of aquaculture and to place this in the context of other animal food production systems, [illegible] and 2008 aquaculture production grew at an annual average rate of 8.4% and remains among the fastest growing food production sectors in the world. But with global demand for aquatic food products continuing apace, there are worries about the development trajectory of aquaculture. Of particular concern for Conservation International and many others is whether and how further growth can be met in ways that do not erode biodiversity or place unacceptable demands on ecological services. In this context, the potential for aquaculture to reduce pressure on wild capture [illegible] food products is also important.

Directed towards helping inform and stimulate policy debate, this report provides a global review and analysis of these issues for both coastal and freshwater aquaculture. Such debate is needed to help ensure that the current and future potential [illegible] captured and the associated costs minimized.

The report begins with an overview of the current status of world aquaculture. It then goes on to describe an approach for estimating the current combined biophysical resource demands of aquaculture for producer countries and regions. Following a comparison of these results with those available for other animal food production sectors the report then examines the consequences of likely future trends in production on the environmental impacts of aquaculture. Finally, [illegible] are discussed along with the research agenda that should be pursued to meet the challenge of sustainable food production.

Acknowledgements

[illegible] several colleagues. We are especially grateful to Professor Max Troell, Mr Patrik Henriksson and Dr Patrick Dugan and colleagues at the World Bank and Conservation International for their insightful comments. We would also like to thank Professor Trond Bjorndal for help with part of the text.

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Acronyms and abbreviations

ARD Agriculture and Rural Development

CED Cumulative energy demand

CML Institute of Environmental Sciences

EU European Union

FAO Food and Agriculture Organization

FCR Feed Conversion Ratio

8 8S SbWQOZZg WSR]R

ICES International Council for the Exploration of the Sea

IFPRI International Food policy Research Institute

IPCC Intergovernmental Panel on Climate Change

IUCN International Union for the Conservation of Nature

LCA Life Cycle Analysis

N Nitrogen

NGO Non-Governmental organization

OECD Organisation for Economic Co-operation and Development

6 H]ZR UOWhOb]T 2W[OZ 9SOZb[TSg TQS:bS OW]OZRSa6 W]b WaS

P Phosphorus

RAS Recirculation Aquaculture Systems

TSP Triple Super Phosphate

USFDA U.S Food and Drug Administration

WWF World Wide Fund for Nature

Units of measure

ha	hectare
Gj	Giga joule
kg	kilogram
Mj	mega joule
m^3	cubic meter
t	metric ton (1000 kg)
US$	U.S dollar
yr	year

EXECUTIVE SUMMARY

PHOTO CREDIT: He Qing Yunnan

Executive Summary

Aquaculture is among the fastest growing food production sectors in the world and this trend is set to continue. However, with increasing production comes increasing environmental impact. For aquaculture to remain sustainable this future growth must be met in ways that do not erode natural biodiversity or place unacceptable demands on ecological services.

This study is a review and analysis of global aquaculture production across the major species and production systems. It compares the aggregate biophysical resource demands of each system and their cumulative environmental impacts. The study then compares these results with those from other animal food production systems before examining the consequences of likely future trends. Finally, the policy implications]T VS S] ba wRWUa O WQcaaSR OZU eWb the research agenda that should be pursued to meet the challenges involved in producing food sustainably.

Worldwide, aquaculture production has grown at O dSOUS OcOZOS]T , (VaQS %- $R O reached 65.8 million tonnes in 2008. The growth W OT[SR aV a Zg OV aUWQObZg bcOQSR growth in world population. China supplies 61.5% of global aquaculture production; a further &-) Q][Sa]T bVS Sab]T 2WO]T Europe, 2.2% from South America, 1.5% from North America, 1.4% from Africa and 0.3% from Oceania. Production in China and the rest of Asia is predominantly freshwater, from other continents predominantly coastal. The annual average growth rate in aquaculture between 2003 and 2005 in North America and Europe is slow (1.4–1.6%); it is rapid in China, Asia and South America (6, 11.2, , Sa SQbWdSZg R SfZ]aWdS 2WQO % & for albeit from a very low baseline.

Carp dominates production in both China and the rest of Asia. In contrast, for Europe and South America it is salmonids; African aquaculture]R cQbW] WaOZ[]a SfZaWdSZg waV W[OWZg tilapias. For Oceania, shrimps and prawns dominate while in North America production is more even across the species groups. Aquaculture VOa ÿeW U aUWOOQS OaC aZWS]TaV/ between 2003 and 2008 the proportion of O_cOQZbS WbbOZaV]R cQbW] WT S]]R O R industrial purposes) increased from 34 % to 42%. EVS]] bW]]T]]R aV a ZWSRP OcOQZbS W &$$, eOa(c DZg][T O_cOQZbS Wa dominant for seaweeds, carps and salmonids.

The rapid growth of aquaculture witnessed over the last forty years has raised questions concerning its environmental sustainability. To answer those questions satisfactorily requires quantitative analyses. This study, based on 2008 data, compares the global and regional demands of aquaculture for a range of biophysical resources across the dominant suite of species and production systems in use today. The units of analysis were the elements of a six dimensional matrix comprising 13 species groups, 18 countries, 3 production intensities, 4 production systems, 2 VOPWba OR)SSR gbSa WEa UOdS]a)WbdS matrix elements that accounted for 82% of estimated total world aquaculture production in that year.

The assessment method chosen to analyse the data was Life Cycle Analysis (LCA). This method required estimates of both the biophysical resource inputs to and outputs from each of the) aSQWSa]R cQbW] gabS[a SWRWSR S EV input resources estimated were the amount of land, water, feed, fertilizers and energy required on-farm. The outputs (emissions) considered were nitrogen, phosphorus and carbon dioxide. From these data the LCA produced estimates of the impact of these species-production systems for each of six impact categories: eutrophication, OQWRWOW QZSW[OOUS [cQZOWdS SSUg demand, land occupation and biotic depletion (use]T aV]T aV[SOZ OR aV]WZ]c RO3WSa eSS set to exclude environmental costs associated with building infrastructure, seed production, packaging and processing of produce, transport and other factors.

[illegible] species-production systems reviewed showed a positive relationship between overall production levels and impact. The levels of impact were then compared across production system, species group and country.

Inland pond culture is the predominant production system and it contributes the greatest impact across all the six impact categories, with demand [illegible] marine cage and pen culture. Similarly carps, as a [illegible] the fact that carp production is greater than that of other species groups. Eel production stands out as highly environmentally demanding, largely due to high energy consumption, and salmonid, and shrimp and prawn production are notable for their [illegible] low demands on the environment and actually reduce eutrophication.

[illegible] countries gave a variable picture. For example, for the salmon producing nations of north Europe, Canada and Chile, the impact from eutrophication was moderate and biotic depletion high, but they [illegible] the other four environmental impacts. Perhaps more interestingly however, were the differences in [illegible] between countries suggesting scope for improving environmental performance. For shrimp and prawn [illegible] relative terms, than other producer countries when [illegible] and energy demand.

A look at the drivers of impact, i.e. those attributes of the production system that contribute most to environmental impact, showed that the aquaculture production system itself contributed most to eutrophication, but impacts on climate change and [illegible] national energy supply; a factor outside the control of the local operator.

Sensitivity analyses were run to determine the [illegible] were made with other LCA studies. Although most variations tested gave results that differed little from the model in use, some notable deviations occurred. Most of these were related to assumptions associated with on-farm energy use and feed supply indicating that improved data in these areas are required.

There is a growing demand for animal source foods, driven partly by population growth but mainly by rising standards of living and prosperity in developing countries. The study continues with a comparison of the environmental impacts of aquaculture with those from other animal food production sectors. This is important because without a balanced picture of the environmental impacts of producing animal source foods through different systems, it is not possible for governments or consumers to understand the true costs of production.

The comparative analysis draws heavily on studies of the environmental impact of livestock produced by the FAO and considers four key aspects: [illegible] (nitrogen, phosphorus and carbon dioxide), land use and water use.

Fish convert a greater proportion of the food they eat into body mass than livestock and therefore the environmental demands per unit biomass or protein produced are lower. The production of 1 [illegible] grain compared to 61.1 kg of grain for beef protein and 38 kg for pork protein. However, although [illegible] livestock there are important issues with respect [illegible] Unfortunately, simply substituting a vegetable-[illegible] present.

Extensive livestock production places heavy demands on land use through deforestation and land degradation. However, land use demands per unit of protein production appear broadly similar across other animal food production systems. Intensive livestock production is noteworthy, however, for the high levels of nitrogen, phosphorus, carbon dioxide and methane produced. Comparatively, aquaculture systems perform well with respect to the emissions produced from beef and pork production. Livestock rearing, especially in intensive systems, also places heavier demands on the use of fresh water.

There are, however, a number of issues concerning the calculations which make true comparisons RWQcZb OR VS S S arTwQWS Rb] b] SZg compare the different intensities and methods of animal production, so the results must be viewed as 'broad-brush'. Certainly there are some STwQWSQWSaQaQWSR eWbOTW U O]R cQb VOb is cold blooded and feeds near the bottom of the food chain but much depends on the species, production system and management used. And there are trade-offs between extensive systems that place higher demands on land use, and ecological services such as water, fuel, nutrient cycling, and intensive systems that require higher levels of fossil fuels, feed, and produce more STxcS b

: VS]cT bV SQW] VS Od a RWgxSdWSeVSb drivers of demand and environmental constraints to aquaculture production, along with published predictions of future trends for the aquaculture sector. Driven largely by increasing wealth and urbanization, published estimates suggest production will reach between 65 and 85 million b Sa P &$&$ RO SeSS - RO %%$ [WZZW] tonnes by 2030. As an illustration of the potential environmental impact of this growth, in the absence]T WUWQO b WdObW]a OR W]dS[S ba W management and technology, a production level of 100 million tonnes by 2030 (excluding seaweeds) will lead to environmental demands that will be between 2 and 2.5 times greater than 2008 levels for all the impact categories studied.

A number of key conclusions and recommendations arise from the analysis, and point the way towards improved productivity for aquaculture with reduced environmental impact. These include the following points.

- As the degree of environmental impact is largely determined by the level of production, with carp production from inland ponds in China and Asia creating the largest environmental footprint, this is an important wSZR eVS S SaSOQV SSRa]b PS cRS bOYS to develop measures to reduce overall environmental impact.
- The variety in impact measured by the same species-production system operating in different countries suggests strongly that the potential to improve performance exists, such as through regional learning networks for both policies and technologies. Much of the aquaculture industry in developing countries provides opportunities for improved STwQWSQWSa
- Feed constraints are key to aquaculture development. Reducing the dependency] aV[SOZ OR aV]WZ SeWZZ Se innovations in technologies and management but the payoffs may be spectacular both in bS [a]T]wbORWZWRT OR cbWb] SQcWgb and reduced environmental impact.
- Analysis shows that reductions can be made to the sector's impact on both climate change OR OQWWBW] P W]dWU S Ug WQTWSQg throughout the production and value chains. The use of water and energy audits and better practices should lead to reduced resource demands.
- It is apparent from this study that aquaculture VOa][TO SQ]ZUWQOZWSSgT R environmental impact perspective, clear PS Svba]dS VS][a]T OW[OZ]c aQS]]RT production for human consumption. In view of this, where resources are stretched, the relative PS Svba]T]ZWQWSab][b S aW OTW U over other forms of livestock production should be considered.

- The growing need for aquaculture to contribute to food security, especially in African and Asian countries will require governments to actively support growth of the sector and stimulate private sector investment.

- Aquaculture affects climate change and climate change will affect aquaculture. To minimise the potential for climate change, energy consumption should be kept as low as possible and new aquaculture enterprises should not be located in regions that are already high in sequestered carbon such as mangroves, seagrass or forest areas.

- There are measures that policy makers can take which include providing support to innovative and technological developments, ensuring a suitable regulatory framework that captures environmental costs within aquaculture processes, building capacity for monitoring and compliance, and encouraging SaSOQV]VS caZg RS[O R]T aV O R aV]R cQa

EWabRg WS ab]b]dWB O UZ]FWQbS]T bVS S[O Ra aV OT[W U [OYSa] SdW [S bOZ resources using Life Cycle Analysis. It illustrates the opportunities and challenges that lie ahead for aquaculture. The key messages for policy makers, NGOs, entrepreneurs and researchers are that there must be a wider exchange of knowledge and technology, with policies and action to promote acabOWDRWZWbR WSab[S b WSaSOQV]b ZZVSb knowledge gaps. These efforts can lead to a more SQ]Z]UWQOZZabOWDFZS RWabgrO W[bO b goal, given the likely rapid growth in aquaculture production. They will also help ensure that aquaculture contributes fully to meeting our future SSRa]T aV

1. AQUACULTURE TODAY

PHOTO CREDIT: © Art Wolfe/www.artwolfe.com

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1. Aquaculture Today: Production and Production Trends

Aquaculture production in context

For several decades aquaculture has been the fastest growing food production sector in the world. Five year averages for global production increases in major food commodities rank aquaculture number] □S T □SdS g □S WR aWQS % □(□H] ZRe VRS □ aquaculture production has grown at an average O□□cOZ OdS] T, (□aWQS % □$ EOPZS %% H W □ poultry showing the next largest rate of increase over this period at 5%, aquaculture's dynamism stands out clearly.

This rate of production growth has ensured that, as OUZ POZOdS OUS TO[SR waV ac □□Zg VOa] cb OQSR □] □cZbW □U] e bV 7] [□O □S QO WOdOZS] T$ □□ YU W% □$ □UZ POZac □□Zg] TTO[SR waV □] aS b □□, □ YU W&$$ □□EVS Sab[V OSR OdS OUS □S QO WOwaV □ consumption for wild and farmed combined was %□, YU W&$$ □□WROQbWUbVObOP] cb(□ □] TwaV T □□ human consumption was supplied by aquaculture at that time. Given the unlikely prospect of increased gWSRa T] [□e WR QO bc S waVS WSa bWdOZSe WZ increase as aquaculture production grows.

Table 1.1: Food production statistics for major commodities. (Source: FAOStat and FishStat)

	Average annual production increase (1970–2008)	Average annual production increase (2004–2008)	2008 Production (tonnes x 1000)
Plant Food Commodities			
Cereals	2.1%	□ □ -	&□)&)□ %$□
Pulses	1.1%	0.6%	□ $□ -&-
Roots and Tubers	$□ -	$□ -	□ &-□),□
Vegetables and Melons	3.4%	%□ □	-%□ □ %$&
Animal Food Commodities			
Beef and Buffalo	1.3%	1.6%	□)□ □ &&
Eggs	3.2%	2.2%	65,586
Milk	1.5%	2.4%	□ -□ □ □ $□
Poultry	5.0%	□ □ -	-%□ □ --
Sheep and Goats	1.8%	2.4%	%□ □ %□ (
Fish	8.4%	6.2%	52,568

Fish is also pre-eminent as an internationally traded animal source food. Representing about 10% of total exports of agricultural products by value, aSOT] RSf] baT] [eWKwaVSWaO RO_cOQcZbcS in 2008 had a combined value of US$102 billion (FAO, 2010), an 83% increase from 2000. The share of exports from developing countries is close to 50% by value and 60% by volume. Of internationally traded agricultural commodities seafood export value is exceeded only by fruits and vegetables (Table 1.2). The European Union is the world's largest seafood importer, followed by the United States and Japan.

Table 1.2: The export value of selected agricultural Q][[R WbSaW&$$]c QSD27 DObO R72 EORSDObOb &$$

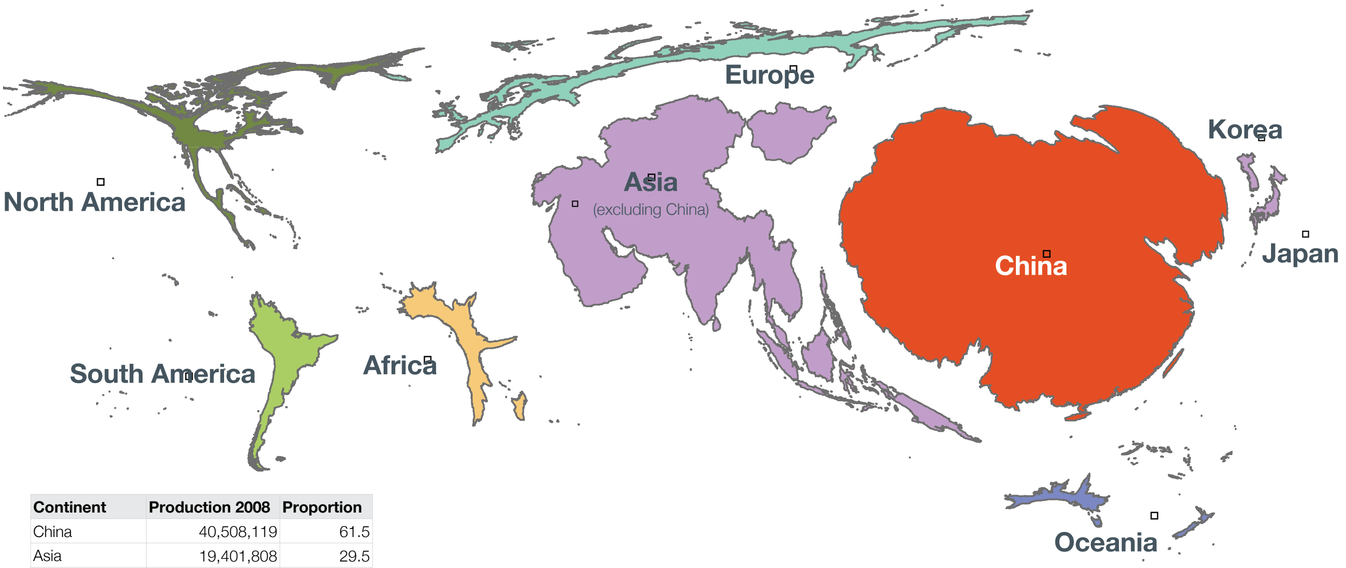
	Trade Value US$ billions 2007
Plant Commodities	
Fruit and Vegetables	%)$,-
Wheat	36.40
Tobacco	&- $
Sugar	18.58
Coffee	%
Rice	13.48
Pulses	4.82
Animal commodities	
Fish	-& ,$
Pigs	30.21
Cattle	&, --
Poultry	22.10
Sheep and Goats	4.35

Unfortunately national trade statistics do not distinguish between aquaculture and wild capture OabVSa] cQS] TW] ba:bWbVSTSRWcZb b RO e w[Q QZaW aObOUZPOZSdSZOP] cb bVS]] bW] Tb bZWS ObW OZwaVbORS volume that aquaculture provides. A 2006 estimate T 4 VWO V] e SdS e OabVOb- Pg d] Z[S O R(- Pg dOZS] TbVSQ c bga O_cOQcZbc S] RcQbW e OaSf] bSR 7O U &$$ 2 VWWZSdSZ of international trade in aquaculture products is important because it offers a potentially powerful entry point for harmonizing and improving environmental standards of production.Several recent reviews of global aquaculture production are SORWg OdOWZOPZS SU cWSbOZ &$$- /3] ab QYSb al., 2010), and the FAO provides biannual updates in its Status of Fisheries and Aquaculture series (FAO, &$$- P H SVOdS PcWb] bVSaSb] TS OQ QWS global overview of current aquaculture production that helps put into context the analyses and results that follow. It also serves to introduce the reader to the data categorization approach we used for analyses described later in the report.

Using FAO data[1] , our starting point is the overall UZ PO WbcS 7Wc S %% EWaWwc S ac[[OWSa how the world's total aquaculture production of 65.8 million tonnes in 2008 was distributed across Q bWS ba Pg ORXcabWU Q bWS bOZOSOab SxSOb production volume. Following convention, we have bSObSR 4 VWOaS OObSZg T] [bVS Sab] T2aWr O decision that is clearly appropriate given its pre-eminence as a producer.

H WW %)] TUZ PO] RcQbW ($) $, %%- tonnes) China deserves special attention. The further &-)] TUZ PO] RcQbW % ($%, $, b Sa supplied by the rest of Asia places the continent as a whole in an overwhelmingly dominant position. By contrast, production in Europe with 3.6% (2,341,646 tonnes), South America with 2.2% (1,461,061 b Sa ?] bV 2[SWOe W %) -) - & b Sa 2TWOe W %(-) & % b Sa O R QSO We W $ % %, % b Sa WbWZW] dS OZbS[a

[1] All data are from FAO FishStat unless otherwise stated.



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 1.1: World aquaculture production by continent in 2008 (China treated separately). Land areas are adjusted]] bW]OZZg SbSQb]R cQbW] d]ZSa

But, despite the overall dominance of Asia, aquaculture is an important economic activity on most continents and its importance is growing almost everywhere. To illustrate how production is distributed within regions Figure 1.2 lists the Q] c bWSa bVObOQQ] c bT OZbZSOab-$] T] RcQbW on each continent. Production is spread most widely Q[UQ] c bWSa W6c] SOR2aWe W] dS -$] T] RcQbW OQQ] c bSR T Pg %%O R- Q] c bWSa respectively. In contrast, most African and South American production is accounted for by only three countries on each continent.

Figure 1.2 also shows how production is distributed in each country between coastal[2] and freshwater systems. Overall, 60% of global production occurs in freshwater. China and the rest of Asia contribute [ ] abb bWaVOdS OUS dOZS] RcQWU] dS) - O R 64% in freshwater, respectively. In contrast, coastal production dominates in South America, Europe and QSO We W Sa SQbWS dOZSa] T , , $ O R- , from coastal areas. Production in North America is almost evenly split between coastal and freshwater habitats, while FAO reports there is a 60:40 split between coastal and freshwater in Africa. This picture is dominated by production from Egypt, which OQQ] c ba T] Tb bOZO_cOQcZbc S] RcQbW on the continent. Data for Egypt are somewhat misleading, however, because although the FAO QZaaWSabVS[O Wg] T] RcQbW Oa Q[WUT] [brackishwater, almost all of this is from very low salinity ponds in the Nile Delta.

[2] 7] Wa OZgWa eS Q]PWSR OO QZWOSR WS 2 DOb OOPOaS] T POQWeOLS OR [OWS]R cQbW] W OWaZS Q]OZ]R cQbW] QSb]g

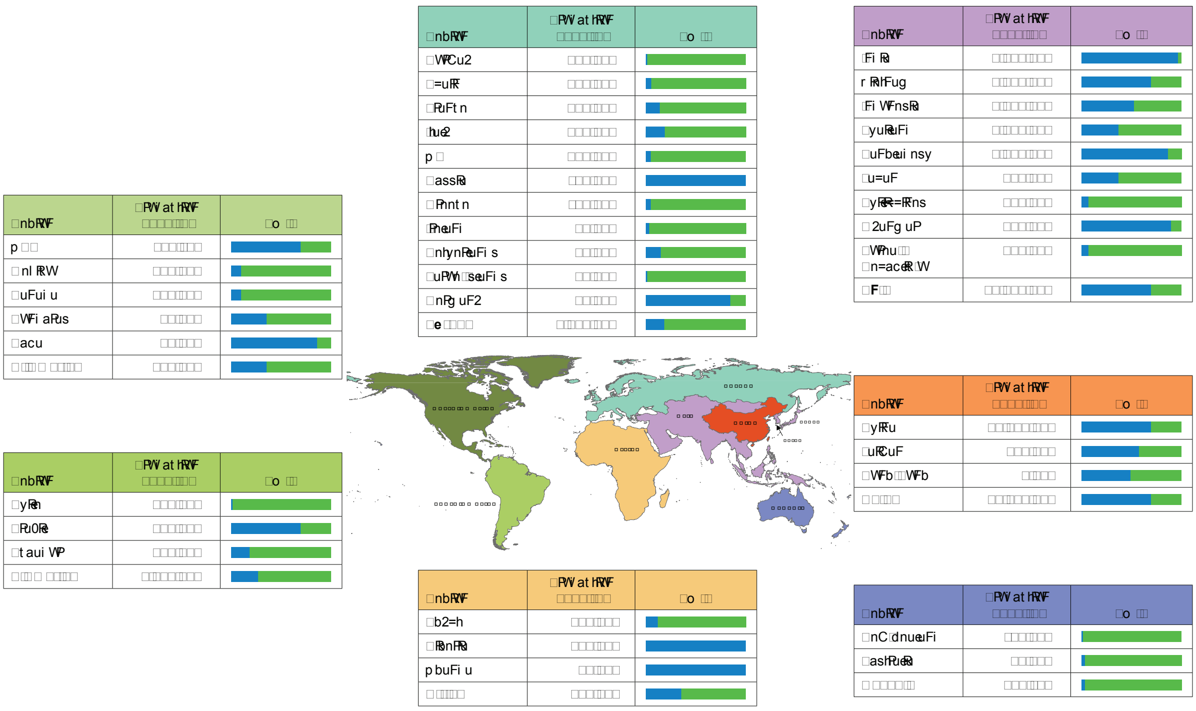


Figure 1.2. [illegible]

To summarize the distribution of production with respect to species we have constructed treemaps that show the relative proportion of production by continent for each of 12 species groups (excluding seaweed, Figure 1.3). These maps show how carp dominates production in both China and the rest of Asia. In contrast, for Europe and South America salmonids dominate and account for more than [illegible] and culture). African aquaculture production is [illegible] most important. For Oceania, shrimps and prawns dominate while in North America the pattern of production is somewhat more evenly distributed [illegible] bivalves and salmonids accounting for the majority.

Rates of change in production (indicated by color [illegible] China and Asia continue to grow apace. Overall [illegible] highest growth rate over the period, however, was Africa at 81%. Admittedly, this growth was from a very low baseline, but these “blue shoots” provide an indication that Africa may be poised for further dramatic production increases. In contrast, growth patterns in Europe and North America were the [illegible]

[illegible] show how quickly a sub-sector can develop. While not so spectacular, growth for many other species groups is also high. In Asia, for example, tilapia production increased by 121%, carp production [illegible] for several species groups can be found on all continents.

Another feature of these production growth data is that the only regions where production changes were positive for all species groups cultured were China and Oceania. In contrast, the rest of Asia [illegible] category, Europe for bivalve and carps and North [illegible] in Africa and South America were restricted to groups that contribute relatively little to the total continental production.

[illegible] 18.4%, respectively.

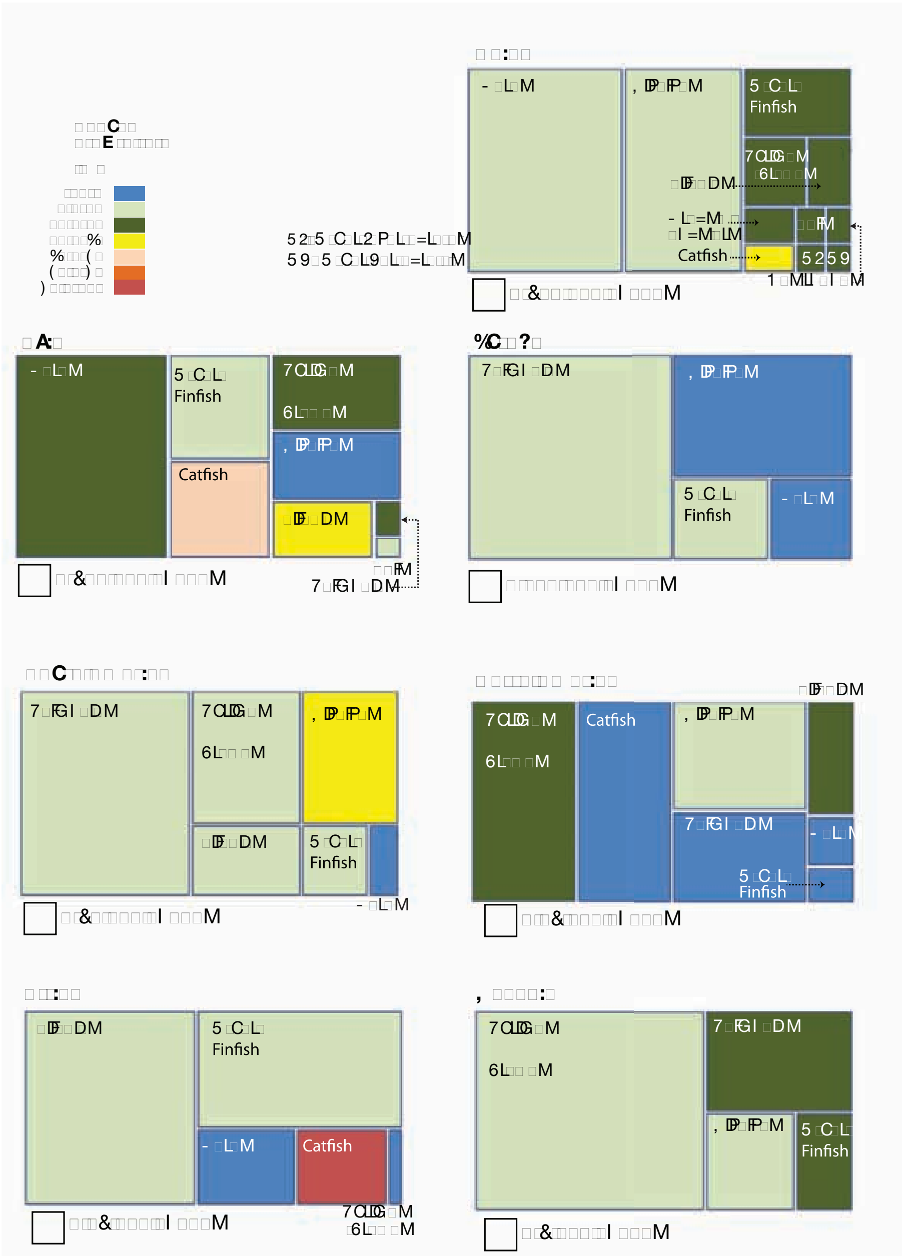


Figure 1.3: Treemaps summarizing 2008 production by species group for each continent (excluding seaweed). The area for each species in a map is proportional to the tonnage produced (Note differing scale for each map). The color of each block indicates the rate of increase between 2003 and 2008.

Table 1.3: [illegible]
(Source: FAO FishStat)

	Capture production (Mt)		Aquaculture production (Mt)		Proportion of total production from aquaculture (%)		
Species Group	**2003**	**2008**	**2003**	**2008**	**2003**	**2008**	**Difference**
Carps	2.02	2.21	15.04	[illegible]	88.2	[illegible]	1.8
[illegible]	2.33	[illegible]	1.03	[illegible]	30.8	50.1	[illegible]
Tilapias	[illegible]	3.14	[illegible]	2.80	28.6	[illegible]	18.4
Eels	0.65	0.62	0.32	0.48	[illegible]	43.4	10.5
Salmonids	1.16	0.84	1.85	2.26	61.5	[illegible]	11.3
[illegible]	50.81	[illegible]	4.40	[illegible]	8.0	10.0	2.1
Bivalves	18.43	[illegible]	11.06	12.65	[illegible]	[illegible]	1.6
Gastropods	0.30	0.32	0.21	[illegible]	41.4	[illegible]	12.3
Crabs and Lobsters	[illegible]	[illegible]	[illegible]	[illegible]	34.4	[illegible]	15.0
Shrimps and Prawns	8.85	[illegible]	[illegible]	4.35	[illegible]	[illegible]	11.3
Other Invertebrates	1.14	1.18	0.12	0.31	[illegible]	20.5	10.8
Seaweeds	0.34	[illegible]	[illegible]	13.24	[illegible]	[illegible]	3.1
TOTAL	**91.31**	**92.3**	**47.9**	**65.81**	**34.4**	**41.6**	**7.2**

Conclusion

This brief overview highlights several key features of the aquaculture sector: high overall growth in [illegible] *Pangasianodon hypophthalmus)* [illegible] But growth in production has not come without environmental cost. In the next section we examine how these costs compare across the sector.

2. IMPACTS

PHOTO CREDIT: The WorldFish Center

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2. Aquaculture production: Biophysical demands and ecological impacts

The rapid growth of aquaculture described in the previous section raises questions concerning the environmental sustainability of future industry growth. Central to these concerns is the demand aquaculture places on biophysical resources. Unsustainable consumption of these resources will ultimately undermine the productivity of the sector and bring it into competition for resources with other sectors (Gowing et al., 2006; Primavera, 2006).

Balanced against these concerns is the fact that farming aquatic animals that feed low in the food [illegible] of producing animal proteins. Some forms of aquaculture can also help mitigate environmental impacts. For example seaweed and mollusk farming are known to mitigate the effects of eutrophication [illegible]

To better understand the effects of aquaculture on the environment and its demands on biophysical resources, we need quantitative analyses. These are needed at several scales, from detailed studies for production of a particular species through to larger scale studies across regions and species-production systems. This study focuses on the larger scale, comparing and contrasting the global and regional environmental demands of aquaculture for a range of biophysical resources across the dominant suite of species and production systems in use today. It then goes on to examine their ecological impacts. This section describes our approach for achieving this.

Preliminary data analysis

We have based our assessment of environmental demands on the 2008 estimates of aquaculture production summarized in Section 1. To produce a manageable data set for analysis, however, some data reduction and aggregation of the full disaggregated data set was necessary. This was achieved using the following steps. First, we [illegible] Extracting records for these species revealed that [illegible] data set, each of the individual species was then allocated to one of twelve separate species groups. Production for a given species by a given country was then further categorized into one of four separate production systems, resulting in 16 species [illegible] 2.1). For each production system we made a further distinction between production in inland (freshwater) and coastal (marine and brackishwater) habitat, recognizing that some production systems are used in both (Table 2.1).

Table 2.1: VESUSSWaSQWaSU]c r]RcQbW]agabS[acaSRb OaSaaSdW[SbZRS[ORaEVSacPaQWb c denotes a coastal system and i denotes an inland (freshwater) system. ci indicates that the system occurs in both inland and coastal systems. (Note: Although carps are also cultured in cages and pens, this accounts for a small proportion of production and has, therefore, been omitted).

Species Group	Bottom Culture	Off-Bottom Culture	Cages & Pens	Ponds
Bivalves	□ c	□ c		□ ci
Carps				□ i
4ObwaV				□ i
Crabs and Lobsters			□ c	□ c
Eels				□ i
Gastropods		□ ci		
bVS 7waV			□ ci	□ ci
Other Invertebrates				□ ci
Other Vertebrates				□ i
Salmonids			□ c	
Shrimps and Prawns				□ ci
Tilapias				□ ci

From the resulting data set we then extracted the species-country production records that Qdc ZOWSZg OQQRS]T -$]TVS]RcQbW] for each species group. To this we added the SQ]Ra QQ]cbWU]T -$]TSOeSSR]RcQbW] OZZ]aWQ eS OZWSR OaTT]bj[[O WS culture.

In total, these combined records accounted for just over 82% of total world aquaculture production in 2008 and reduced the number of countries in our data set to 18. Further data reduction was then achieved by summing production within each unique species group, country, production system and habitat combination.

For the relevant production systems (e.g., coastal pond culture) we also considered the intensity]T]RcQbW]]T SOQVSQWSa]c rQ]c bg combination in our data set. This is important because intensity of production determines the amount and type of feed and fertilizer regime required and the consequent level of emissions (Table 2.2).

Table 2.2: EVS]RcQbW]WS aWbOQSU]WScaSRWbVWa OZgWa TS RSDWZOR9OaO &$$

Production Intensity	Description
Extensive	Systems requiring large areas of earthen ponds or water area; primarily for aSQWSaWS waV []ZZc SOeSSRa RO VaW[a OR Oe a aSQWSa groups. Extensive production relies on natural productivity, but in ponds it is often supplemented by locally available crop wastes and other material. Little or no processed feed is used.
Semi-intensive	Primarily freshwater but also some coastal earthen pond systems in which natural productivity is augmented with fertilizers and farm made or industrially produced TSSRa SEV[OXWgb]TaWO waV Oc_OQZcbS WaRcQSR WSaVeObS S[W intensive earthen pond culture systems.
Intensive	D][S VWUZg]RcQbWdS] R gaSb[a S VUW[bWaSR QaW waVw QOUS culture and some high value species, such as eels in China. Intensive systems are mostly supplied with complete industrially produced pellet feeds that meet all of the nutritional requirements of the culture species.

To assign intensities to the data records we examined the available literature and consulted experts on species production methods within each species group within a country. For countries where species within a species group were produced at more than one intensity we duplicated the data record and adjusted production values for each [illegible] each production intensity.

Finally, we considered the types of feed used for each species group, country, production system, habitat and intensity combination. Drawing on Neori [illegible] 2.3). We then examined the literature and combined this with expert opinion where necessary (6% of records) to estimate the dominant feed type for each data record.

Assessment method

The objective of this study is to compare and contrast the global and regional demands of aquaculture for a range of biophysical resources across the entire suite of species and production systems in use today. Examples of the sorts of questions we wish to ask include:

- **How do countries or regions differ in their resource demands for aquaculture production?**
- **Which species groups or production systems are especially demanding, or ef-** [illegible]
- **Are there particular areas of the production process to which attention might most** [illegible] **demands?**

Table 2.3: [illegible]

Feed Category	Description
Natural Feeds	Plant materials, mainly crop waste, used in combination with other material but with little or no processing. The feeds vary in nutrient quality.
Trash Feeds	[illegible] no processing energy (except occasionally for chopping before feeding).
Mash Feeds	[illegible] requirements. These are 'farm-made' feeds and the major feed input for semi-intensive aquaculture.
Pellet Feeds	Feed pellets are manufactured in industrial feed plants and distributed through conventional [illegible] species. The pellets are mainly used in intensive aquaculture operations.
Extracted Food	Organic matter and nutrients for growth are assimilated from the environment through [illegible]

With the data reduction described above our fundamental units of analysis are the elements of a sparse six dimensional matrix comprising: 13 species groups x 18 countries x 3 production intensities x 4 production systems x 2 habitats [illegible] matrix elements, accounting for 82% of total [illegible] unique production elements form the basis of our assessment.

To facilitate meaningful comparisons of this sort, we require a method that can be applied in a standardized way across all units of analysis. Several approaches have been used previously to examine the sustainability of aquaculture and we were faced with a choice of the most appropriate method for this study. Table 2.4 summarizes the key features of several of these approaches.

Photo by Kam Suan Pheng
CHINA

Table 2.4: [illegible]

Method	Key attributes	Advantages	Disadvantages	[illegible]	Ease of application and communicability
Environmental Impact Assessment	Project-based Descriptive [illegible]	Public planning and transparent process Based on multiple criteria and can be used in sensitivity analysis [illegible] Allows redesign of project to reduce impacts	Does not quantify trade-offs or effects Does not provide a single performance indicator for comparisons Problems with how to interpret data	Variable (very high to low) Lots of uncertainty due to lack of data Often time-constrained due to development deadlines	Good [illegible] decision-making
Risk Assessment or Analysis	Tool for understanding environmental processes	Contributes to better understanding [illegible] Attempts to be quantitative but can also be qualitative [illegible]	Relies on qualitative judgments and estimates due to knowledge gaps Limited comparative use (some risks apply to some sectors, others not)	Variable at present Quantitative measures need to be developed (environmental indicators)	Good Formalized in legislation as decision-making tool
Material Flows Accounting, Mass Balance, Input/Output models	Examines input and output of key materials Accounts for biological [illegible] economic activities Applicable to systems at many scales	[illegible] outputs Can produce comparable information over time and space [illegible] Well-known tool with standard protocols	[illegible] [illegible] in time and place	High	Very good
[illegible] including environmental costs	Uses valuation techniques for non-marketable goods to compare net results of activities of different sectors (e.g., contingent valuation, willingness to pay, hedonic pricing)	Can compare production systems Can be very inclusive of many types of information, including non-marketable goods Long history and familiarity with concept; decision-makers need and want to know this information Provides aggregate measures of the relative performance of various production systems	Environmental values hard to determine Ecological function changes hard to predict Often environment is not included Normally long term sustainability issues not addressed Discount rates are arbitrary and may be political Loses information during aggregation	High	Results easily communicated and understood Including valuation of environmental goods and services and non-marketable goods [illegible]

Method	Key attributes	Advantages	Disadvantages	[illegible]	Ease of application and communicability
Ecological Footprint	Method to aggregate impacts into a single statistic to address [illegible] activities Converts all impacts to a measure of area needed to support a given activity	Provides a single indicator for comparison Can be applied to many levels and scales (e.g., a footprint for an individual to one for a national economy) Provides accumulative/aggregated effects	[illegible] Applications to food production systems are not obvious Method does not deal well with water [illegible] impacts or effects [illegible] environments Aggregated statistic treats all environments as homogenous and equal	Low	Easy to communicate, but statistic is often misused or can be misinterpreted Application is constrained by knowledge gaps on environmental differences among habitats
Life Cycle Analysis (LCA)	Examines a range of impacts of food production systems Product-oriented environmental impact assessment, with a cradle to grave perspective, multiple criteria analysis [illegible] contribution to global impacts	[illegible] prioritized Can build on previous work/data Can compare between products/processes/alternatives and different scenarios Basic method to develop eco-labeling criteria to support purchasing decisions for consumers Can provide policy-relevant insights	Large data requirements Some studies use different functional units Results address global impacts at expense of local impacts Some indicators may not be appropriate for [illegible] Results are not directly applicable unless [illegible] Some standard impact categories may not be relevant to food product systems, thus need to develop new ones	High	[illegible] comparisons Communication on multiple [illegible]

From our review we concluded that the Life Cycle Analysis (LCA) approach provides the strongest platform to conduct analysis over a range of different production systems, and at different scales of analysis. The approach is also readily amenable [illegible]

LCA approaches are now in widespread use and are conducted at a variety of scales. There is an emerging body of LCAs that examines the environmental resources and emissions of aquaculture production systems (Pelletier and [illegible] of LCAs have been undertaken for single species and production systems (e.g., Mungkung et al., [illegible] to the very wide range of choices available for describing LCA processes. There has been no effort to undertake a systematic global and regional level LCA comparison for aquaculture production of the type presented here.

LCA is a systematic four phase process comprising:

1. [illegible] and describe the product, process or activity, b) establish the context in which the assessment is to be made and c) identify the boundaries and environmental effects to be reviewed for the assessment.

2. *Inventory Analysis* [illegible] quantify energy, water and materials usage and environmental releases (e.g., air emissions, solid waste disposal, waste water discharges).

3. [illegible] potential human and ecological effects of energy, water, and material usage and the [illegible] inventory analysis.

4. *Interpretation* [illegible] of the inventory analysis and impact assessment to select the preferred product, process or service with a clear understanding of the uncertainty and the assumptions used to generate the results.

LCA practitioners make a distinction between screening studies that use readily available data and extensive studies that require a major investment of [illegible] at the screening end of this continuum and aims to provide a robust approach for answering the questions we pose. It also provides a foundation for [illegible]

[illegible] boundaries for our analysis. In its full form LCA is a cradle-to-grave approach that begins with the gathering of raw materials from the earth to create the product and ends at the point when all materials are returned to the earth. When complete, an LCA estimates the cumulative environmental impacts resulting from all stages in a product's life cycle. This often includes factors such as raw material extraction, material transportation, ultimate product disposal, that are often ignored by other methods.

In common with others studying aquaculture, however, we have adopted a more bounded approach (Figure 2.1) that excludes environmental costs associated with building infrastructure, seed production, packaging and processing of produce, transport of feed or produce, cooking the produce and disposing of the waste. Previous studies suggest that setting limits as shown in Figure 2.1 is defensible because the bulk of environmental resources and environmental emissions lies within [illegible] Pelletier and Tyedmers, 2010). The biggest energy demands for aquaculture production systems occur on farm, for processing feed, for reduction of wild [illegible]

The main sources of eutrophying emissions (nitrogen and phosphorus) are those released from [illegible] Tyedmers, 2010).

The system shown in Figure 2.1 is generic and [illegible] combinations of species group, country, production intensity, production systems, habitat and feed type. For some combinations 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, since these extract food from the environment we set the feed production process to [OYS] RS[O Ra] S S Ug Q] [SOZwaV[SO] waV] V

Unit Processes

Data collection is the most time demanding task of LCAs. There are two types of LCA data required; foreground data and background data. Foreground RObOWbVSa SQWQROb S_cWSR b [ ] RSZbVS systems (Goedkoop et al., 2008). This data refers to the biophysical resources required during O_cOQcZbc S] RcQbW a SQWQOZg bVS Q[ ] c t of land, water, feed, fertilizers and energy required on farm. This data was collected from a variety of sources during a literature review.

3OQYU] c R ROb O STS a b SRSw SR c V processes available in the standardized databases used by LCA practitioners and provided with several LCA software tools. Background data have PSS RSw SR T OdO Wg] TOU Wcbc OZ] RcQbW and energy production processes.

Figure 2.1 illustrates the system boundary of the model, distinguishing between the biosphere inputs (raw materials) and the technosphere inputs (any material transformed by human action) and indicating where emissions are released. EVS Uc S QZaRWaWUcWSa eVS S] TSU]c R and background data has been used. By linking the foreground data to the background unit processes we capture upstream processes and their associated inputs from the biosphere and thetechnosphere (Goedkoop et al., 2008).

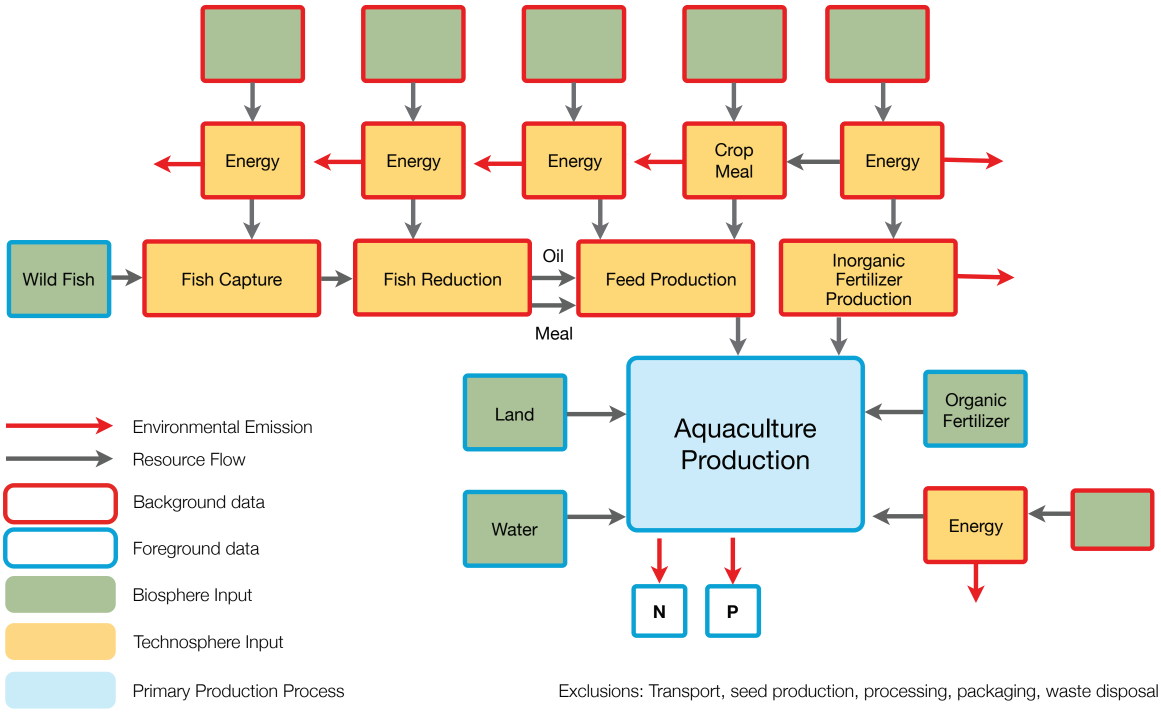


Figure 2.1: Graphical summary of the system boundaries and model structure for the Life Cycle Analyses undertaken in bWa bRg ?]bS WbVS QOaS]T aSOeSSRa bVS xea b WbS ?O R V] a V] ca Ae] cZRPS SUObWb SdS aSR

In LCA parlance, the following demands on resources become our inventory categories:

1. EVS SO]TZBO S_cWSR]b Uje waV
2. EVS O[]c b]T eWZR aSR OaV STSR
3. EVS O[]c b]T]UO WQ RO]WUO WQ& bWZWS_cWSR b U]e waV
4. The energy required for the various production processes involved (shown in Figure 2.1).
5. The amount of carbon dioxide the environment must assimilate from the production processes.
6. EVS O[]c b]T eOaS WbS OR V]a V] ca bVS S dW [S b[cabOaaW[WZSOT][waV production.

As noted above, these six categories of demand were chosen because they are most likely to constrain the potential for sustainable aquaculture growth (Rockström SbOZ &$$- /5 cObS SbOZ &$$- / cWSbOZ &$$-

1GD HH OCIDC7C BD AE7G7B I G7IDC

9OdWU WS bWSR bVS QObSU] WSa T WdS b ge S[cab] e a SQWg V] e W cba b bVS =42 OS QOZQcZObSR The following section describes the basis for this. Literature sources and the approach used to estimate model parameters are given in Table 2.5.

The foundation of our approach is to work back from aquaculture production P for each species group **i** within production system **j** in habitat **k** at intensity **l** with feed **m** for country **n**. (Note: These subscripts remain Q] abO bbV] cUV] cbbVW O S c Zaa] bVS e VS abObSR F aWU bVSaS RObO e SwabcaSR bVS T Z e WU equations to calculate the land or sea area required for production and the volume of freshwater required for inland systems:

$$Area_{i,j,k,l,m,n} = \frac{P_{i,j,k,l,m,n}}{\alpha_{i,j,k,l,m,n}}$$

$$Water_{i,j,k,l,m} = \frac{P_{i,j,k,l,m,n}}{\beta_{i,j,k,l,m,n}}$$

Where α WbVS] RcQbW STwQW Qg S c W] RcQbW OSO O R β WbVS] RcQbW STwQW Qg S c W water volume. For production from coastal systems (marine and brackishwater) the freshwater requirement was set to zero.

E QZOZcObS]bOZ]OT[S S Ug aS eS []BZSR Q]cbg aSQWQw S Ug [Wfa 62: &$%$ SbW[ObS bVS S Ug aS SQWSgy such that:

$$FarmEnergy_{i,j,k,l,m,n} = P_{i,j,k,l,m,n} \cdot \gamma_{i,j,k,l,m,n}$$

UO WQ SbWZWhSS SwSR SVS Oa] OT[eOaSa VOb SVO QS VSb Ob OZ]R cQbWdWbg TS ZbS system. We distinguished four categories: cow, chicken and pig manure and plant compost and calculate organic fertilizer input as the sum of inputs into a given system from these sources i.e.:

$$OrgFertilizer_{i,j,k,l,m,n} = \sum_{p=1}^{4} \vartheta_{p,i,j,k,l,m} \cdot Area_{i,j,k,l,m,n}$$

Where $\vartheta_{p,\ldots}$ is the application rate of fertilizer **p** per unit aquaculture production area for a given production system.

Similarly, for inorganic fertilizer inputs we distinguished two sources, urea and Triple Super Phosphate (TSP), and calculate total application as the sum of these two inputs:

$$Urea_{i,j,k,l,m,n} = \mu_{1,i,j,k,l,m} \cdot Area_{i,j,k,l,m,n}$$

$$TSP_{i,j,k,l,m,n} = \mu_{2,i,j,k,l,m} \cdot Area_{i,j,k,l,m,n}$$

Where $\mu_{1,\ldots}$ and $\mu_{2,\ldots}$ are the application rates per unit area for urea and TSP, respectively for each production system.

[illegible] following equations:

$$FishMeal_{i,j,k,l,m} = \frac{P_{i,j,k,l,m,n} \cdot FCR_{i,j,k,l,m,n} \cdot \pi_{meal}}{\rho_{meal}}$$

$$FishOil_{i,j,k,l,m} = \frac{P_{i,j,k,l,m,n} \cdot FCR_{i,j,k,l,m,n} \cdot \pi_{oil}}{\rho_{oil}}$$

Where *FCR* [illegible] π [illegible] ρ is the yield of meal or oil per [illegible]

[illegible] DK data library supplied with SimaPro, the software used for our LCA analyses. This unit process states [illegible] produced. We allocated environmental burdens for each product based on the weight of each produced.

Total crop meal required was estimated from:

$$CropMeal_{i,j,k,l,m} = P_{i,j,k,l,m} \cdot FCR_{i,j,k,l,m} \cdot (1 - (\pi_{meal} + \pi_{oil}))$$

[illegible] the EcoInvent library that represented these crops. This was then used to estimate the energy needed to [illegible] the grow-out of a unique species combination.

To calculate nitrogen and phosphorus emissions from aquaculture production we used a simple mass balance approach where the total weight of N or P from processed feed and fertilizer inputs was calculated [illegible] the following equations:

$$Nfeed_{i,j,k,l,m,n} = P_{i,j,k,l,m,n} \cdot FCR_{i,j,k,l,m,n} \cdot \omega$$

Where ω is the percentage nitrogen by weight in feed.

$$NOrgFert_{i,j,k,l,m,n} = \sum^{4} \sigma_1 \cdot Area_{i,j,k,l,m,n} \cdot \vartheta_p$$

Where $\sigma_{1,1,..,4}$ is the percentage nitrogen by weight in cow, chicken and pig manure and plant compost, respectively.

$$NInorgFert_{i,j,k,l,m,n} = \tau_1 \cdot Area_{i,j,k,l,m,n} \cdot \mu_1$$

Where τ_1 is the percentage nitrogen by weight in urea.

$$NFish_{i,j,k,l,m,n} = P_{i,j,k,l,m,n} \cdot \varphi_1$$

Where φ_1 WS SQS bOUS WjbUS WaV WacS

Phosphorus was calculated in the same way except that the percentage phosphorus in TSP replaced percentage nitrogen in urea to calculate the contribution from inorganic fertilizers. Although this approach is SOa OPZS OOabwO]f W[OW] eSQ]UWhSVOb]b OZZbWSa S Zpa]S] R gaaS[a] T example, up to half of the nutrients may end up in sediments which can be re-used for agriculture (Islam, 2005).

Table 2.5: Parameter estimates and data sources for foreground data calculations. In cases where parameter estimates for a particular system could not be obtained directly from the literature, values for the system with the closest similarity or expert opinion was used. The proportion of records determined by expert opinion are shown in parentheses at the end of each list of data sources.

	Parameter	Description	Units	Data Sources
1	$\alpha_{i,j,k,l,m,n}$	Production per unit area.	$t.ha^{-1}$	Atmomarsono and Nikijulluw, 2004; Barman OR W[&$$WO] 3RO OWXW&$$]e 3 &$$/ 4O] SbOZ &$$ / &$$ 72 4: OQQSaSR W&$%$/ch4 %--Z /OgSR &$$ / Gupta and Acosta, 2004; Losinger et al., 2000; ?OYOR &$$&/ ?c&$$VO ASbOZ &$$-/ AVc] U &$%j&/S ES g %---bc [QY SbOZ &$$,/ D[OUOgaOg 4Od]a] &$$ Y]e OQQSaSR W&$%$/SWVW OR SJ_WU &$$ -
2	$\beta_{i,j,k,l,m,n}$	Production per unit water volume.	$t.m^3$	5cUO SbOZ &$$ SbOZ c &$$- %,
3	$\gamma_{i,j,k,l,m,n}$	OT[SSUg aS OWSg S cWbaV]R cQbW]	$Mj.t^{-1}$	253 &$$)/ 3]a [O SbOZ &$$-/ 3c bWU OR ASbg &$$ /9S WYaj &$$-/ ZOYOR DWYO %-, /ASZZWSO R EgSRS a &$%$/EZabg OR =OUcScf &$$-]SZE SbOZ &$$(&)
4	$\vartheta_{1....4.i.j.k.l.m}$	Application rate of cow, chicken and pig manure and plant compost for each production system	$kg.ha^{-1}$	3O[O OR OW[&$$ /4 ch %-- /4 ch =OQWRO SbOZ &$$,/ RS DWZOR 9OaO &$$ / 6Z OgSR &$$ /6Z OgSR &$$ /72 OQQSaSR W&$%$/7Z]Sa ?OdO&$$ /9c UOR 9cg &$$ / HSW[W OR SJ_WU &$$
5	$\mu_{1,..,2,i,j,k,l,m}$	Application rate per unit area of urea and TSP, respectively for each production system.	$kg.ha^{-1}$	Atmomarsono and Nikijulluw, 2004; Barman and OW[&$$ /4 ch %-- /4 ch =OQWRO SbOZ &$$,/ 6Z OgSR &$$ /6Z OgSR &$$ /7Z]Sa ?OdO &$$ /9c UOR 9cg &$$ /ASZZWSS SbOZ &$$- $
6	$FCR_{i,j,k,l,m,n}$	Food conversion ratio. (Food required: Fish produced, by wet weight)	-	Tacon and Metian, 2008; FAO, 2004. (10%)
	π_{meal} π_{oil}	The proportion by weight of waV[SOZ OR]WZ SZZSSSRa	-	3O[O OR W[&$$OQ]EOR Y]O 2008. (10%)

	Parameter	Description	Units	Data Sources
8	ρ_{meal} ρ_{oil}	EVS gWSZZTaV[SOZ]]WZ cWb eSb eSWbUVTaV	-	Péron et al., 2010.
-	$\omega_{1,..,2}$	The proportion by weight of WbUS OR Va V] ca aW feed.	-	4 OWU RO 9SZZTQV &$$-
10	$\sigma_{1,,2,1,..,4}$	The proportion by weight of nitrogen and phosphorus (i = 1,..,2, respectively) in cow, chicken and pig manure and plant compost (j = 1,..,4, respectively).	-	3O[O OR VO[&$$
11	$\tau_{1,..,2}$	The proportion by weight of nitrogen and phosphorus in urea and TSP, respectively.	-	Graslund and Bengtsson, 2001.
12	$\varphi_{1,..,2}$	The proportion by weight of WbUS OR Va V] ca aW tissues.	-	Ramseyer, 2002; Tanner et al., 2000.

Note: In all cases subscripts denote: species group *i* within production system *j* in habitat *k* at intensity *l* with feed *m* for country *n*.

GDB -C CIDGMID-BE7 I 7I DG H

From the estimates derived using the methodology described above we ran an LCA analysis for each]T VS)WcS Q][PWObW]a ZZ OaSa eS S Q] RcQSR aWU D[OA] G $ Y]8]SRbOZ 2008). In common with other LCAs impacts were assessed using a mid-point approach, which takes the inventory results and translates them into impact measures that fall somewhere short of the ultimate W[OQba RS]Wba]TSab Wb OQRQObW] for example, one might choose an impact end point as area of forest lost through acid rain. This will be RWQcZb]b SaW[OS]eSdS] SaSOQVS a cacOZZg use the inventory data to estimate the aggregate OQWRWOW] PRS]]TSaba OaO [WTWb measure. For this study, the following six impact categories were used:

Eutrophication: includes all impacts due to excessive levels of macronutrients in the environment caused by emissions of nutrients to air, water and soil. Expressed as t PO_4 equivalents[3].

: :G : acidifying substances impact on the functioning of ecosystems and human well-being. 2QWRWOW]]bS bWOZS SfSaSR WD $_2$ equivalents.

Climate Change: SxSQb VS OOOSWhW] model developed by the Intergovernmental Panel on Climate Change (IPCC). Results are expressed as climate change potential in t CO_2 equivalents.

Cumulative Energy Demand (CED): represents the direct and indirect use of industrial energy, expressed in Gj, required throughout the production process.

Land Occupation: calculated as the sum of direct and indirect land occupation, using equivalence factors adjusted for each type of land (e.g., arable, pasture, sea) for relative levels of bioproductivity. The higher the bioproductivity of the land, the higher the equivalent factor becomes (Wackernagel et al., 2005)[4]. Land occupation is expressed in ha equivalents.

Biotic Depletion (Fish): the amount (t) of wild waV S_cWSR]b a] b]aS dSR QOQZb S production. There was no differentiation of the type]T aV aSR RWU VS]R cQbW]]QSaa Pcb eS Oa[S bOb OZS aW aSR]T SSR Sa[OZZ SZOUWQ aSQWSa

[3] Although nitrogen is often the limiting nutrient in marine systems, it is convenient to express eutrophication potential in terms of PO4 throughout and does not affect the conclusions.

[4] 2Za SQSa e WWuQ OaZVOPWa e S S QZaaWSR Oa] QQc gWUaSO_cWOS QS TQ] $ D SQSa QcZWSR WuWZ RvVOPWa e S S Oaac[SR] QQc g OOPZS ZO R_cWOS QS TQ] &% EVca TQcZWQ W] TOa SQSa U] c S_cWSR %VSOS] TaSO area it was characterized as requiring 0.36 hectares. In contrast, species requiring 1 hectare of arable land (e.g., carp, tilapia) was QVOOQS WSR Oa S_cWU &% VSObOSa] TZO R

[illegible] 'CML Baseline 2001' impact assessment methodology of The Institute of Environmental Sciences of Leiden University (CML) (Guinée et al., 2002). The standard method to calculate Cumulative Energy Demand (CED) was based on the method published by EcoInvent version 1.05 and expanded by PRé Consultants for [illegible]

Results

Table 2.6a summarizes the overall impact of the 82% of 2008 production that was modeled in this study [illegible] one compares estimates for CO_2 emissions with those available for other sectors (Table 2.6b). This table [illegible] of agriculture emissions. This is based on IPCC estimates of total agricultural emissions ranging between 5120 $MtCO_2$ [illegible] $_2$-eq/yr (US-EPA, 2006) in 2005. If one were to offset the CO_2 contribution from all aquaculture production it would cost about US$ 52.5 billion at the current market price for CO_2 in offset markets of around US$ 15 per tonne (World Bank, 2010).

Table 2.6: [illegible] complete global impact assuming that, as with total aquaculture production, each calculated estimate represents 88% of the total. (b) Sectoral comparison of CO_2 [illegible] add up to the total estimate). Source: UNSTATS Environmental Indicators, accessed December, 2010.

a)	Eutrophication (Mt PO_4 eq)	[illegible] (Mt SO_2 eq)	Climate Change (Mt CO_2 eq)	Land Occupation (Mha)	Energy Demand (Tj eq)	Biotic Depletion (Mt)
Modeled	3.33	2.60	[illegible]	[illegible]	3,431,361	15.11
Total	[illegible]	3.06	[illegible]	65.61	[illegible]	[illegible]

b) Sectoral Source	Total Emission (M tonnes CO_2 eq)
Energy	[illegible]
Transport	4,815
Industrial Processes	2,105
Agriculture	4,650
Waste	[illegible]
Aquaculture (this study)	385
Total	**30,824**

[illegible]

As expected, for the most part, data for all impact categories show a positive relationship between overall production levels and impact (Figure 2.2). The only exceptions to this are for the subset of the data representing species that extract food from the natural environment. With the exception of a relatively minor contribution (on a global scale) to eutrophication through pseudo-feces deposits to bottom sediments by [illegible] horizontal line of data points at the bottom of these panels in Figure 2.2. Despite these linear relationships, however, there is clearly considerable variance in impact for a given level of production. This is especially [illegible]

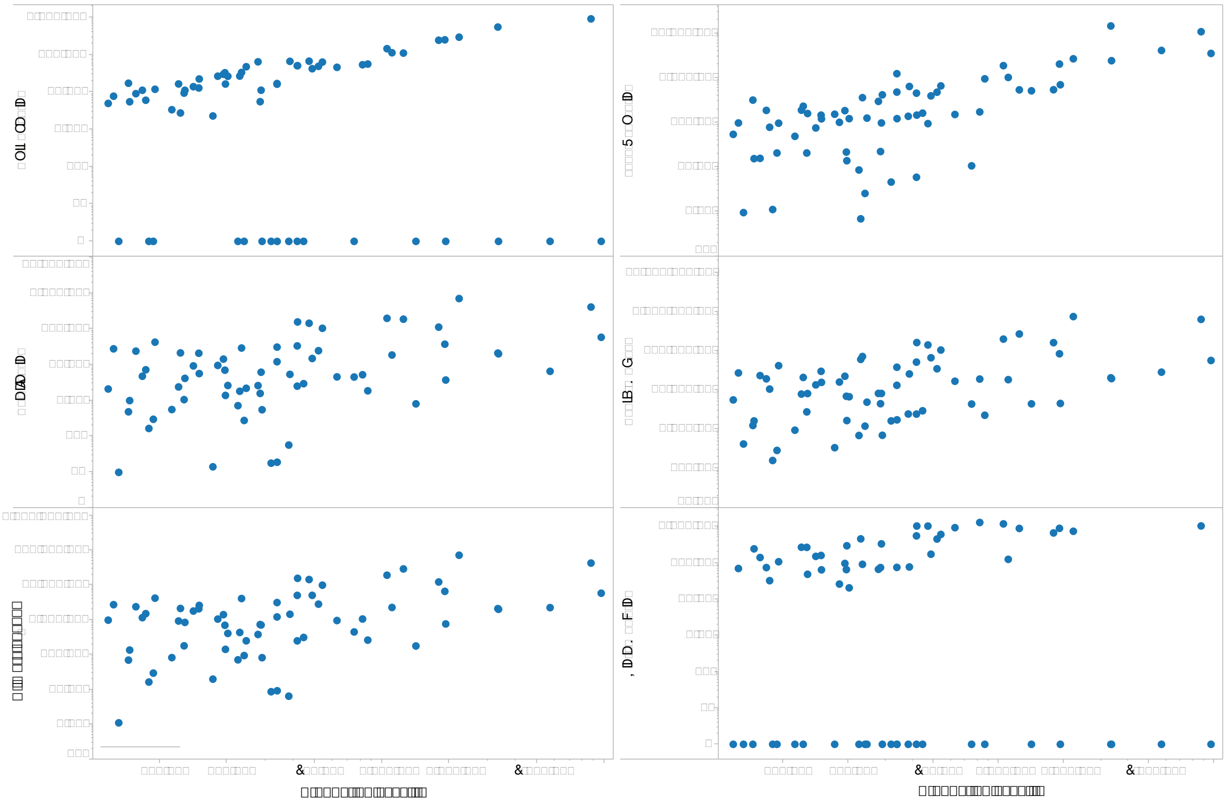


Figure 2.2: ESSZObW aWW SleSS]dSOZZ] RcObW]ZSSZaT SOQV] TbVS)c WcS]R cObW]Q[PWObW]a O R level of impact: Eutrophication (t PO_4 S_/OWZRQObW] D $_2$ eq); Climate Change (t CO_2 eq); Land Occupation (ha eq); Cumulative Energy Demand (Gj); Biotic Depletion(t).

-B E7 IH M 7 I7I 7C EGD I DC HMH B

Given the positive relationship between production and absolute levels of impact described above it is unsurprising that, with its dominance as a production system, inland pond culture contributes the greatest impact overall for all impact categories (Figure 2.3, upper panel). Nevertheless, despite bWa]dSOZZ[WR O QS S[OR R]T eWZR WbWQ depletion) is also notable for marine cage and pen production. Negative values for eutrophication W]Pb[O R]T]Pb[QcZb S SxSObPWOZS farming where nutrients are taken up from the environment. However, although we can rightly view this as a regional removal, we must recognize that at a more local scale impact through the deposition of pseudo-feces will occur.

HVS]S QaWSa SQWSg]T]R cObW] and compares levels of impact for a given unit of product, impacts from pond and cage and pen production dominate in both freshwater and marine systems (Figure 2.3, lower panel). With the exception of land occupation, however, cage and pen culture has consistently greater impact. Overall, however, cage and pen production in inland waters appears to cause the greatest impact. One must also bear in mind that deposits into freshwater pond sediments are also often used for agriculture.

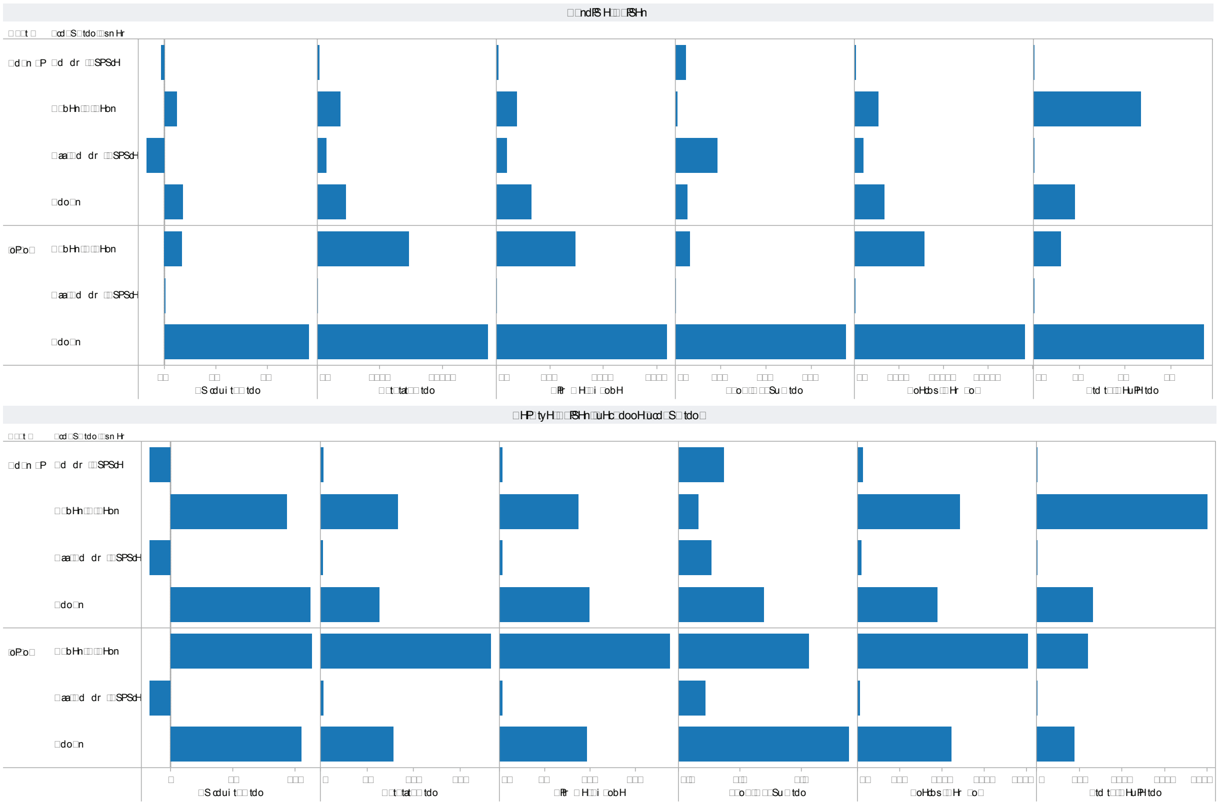


Figure 2.3: Upper panel: The absolute environmental impact of 2008 aquaculture production categorized by production system and habitat: Eutrophication (t PO_4 S_/QWRQW] bD $_2$ eq); Climate Change (t CO_2 eq); Land Occupation (ha eq); Cumulative Energy Demand (Gj); Biotic Depletion (t). Lower panel: The relative environmental impact, per tonne of product categorized by production system and habitat: Eutrophication (kg PO_4 S_ 2QWRQW] YD $_2$ eq); Climate Change (kg CO_2 eq); Land Occupation (ha eq); Cumulative Energy Demand (Mj); Biotic Depletion (kg).

-B E7 IH MHE H GD E

In absolute terms, we see that carps dominate]dS OZZ OQb WU6S & (S cO SZ SxSQbWU the fact that carp production is greater than that of other species groups. Production in the s VS waVt QSb] g Wa]Za]bOZS]eSVS ObWZZg] T OQWRWb] QZSW[Ob/US B energy demand, three measures that are correlated with one another. A recent review of environmental W[OQb]T [OWS waV Qb S]dWBa cTbVS perspectives on this production category (Volpe et al., 2010). For the biotic depletion category, total RS[O R]T aV]b]R cQS VaW[a OR Oe a and salmonids almost reaches that for carps.

In relative terms, eel production stands out as being especially environmentally demanding (Figure & (Z]eS SZ SxSQbWU VS WUZg bSVaWdS and energy demanding nature of eel production systems. No other species group dominates impact categories to the same extent, although shrimps and prawns tend to be among those causing the most impact, while salmonids are]bOZS] TVSW S[O R]T aV WU6S & c)bVS ac[[O WhSaVS SZOWdS wSWSQg]T]R cQbW] for species groups categorized by habitat and production system.

Land occupation impacts vary with species group and system, but largest impacts are not surprisingly associated with pond farming, particularly in Asia and South America. One should recognize, however, that LCA does not fully capture biodiversity and other values associated with land use for aquaculture. More local analysis will be is required to determine such impacts. Impacts of concern may relate to loss of biodiversity associated with replacement of habitat by ponds, or loss of ecosystem functions such as those associated with carbon sequestration or provision]T caSg SOa]T eWZRW] cZOb]a

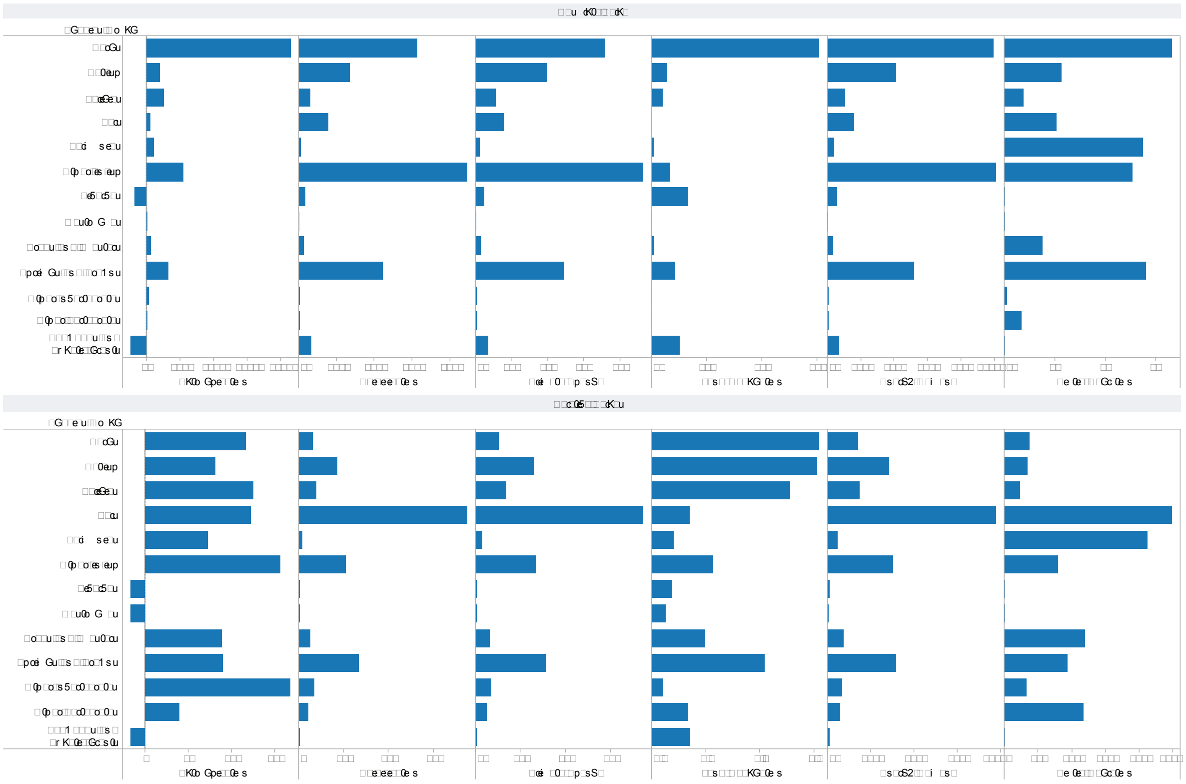


Figure 2.4: Upper panel: The absolute environmental impact of 2008 aquaculture production categorized by species group; units as for Figure 2.3 (upper panel). Lower panel: The relative environmental impact per tonne of product categorized by species; units as for Figure 2.3 (lower panel).

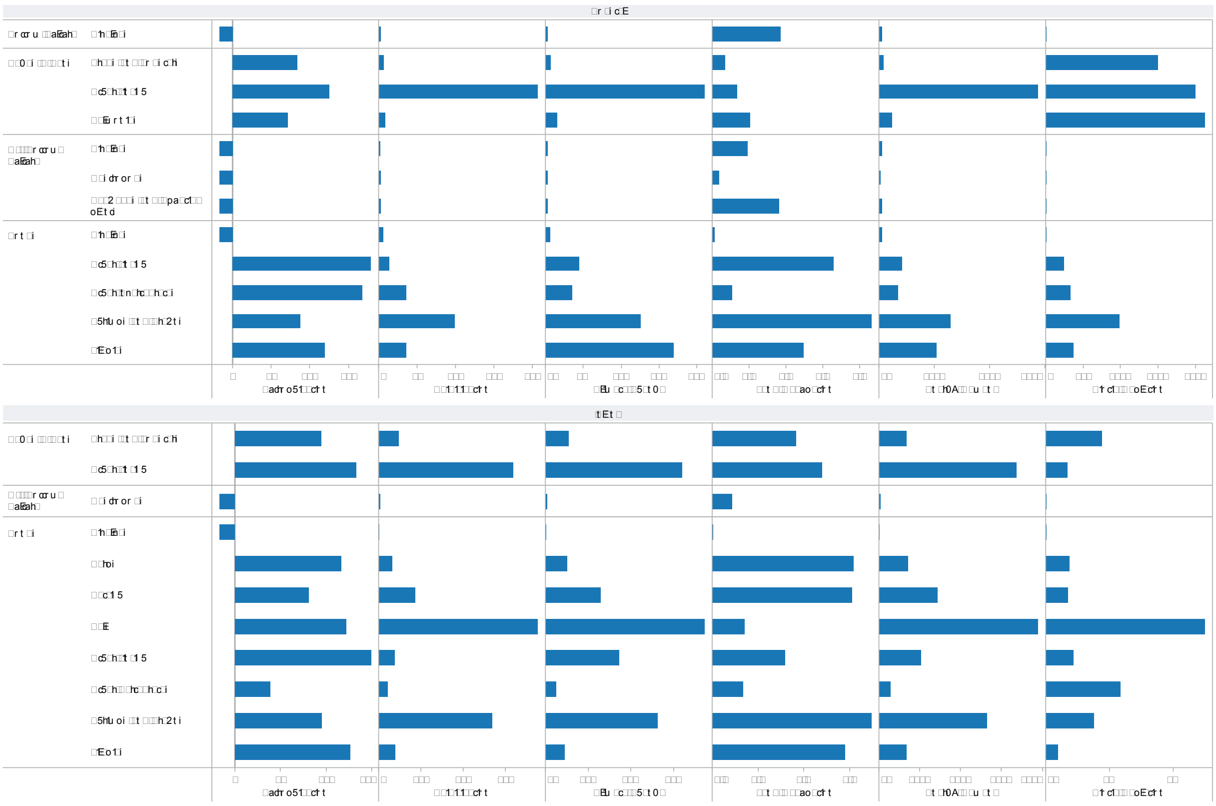


Figure 2.5: The relative environmental impact of 2008 aquaculture production categorized by habitat, production system and species group; units as for Figure 2.3 (lower panel).

[illegible]

[illegible]
countries in our analysis[5]. Figure 2.6 gives a clear sense of the overall dominance of China, but also
[illegible]
species that are produced in different regions. The demands of salmonids and shrimps and prawns, for
[illegible]

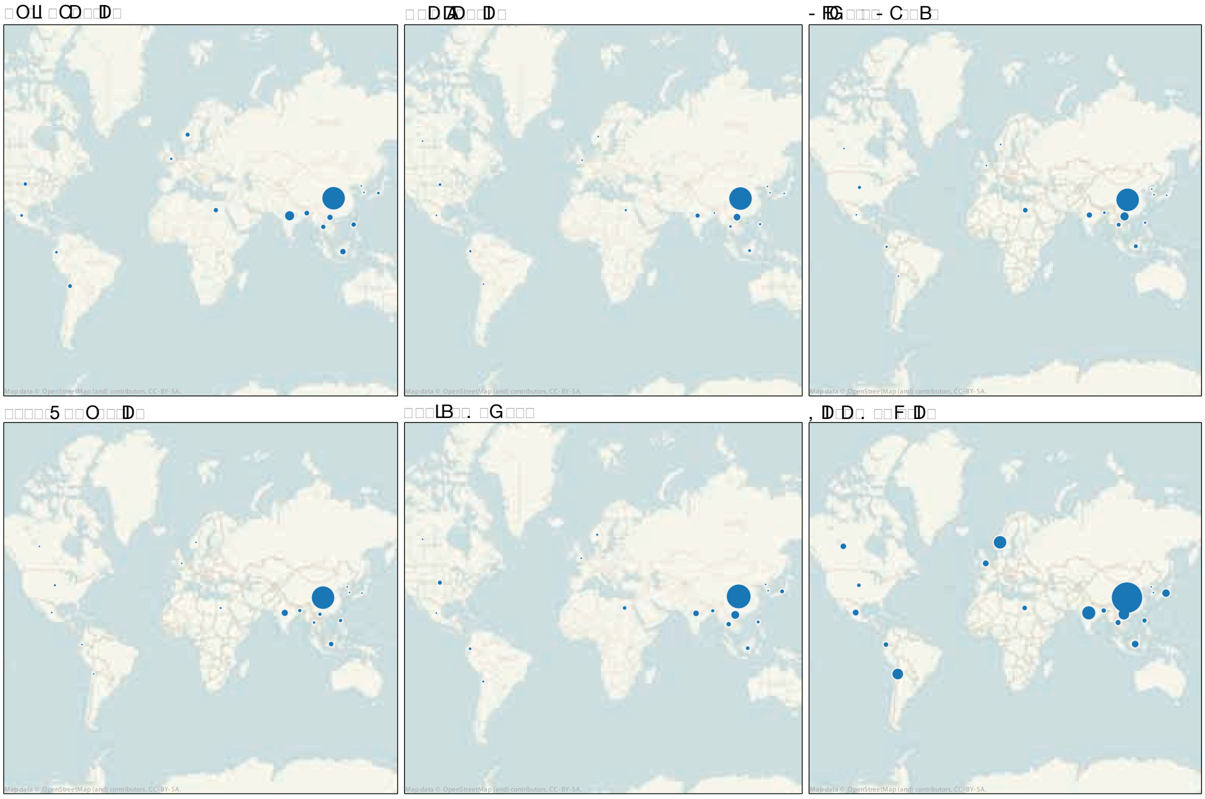


Figure 2.6: Maps showing the absolute size of total environmental impacts of 2008 production for each of the 18 [illegible]

[illegible]
countries, whereas for four of the remaining impact categories, aquaculture production is markedly
[illegible]
consumption (biotic depletion) where the salmon producing countries, are joined by those where shrimps and prawns dominate the production mix.

5 [illegible]

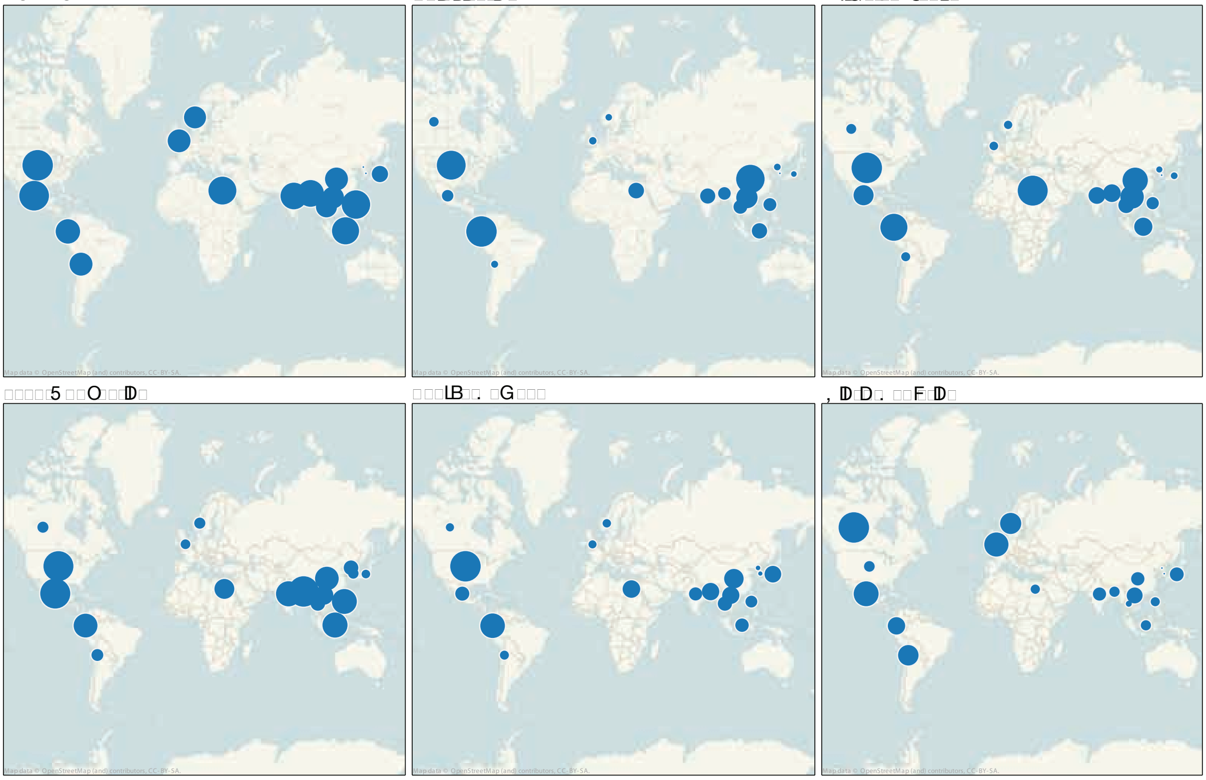


Figure 2.7: [illegible] impacts per tonne of production) for each of the 18 countries analyzed in this study.

Further insight into how these values are derived can be obtained by looking in more detail at how [illegible] demand (Figure 2.8 upper panel). By contrast, the eutrophication burden through production of other [illegible] production, environmental performance is broadly similar across countries, but Canada appears to [illegible]

Of particular interest in Figure 2.8 is the variation between countries for a given species. In 22 of the 36 comparisons shown, the best performers had impacts per tonne produced that were more than 50% [illegible] performance exist between countries, indicating great potential for improvement (see discussion).

Figure 2.8: 2 Q][OWa]TS dW[S bOZSTWQWSQWSOQ]a aQc bWSU]eW UbS aQ[S a SQWSU]c

G GHD B E7 I

An important tool in understanding our results is contribution analysis. This shows which processes OS ZOgW OWUaWOb]ZS WS WQQbSacZb Often, even in an LCA containing hundreds of RWSTS b]QSaaSa []S VO -)]TVS SacZb OS SRS [W SR P abc Sb]SES WUS & - summarizes the contributions to impact of the wdS [OW]QSaaSa W]c []RSZa]T SOQVTVS species groups[6].

EWVaVJea QZSgVOb WVS aW]R cQW] process itself which contributes most to eutrophication, whereas, for most groups, OQWRQW] OR QZWS[ObQVUS WQQb S contributed primarily by the national energy production process. This indicates that much of the dOWbW] WOQWRW] OR QZWS[ObQVUS WQQb

across countries for a given production system will be driven by the energy mix that supplies that country. Production in a country such as China that is dominated by coal production, therefore, will be greater than in a country with a large proportion of energy coming from nuclear or hydro power.

2a eS eZR SfSQb PWbQaV S ZSW] WaWdS primarily by the feed production process. Fertilizer production processes for urea and TSP, generally contribute little to the total impact.

An interesting feature of this analysis is the exceptions to the general pattern. It is notable, for example, how the feed production process dominates most impact categories for salmon aquaculture and, to a lesser extent, for tilapia and carps.

[6] One feature of this analysis that it is important to bear in mind is that a given process may occur in several places in the model; energy production, for SfQ ZS eWQ bWcbSb P] bVTSSROR TS bWS]RcQW]QSaaSa 7Wc S & - aV] e a bVS ac[ ] TQZbVSaS Q bWcbW aT] [OUWS]QSaa

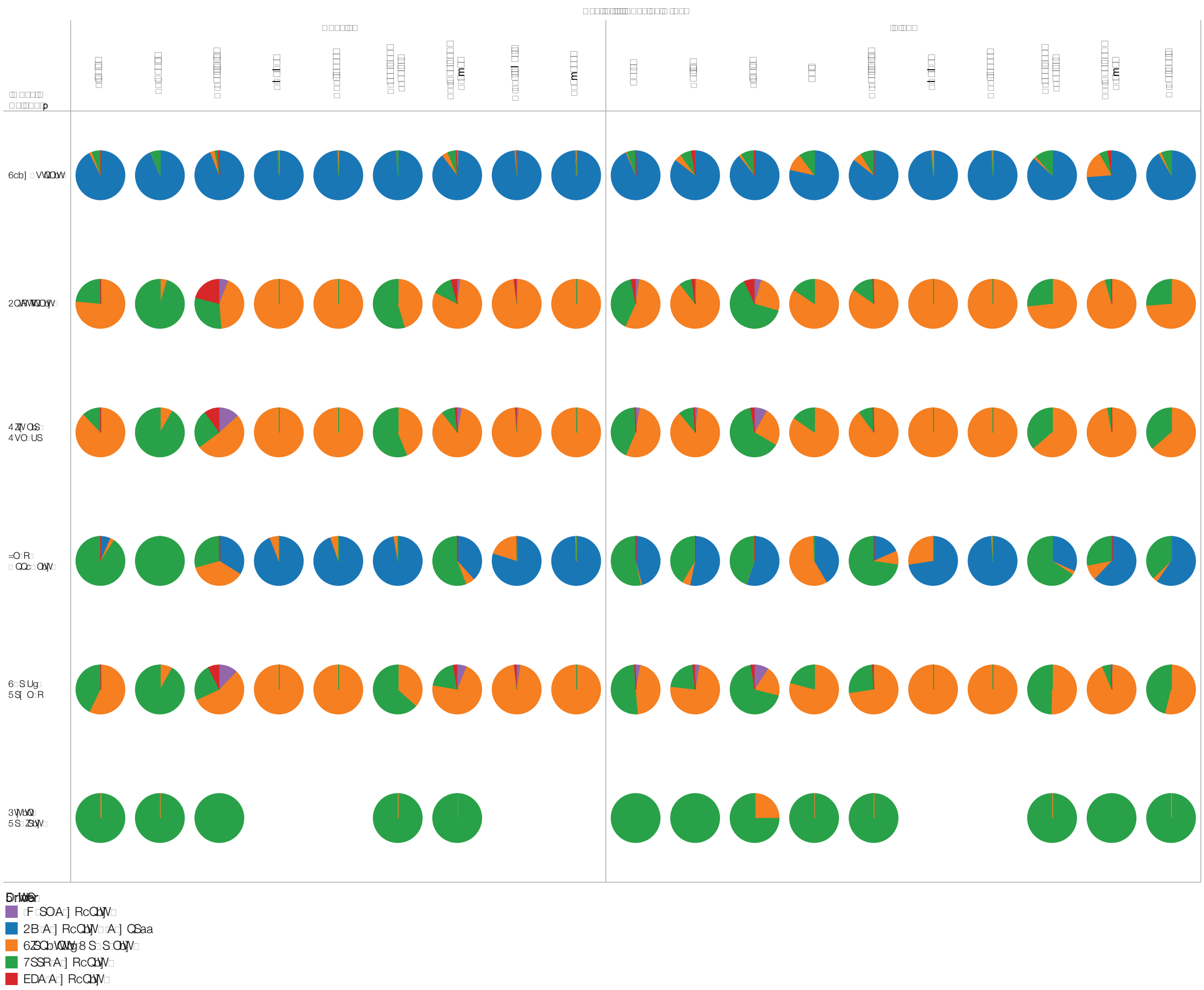


Figure 2.9: ESV]boZ]]bW]OZ ObWPW]bW[OOb]TbVSwdS[OW]QSaaSaT SOOVaSQWSU]c

3 CHI IM7C7AMHH

H Wb)SaOS 42 a O Q[ZSb OZgaa]T both within and between model sensitivities would be an enormous and impractical undertaking. In view of this, we focused on those models where we felt the greatest uncertainties existed. The results of our analysis can be sensitive to both the functional form (structure) of our model and its parameterization. Assumptions made during the goal setting and scoping phases affect model structure and the quality of available data determines the uncertainty in input parameters. Our primary uncertainties concerning both model structure and parameterization are with feed and fertilizers.

For feed, we used 5 categories and assigned each]T]c)]RcQbW]gaSa]b]S]TSaS Natural feeds provided by the inherent productivity of the system were not considered as having any negative environmental effect and were not, therefore, included in the inventory stage of the LCA. Mash feeds are farm-made and require little processing. Where the databases provided with Simapro allowed, we chose crops ‘at farm’ to represent the lesser degree of processing of mash compared to pellet feeds. Pellet feeds were treated as industrial feed, meaning that processes were chosen from the database to better represent the higher degree of processing needed for this feed type.

For fertilizers we assumed that organic fertilizers are only used in extensive and semi-intensive systems, inorganic fertilizers only in semi-intensive systems and none of them in intensive systems (unless otherwise stated). As noted earlier, we SQ]cbSSR][SRWQZWSaWRWUOb] fertilizer use and had to appeal to expert opinion to wZZWSUOSaWOZg4WO

For some systems where data were poor, we also examined sensitivity to the food conversion STWQWSgOaWa QPb]OTSSUg use.

To explore the sensitivity of impact results to these issues we examined models for 3 species groups (carps, shrimps and prawns, tilapias) and for each species group we compared the results for 2 countries (China + 1). We changed the assumptions on feed, by either modifying the feed source, by assuming that there is only one crop in the diet (the one having the biggest share in the feed composition) or by substituting one crop by another when it couldn't be found in the EcoInvent database (e.g., coconut (=husked nut) for groundnut). We only changed one parameter at a time unless otherwise stated. Table & c[[Oa WhSaVS Sb]T Q]bOaba eS QS[W SR :SaS QS VSaS QO SP Q]aWSRSR ZOaWZS cb PZSa likely options compared to our baseline choices.

Table 2.7: Summary of the models used to examine sensitivity relative to baseline results.

Country	Intensity	Uncertainty	Variation from Baseline
			Carps
India	semi-intensive	Feed source	Replaced husked nuts PH by rapeseed extensive at farm CH
		Feed source	Rice only (main crop)
		Food conversion	FCR 2 instead of 1.5 (i.e. same as for intensive)
India	intensive	Feed source	Replaced husked nuts PH by rapeseed extensive at farm CH
		Feed source	Replaced husked nuts by rapeseed conventional FR
		Feed source	Rice only (main crop)
		On-farm energy	Changed on farm energy (=20,000 instead of 65,000)
		On-farm energy	Changed on farm energy + rapeseed extensive
China	semi-intensive	Feed source	Rapeseed only (main crop)
		Food conversion	FCR 2 instead of 1.5 (i.e. same as for intensive)
		Fertilizer	Added inorganic fertilizers (150/150)
		Fertilizer	Removed organic fertilizers
China	intensive	Feed source	Rapeseed only (main crop)
China	extensive	Fertilizer	Added inorganic fertilizers (50/50)
			Tilapia
Thailand	semi-intensive	Feed source	Cassava only (main feed)
		Food conversion	74C %
Thailand	intensive	Feed source	Cassava only (main feed)
		Food conversion	FCR 1.3
China	intensive	Feed source	Wheat grains extensive at farm/CH cf livestock feed wheat
		Feed source	Livestock feed soy instead of soybeans at farm US
		Feed source	Soybeans at farm US only (main feed)
			Shrimps and Prawns
China	extensive inland	Fertilizer	Removed urea and TSP
	semi-intensive	Feed source	Wheat only (main crop)
	inland	Feed source	Replaced wheat grain organic CH by livestock feed wheat
		Fertilizer	Added urea and TSP (50-50)
	intensive inland	Feed source	Replaced wheat grain organic CH by livestock feed wheat
		Feed source	Wheat only (main crop)
	semi-intensive coastal	Feed source	Wheat only (main crop)
	intensive coastal	Feed source	Wheat only (main crop)
		Feed source	Soy meal instead of husked nuts
		On-farm energy	Change on farm energy to be same as Thailand
Thailand	intensive coastal	Feed source	Replace soybean meal Brazil at farm by soy meal

CH = Switzerland; FR = France; PH = Philippines; US = United States.

Results

Most of the results for our alternative models differed relatively little from their baseline counterparts (Figure 2.10). Of the 180 comparisons that were made, 113 (63%) were within ± 10% of their baseline value. Given that these comparisons were chosen as those most likely to be sensitive to our assumptions, this is encouraging.

There were, however, some notable deviations. The most striking of these concern assumptions about on-farm energy use in China for shrimp and prawn farming. Using energy-use values equivalent to those used for Thailand reduced impacts on OQWWRW QZSW[OObVUS RZOWDQb OR energy demand by between 50 and 60% over baseline estimates. Other comparisons for shrimp and prawn farmed were very similar to one another.

For tilapias, the only major deviations occurred with respect to estimates of land occupancy for intensive farming in China, which increased from between 110 and 140% with altered assumptions about feeds. For carps, changed assumptions concerning on-farm energy use in India reduced SabW[OSa]T OQWWRW] OR QZW[ObQVUS gP between 50 and 60%. A large (50%) increase in estimates of land occupation also occurred when feed supply assumptions were altered for intensive carp production in China.

Overall, we conclude that our baseline models are generally robust and are not overly sensitive to []R SZ aca bW]a :Q][] eWbS RWUa]T bSa SdS WaWQOb SaaWbWSa]R exist and can markedly affect results. This helps point towards those areas for greatest immediate attention. Improving estimates of on-farm energy use in emerging economies, developing new process descriptions for crop production in developing countries and improving data on the exact feed sources used for aquaculture are particularly important.

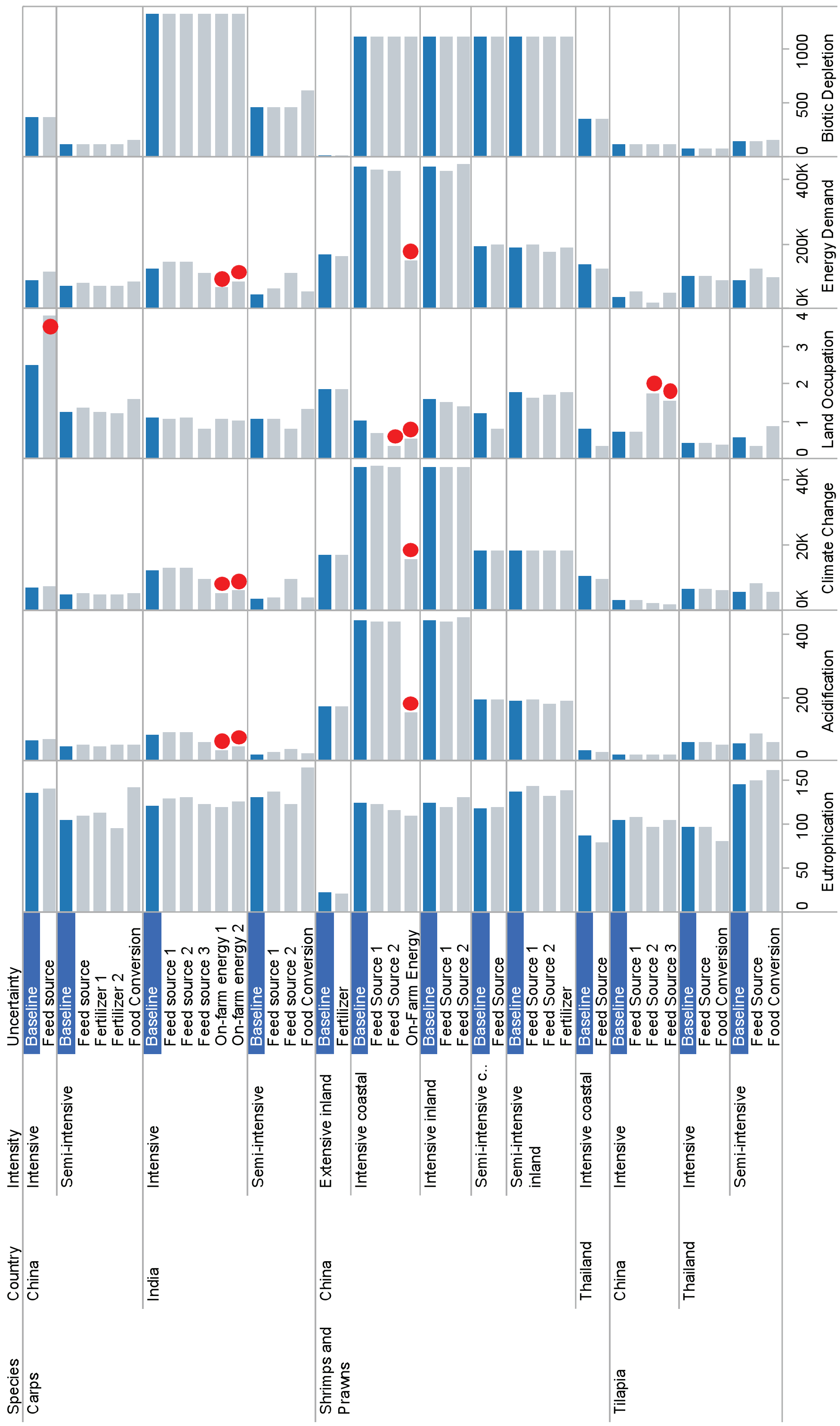

Species
Country
Intensity
Uncertainty
Carps
China
India
Shrimps and Prawns
Thailand
Tilapia
Intensive
Semi-intensive
Extensive inland
Intensive coastal
Intensive inland
Semi-intensive c..
Semi-intensive inland
Baseline
Feed source
Feed source 1
Feed source 2
Feed source 3
Fertilizer 1
Fertilizer 2
Fertilizer
Food Conversion
On-farm energy 1
On-farm energy 2
Feed Source 1
Feed Source 2
Feed Source 3
On-Farm Energy
Feed Source
Eutrophication
Acidification
Climate Change
Land Occupation
Energy Demand
Biotic Depletion
0
50
100
150
200
400
0K
20K
40K
1
2
3
4
200K
400K
500
1000

Figure 2.10: [illegible]

[illegible]

As well as exploring the sensitivity of our results to model assumptions and parameter estimates, we can also ask how our results compare with those from other studies. We can get some insight into this question by comparing them with those of the more detailed LCA studies that have been undertaken for selected systems. Table 2.8 [illegible]

In drawing these comparisons, we stress that our system boundaries exclude medicine, seed [illegible] other processes. In contrast, the data we are comparing them with come from cradle-to-farm-gate LCAs, which include some or all of these processes. These considerations, combined with the high degree of complexity and choice available when constructing LCAs, render ‘like with like’, or benchmark comparisons with other studies impossible. The value of our study is in the comparative analysis across systems globally, using a consistent, albeit coarse approach. The comparisons below are offered, therefore, to stimulate debate, rather than validate estimates.

Comparing data from these studies with our own [illegible] considerable variation in the level of agreement across impact categories and systems. While broadly comparable, estimates from our four salmon studies for energy use, climate change [illegible] published by Pelletier and co-workers. In contrast, our estimates for eutrophication are consistently higher. Examination of the inventory data for these studies show that our input values for feed, on-farm energy use, and nitrogen and phosphorus emissions are very similar to these earlier studies. This suggests, therefore, that the discrepancy is largely due to the less comprehensive treatment of feed formulation in our study.

Table 2.8: Comparison of results from other published studies. All values are per tonne live weight of product. Data in [illegible]

Study	Source	Energy Demand (MJ-eq)	Climate Change (kg CO_2-eq)	Eutrophication (kg PO_4-eq)	[illegible] (kg SO_2-eq)
Salmon Norway	1	26,200 (23,300)	[illegible]	41.0 (66.1)	[illegible]
Salmon Chile	1	[illegible]	2,300 (1,520)	[illegible]	[illegible]
Salmon Canada	1	31,200 (22,300)	[illegible]	[illegible]	28.4 (13.5)
Salmon UK	1	[illegible]	[illegible]	[illegible]	[illegible]
Tilapia Indonesia	2	26,500 (33,300)	2,100 (2,010)	[illegible]	[illegible]
[illegible]	3	13,200 (215,000)	[illegible]	[illegible]	[illegible]

On a comparative basis the more detailed LCAs of Pelletier and colleagues rank the UK as being the [illegible] own analysis is much more variable. Again this may [illegible] various studies, but it may also be a function of how nitrogen and phosphorus emissions are treated.

For tilapia in semi-intensive systems in Indonesia, [illegible] are consistently and considerably higher than those of Pelletier and Tyedmers (2010), but the largest single difference is between the estimates of energy [illegible]

Discussion

Life Cycle Analysis in aquaculture is in its early stages and, of the few case studies available, most focus on salmon. This is, perhaps, unsurprising given the relatively dispersed and small, to medium, scale nature of much of the industry and the fact that so much of aquaculture production occurs in developing countries.

The objective of the analysis described in this section was to compare and contrast the global and regional demands of aquaculture for a range of biophysical resources across the suite of major species and production systems in use today. This complements the more detailed studies for production of particular species. By undertaking a broader scale scoping comparison we are able to identify more clearly, and on a standard methodological foundation:

1. How environmental impact compares across systems and geographies.
2. Which species groups or production systems are especially demanding on biophysical resources.
3. How environmental performance differs among countries for similar systems.

The distribution of absolute impact values shows where greatest attention should be paid for achieving environmental performance improvements.

In many respects, our results are broadly consistent with expectations. First, with explainable departures, such as for bivalve and seaweed culture, absolute impact levels correlate with overall levels of production. As a consequence, when one looks at the global picture in absolute terms, the impact of Chinese aquaculture, and carp culture in particular, stands out.

[illegible] species, system or country provide an indication of the potential for performance improvement. [illegible] comparisons between species cultured in the [illegible] differences, both in production practices where farm level choices and management may exert [illegible] farmers cannot control, for example, is the mix of energy sources used by a country to generate electricity, which has impacts on climate change and [illegible]

[illegible] differences in species and system choices and management practices, we have an indication of the [illegible] learning of best practice across the industry should [illegible] (productivity) gaps. It is perhaps unsurprising that the salmon industry shows least variation across both countries and impact categories (see Figure 2.8). The explanation for this almost certainly lies in 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. This suggests that similar research investments, combined with the right institutional, policy and market drivers, could lead to dramatic performance improvement in many other aquaculture sub-sectors.

We return to these issues when we consider the policy implications of this study. Before doing so, however, we explore how production in the aquaculture sector compares with that for other animal food sources.

Photo by Francis Murray
CHINA

3. COMPARISON

PHOTO CREDIT: The WorldFish Center

3. The environmental □□G:□□□:□A□□□□□□:□ □□□ production systems: How does aquaculture compare?

"there isn't any more land. We are exploiting the available production factors to a great extent. The environment is becoming more polluted. Increased production has to come from high-yielding farming." (Jacques Diouf, 2006 in *Flachowsky, 2007)*

The growing demand to consume animal products continues to rise. This is particularly true of the RSdSZ]□WU□ e]ZR eVS□ SlPSS□□ %-,$□ RO□ 2005, the consumption of terrestrial animal [SO b□ WSOaSR□]T□ %(□ %□ b $□ -□ YUWbQOWa □□SRWQS□]b WQSOS□cTVS□]b □ □ □ □ □ WU gPQO□ &$□ $ 2□7□ □ &$$-O□ □ H9□ □ □W&WW U□□ EV demand for animal products risks increasing undesirable impacts on the environment.

Livestock meat production can be grouped into two categories: ruminant species (such as cattle, sheep and goats) and monogastric species (such as pigs and poultry). Generally speaking, ruminant species are either produced intensively or in extensive grazing systems, while monogastrics are produced W□□RWb]OZ□□]RcabWOZZaSa□ □ 2□7□ □ &$$-O□ □ □ Four production systems, however, dominate bVS□ aQb□.□ OhWU□ OWSR□ [WSR□ SWRSR□ OaO□ combination of rain-fed crop and livestock farming), irrigated mixed, and landless/industrial systems (Steinfeld et al., 2006).

These species categories and production systems place different demands on ecological goods and services. For example, the traditional monogastric production systems for chickens and pigs are considered overall to have negligible environmental impact due to their extensive nature, limited manufactured feed demand and their dominant position in small-scale household oriented production systems. Intensive systems for pigs and poultry, however, lead to greater impacts, although they are less damaging than beef production (see below). As detailed in Table 2.2, aquaculture production systems also fall into several categories: extensive, semi-intensive and intensive. As with livestock these systems differ in the environmental impacts they impose.

Because livestock farming is more established as a major food production sector its impact on the environment has received more attention than aquaculture. In recent years, for example, a large number of studies on the environmental impact]T□ ZWdSa□ VdS□SB□ □]R cQSR□ 2□7□ □ &$$-O□ □ □ In 2006, however, an early effort to compare the environmental costs of aquaculture with those of livestock was undertaken by the FAO (Bartley et OZ□ □ □ &$$V□ Q][□ODWa a□ O□ W[□bO b]b help ensure that the animal food production sector develops in ways that use available resources wisely. As the authors of the FAO report point out, there is thus "a need to present a balanced picture of the environmental costs of all food-producing sectors and to formulate environmental policies that deal with the impacts of all sectors... So long as this balanced picture of environmental costs is OPaS b□]ZWQgSaR]b□SxSQbOT[W□U□SOZWWSaVSb □□WQSa]T]]R □ □]R cQba□ QO]b□SxSQbVS□SOZ□ Qa of their production, especially for ecosystems and communities, and both the public and government receive very mixed messages [regarding policy options]". (ibid., p.5).

Although largely focused on methodological issues, the FAO study provides some initial comparative c RS abO RWU SS eS WRgx a[O WhSVS b w RWUa]T bVS 27 bcRg OZU eWbVS available literature. We stress, however, that the methodological foundations for such comparisons remain under-developed and appropriate data are sorely lacking.

Comparative analysis of impacts

DC GHDC O C H

An important (and perhaps the clearest) perspective on relative impacts of animal-source food production can be obtained by considering TSSR Q]dSaW] ObW]a][7 bVWaS a SQbWdSaVw come out well because, in general, they convert more of the food they eat into body mass than livestock. Poultry for example, convert about 18%]T VSW]]R OR WUaQPb % / WQ]bOab aVw Q] dSb QPb $ 9Oa OR 9OZeO &$$- cQV]TWaWTS QS SxSQb VS OQbVOb aV O poikilotherms (cold blooded) and do not expend energy maintaining a constant body temperature. Moreover, because aquatic animals, especially w aV SOVgaWQOZZg] aSR P VS Q_bWQ medium few resources are expended on bony skeletal tissues. As a result the usable portions

]T waV O WUVQ][OSR]bVa S]TSbSabWO O W[OZa SaQWOZZgZSQObb]T &$$][7 such principles, therefore, it would appear that the S dW [S bOZ S[R Ra]T waV]R cQbW] eWZZS lower. This certainly appears to be the case when Q][OWU waV eWbSST]] Y]]YSR ObW another way, the production of 1 kg beef protein requires 61.1 kg of grain while 1 kg pork protein S_cWSa , YUR % YU]bSW S_cWSaZSa than 13.5 kg (calculated from White, 2000).

Of course, for species such as mussels and oysters that grow on the natural productivity of the ecosystem, the question of food conversion SWQWSQg SR][Sa []b ZWc UV cZWYSZg to be a mainstream food commodity, in many respects, these animal food sources are among the most desirable from an ecological sustainability perspective.

A complementary perspective on the question of SWQWSQgWa]dWRSR Pg D[WZ &$$%V]Q][OSR TSSR OR]bSW Q]dSaW] SQWSQWSaTaSdS OZ animal based foods (Table 3.1). As with other O OZgaSa waV Q][S]b OTd] OPZg Q][OSR eWb pork and beef, and are broadly comparable with poultry and dairy products. With these superior conversion ratios aquaculture may become a aWUWQOb Q][SbWb]b []]UOabWQ SaWSW regions such as South East Asia and sub-Saharan 2TWQO ObZSg SbZ &$$

Table 3.1: A]bSW Q]bS b]T [OX] OW[OZ]RTa O R TSSR Q dS aW] STWQWSQWaST bVSW]R cQbW] OaSR] 7Wc S)]T [DWZ &$$% ZOW]4OZOSSR Q]dS aW] SQWSQWSPOaSR] OdS OUSFD TSSR S_cWS[S baW% - -

Commodity	Milk	Carp	Eggs	Chicken	Pork	Beef
Feed Conversion (kg of feed/kg live weight)	$	1.5	3.8	2.3	) -	%&
Feed Conversion (kg of feed/kg edible weight)	$	2.3	4.2	4.2	%$	%
Protein Content (% of edible weight)	3.5	18	13	20	14	15
A]bSW 4] dSaW] SQWSQg	40	30	30	25	13	5

[illegible] 2000 (Delgado et al., 2003) to 45% in 2005 (World Bank, 2006) and estimated to be 56% in 2010.

Species such as salmon are particularly dependent, because the main source for several essential fatty [illegible] aquaculture and the growth of the aquaculture sector that is believed to have forced the livestock sector to search for other protein substitutes in [illegible] the use of animal offal in livestock feed to reduce the risk of mad-cow disease, has also increased pressure to produce vegetable protein for animal feed. Recent estimates by the Fishmeal Information [illegible] pigs and 12% for poultry (Table 3.2).

[illegible] quarters, one must also recognize that substitution with suitable land-based crops brings with it demands on land and water use and perhaps the production of a nutritionally inferior product to its wild counterpart (Karapanagiotidis et al., 2006, 2010). As production methods intensify, and the animal derives more of its nutritional requirements from crop-based feedstuffs, total lipid levels tend to [illegible] less desirable omega-6 fatty acids.

Despite such concerns, however, the high cost [illegible] likely to drive the current trend of increased use of crop substitutes in animal-source food production. Soybean meal use rose from around 20 million [illegible] increases in its use seem assured.

Table 3.2: [illegible] 2010)).

	2002	2007	2008	2010
Ruminants	1	-	-	<1
Pigs	24	24	31	20
Poultry	22	[illegible]	-	12
Fish	46	65	[illegible]	56
Others	[illegible]	4	1	12

[illegible]

With respect to environmental emissions, the livestock sector is often characterized as having a “severe impact on air, water and soil quality because of its emissions” (de Vries and de Boer, 2010). It has also received considerable attention as a contributor of greenhouse gases (Steinfeld et al., 2006). Extensive livestock systems contribute indirectly through land degradation and deforestation, while in intensive systems, the application of manure that emits methane and enteric fermentation directly contributes to climate change. All this said there is considerable variation among meat production [illegible] With the exception of poultry, however, it seems likely that aquatic animal products have rather less impact than other animal production systems from an environmental emissions perspective. This conclusion is further supported by the data on nitrogen emissions shown in Table 3.3, which show that, while emissions of waste nitrogen and phosphorus vary considerably, aquaculture systems generally perform well compared to beef and pork.

Table 3.3: Summary of data on nitrogen and phosphorus emissions for animal production systems. Data for beef, pork
O R QWQYS O SRWdSRT 7ZOQya Yg &$$%A] abY &$$ 5ObOT waV OS RS WSRT] [bWabcRg

Commodity	Nitrogen emissions (kg/tonne protein produced)	Phosphorus emissions (kg/tonne protein produced)
Beef	1200	180
Pork	800	120
Chicken	300	40
Fish (average)	360	102
Bivalves	&	&-
Carps	(%	148
4ObwaV	415	122
bVS waV	((	153
Salmonids	284	%
Shrimps and prawns	$-	,
Tilapia	)-	% &

. 7C 5 H

E Q][OS ZRaS eS]]Yb]c Rb]VS ZR S_cWSR]b]R cQS % $]T SWZS aW]R cQbO R
compared this with data provided by de Vries and de Boer (2010) who summarized the land required to produce 1 tonne of edible beef, pork and chicken (Table 3.4). These data suggest that land use demands are broadly comparable.

Table 3.4: Estimates of land demand (direct and indirect) for animal-source food production.

Commodity	Yield tonne/ha (edible product)
Livestock	
Beef	$ &(q $
Chicken	1.0 – 1.20
Pork	0.83 – 1.10
Aquaculture	
Bivalves	0.28 – **20**
Carps	$ % q $ -$
4ObwaV	0.20 – 1.23
bVS waV	$, q $
Shrimps and prawns	0.34 – 1.56
Tilapia	0.15 – 3.30

Alternative approaches to calculating land use, however, come up with markedly different conclusions. 3OaSR] O OZgWa] T 3WWa 4]ZP WOc[[a WhSRWB]% S[TZS]]Ya &$$ QZRSR that "the landscape directly affected for cattle production is several hundred times greater than it is for production of the same amount of food in salmon aquaculture". Such contrasting conclusions serve to illustrate the complications of comparative analysis and point towards the importance of adopting a standardized methodology that is explicit about the basis for calculation.

Environmental impacts associated with land use will also vary with the ecological values of land used, for example grasslands, wetlands, mangroves and seagrass beds all providing different ecological services. More detailed analysis is required to account for these differences.

6 7I G5 H

=WdSQY]R cQbW] WaWaWaQb aS]TSaVeObS resources, with an estimated 8% of global human water use devoted to the sector. While around 2% is consumed through direct consumption the majority []S Vb -, WaOWZga]QaWOR eWbS production of feed crops (Verdegem et al., 2006). In intensive systems where livestock are concentrated in feedlots, water use is particularly high because of the high demand for concentrated feed and additives that require an increased production of raw materials such as cereals and oil crops (Steinfeld et al., 2006). Current published estimates suggest that producing 1 kg of edible beef requires 15,500 l of water compared to -$$] Z %T YUSRPS WQYS]HZR 3 Y &$%$ O R dWSaSeSS %%)$R Q $$$] Z %T YUaWT

There are, however, a number of issues concerning calculations of water consumption in food production bVOb [OYS SdOZc OR Q][OWa a RQZb]7 example, much of the water used to produce crops is uUSS v ObS VO RZSv eOb W wSbObWW OR]b surface water from lakes or rivers is used (see Molden et OZ &$$RSUS[G OR]a [O &$$- S SSbW] is, of course, irrigated crop production.

Another complication arises because the bulk of global aquaculture production is from semi-intensively managed ponds. The majority of these ponds tend to PS ZZSROR ROWSR]QS S gSO eWbeOb ORSR periodically to counterbalance water lost through seepage and evaporation. While one might consider this water use, because it is needed for physical support, to supply dissolved oxygen and for dispersal and assimilation of wastes, one could also argue it to be a form of water storage and that seepage losses from ponds represent an ecosystem service, serving to recharge groundwater reserves. The latter argument only holds, however, if seepage is uncontaminated by nitrogen and phosphorus wastes and preliminary experiments suggest that nutrient uptake by sediments is enhanced as seepage water moves through the pond bottom interface (Verdegem et al., 2006). Of course, coastal aquaculture has a further major advantage in this respect in that it makes use of seawater.

Feed associated water use in aquaculture comes mainly from the production of feed crops and grains.

Box 3.1

3]] Ya&$$Q[OSRZOR caS Pg aOZ[] TO[WUOR cattle rearing in the following way:

- The edible meat yield from an Angus steer is 42% of live weight
- EVS gWSRT aOZ[] wZSa WO] f W[OSZg$] TbVSZWS weight
- A salmon farm producing 2500 tonnes of live salmon e]c ZRac Zg%&)$ b Sa] TSRWZSwZSa e WWQWa equivalent to 5411 steers weighing 550 kg each.
- :bVS AQQWQ?]bVeSab] SQQS]TQQbWSZg OQUSR OabcSac]ba] SQ e T)[ ]bVa)OW[OZ month units or AMUs) and it takes approximately 30 months to produce a marketable steer.
- 5411 steers require 162338 AMUs or 8658 acres (3504 hectares) for 2.5 years.
- The substrate under well sited salmon farms chemically remediates in six months to a year and biologically remediates in another year showing a full return of the normal benthic community.
- :Q bOabWbVS AQQWQ?]bVeSabWbWZYSVcRSRa or a thousand years for the pastures to return to the original old growth forest.

	Edible Portion (kg)	Yield	Footprint (ha)	Remediation Time (y)
Salmon	1,250,000	0.5	1.6	2
Angus Beef Cattle	1,250,000	0.42	-,&	200+

FaS QaQWSR eWbaW[SOZ OR aV]WZR QeWb]bS feed sources (e.g. meat and bone meal) are negligible SRSUS[OR]a [O &$$-

Conclusion

Because vegetarianism is unlikely to ever be a voluntary choice for the overwhelming majority of people, as UZ]POZ SPO R]T]]R WSa RWU eOgab PS []S SQ]Z]UWQOZZgWST Q]ac[S a]T QW[OZ]RT eZVZ

5ObO WS ZWb S acOZZgST]b AW[S bSZ SbZ &$$Oac[SaV VObVS]R cQbW]]T % YUSTS_cWSa %$$ $$$ ZSb]T SaS Uc Sa SS[O bZSWW]bROSR
EVS HZR 5SdSZ[S b S] b]dWSa []S SQSb Uc Sa ObS]T eee eSb]]b Wb]U QZWSOb OR WSQb eSb Qac[S bW]

become increasingly important. Indeed, many would argue that it is essential if the ecological demands of our food production systems are to remain within acceptable bounds (e.g., Rockström et al., 2010). Comparisons indicate that dairy foods can be [illegible] come close. In contrast, pork production converts [illegible]

Examining these issues from a nitrogen budget perspective Smil (2001) concludes that American [illegible] the feed energy per unit of lean meat compared to the country's broiler population. As a consequence its production also requires 5 to 6 times as much nitrogen fertilizer to produce the requisite feed. Smil estimates that the United States would have to use less than half its concentrate feed, and hence less than half of the N-fertilizer used to grow it, if its protein-rich diet were composed of equal shares of [illegible]

Beyond the clear issues concerning beef production, however, analyses indicate that there is no simple answer to the question of which animal production system has least environmental impact. Each system makes different demands on environmental services and the appropriate trade-offs between them relative [illegible] products have some advantages, not least the [illegible] animal, but much depends on the species, systems and management practices.

Available analyses also rarely make reference [illegible] associated with the various intensities and methods of production used for the various animal products. This is clearly an important consideration that bears further examination, particularly because, with the high demand put on resources, there is a trend in intensifying animal farming rather than extensifying [illegible] between alternative approaches. Extensive systems require more land and are more dependent on ecosystem services for their productivity (freshwater, [illegible] [illegible] these trade-offs in order to better manage and mitigate environmental impacts. Pathways for future development of these sectors will clearly have a [illegible] for management interventions.

In this context it is important to appreciate that, in contrast to livestock, from a biophysical perspective there remains considerable scope for aquaculture expansion. Limits to land availability mean that livestock production will only intensify, while aquaculture will both intensify within the existing area under production and grow into new areas.

Another issue one must consider is the potential for integrated agriculture-aquaculture systems (e.g., poultry and carp) which, although not examined using life cycle approaches, have been considered [illegible] a trend away from such systems in China, the traditional home of integrated farming, due largely to economic drivers, and the inability to recover value from the ecosystem services they provide. A new look at such systems using LCA tools is warranted, but above a threshold size such systems may [illegible] limit the growth potential of these integrated systems.

Finally, while not a focus for this study, and not really amenable to analysis using an LCA framework, it is also important to recognize concerns over biodiversity loss. The loss of biodiversity is a [illegible] and tropical deforestation for conversion to pasture (Brown, 2000). But, while the scale of habitat loss in the livestock sector, with massive conversion of habitat to extensive grazing, far outweighs that of the aquaculture sector, aquaculture development can still threaten biodiversity. These threats include habitat [illegible] 2006), use of inland wetlands for conversion to ponds, as seen in India and Bangladesh and risk [illegible] also Section 4). Conversion to ponds in wetland areas such as mangroves in particular can lead to loss of ecosystem services, including loss of carbon sequestration properties. For the most part, managing these threats will require local studies coupled with sound planning processes.

4. LOOKING FORWARD

PHOTO CREDIT: The WorldFish Center

4. Looking Forward

With the stagnation or, optimistically, only limited growth in wild catches any increase in demand for [illegible] al., 2003; Bostock et al., 2010). But how big is the aquaculture sector likely to become and what are the environmental implications? In this section we [illegible] of increased demand for aquaculture products and how are these likely to evolve in the coming years. [illegible] to overcome some of the environmental constraints to meeting this demand. Finally, we examine published projections for how production by the sector may evolve and examine the implications of such growth for biophysical resource demands.

Demand drivers

[illegible]

[illegible] production. At present, however, world population [illegible] production. As a result, increased demand resulting from population growth is currently a relatively minor [illegible] and other animal source foods is wealth (Speedy, 2003)[8].

Increases in per capita consumption of animal source foods are fastest where food consumption levels are low, wealth and urbanization is increasing rapidly, and domestic supply is also increasing [illegible] in the emerging economies of Asia. In China, for example, the annual rate of population growth is currently around 0.51%, adding an estimated 6.6 million people to its population each year. And, although the growth of Chinese aquaculture production is many times this rate, Speedy (2003) estimates that, as a result of increased personal wealth, demand is likely to increase from 25 kg per person per year in 2005 to 35 kg per person per year by 2020. And it may not just be wealth. Although increased wealth is closely associated with increased urbanization, urbanization per se may also contribute to increases in animal source food [illegible] suggests that changes in food preference driven by urbanization alone has in the past accounted for an [illegible] urbanization affects animal food consumption rates independently of income. In contrast, however, Stage et al. (2010) present data from India and China and cite studies from Vietnam and Tanzania indicating that families with equivalent incomes in rural and urban settings do not differ in their consumption of animal source foods.

With growing wealth and urbanization as key [illegible] the largest growing market over at least the next decade to come from emerging economies. More generally, global trends in urbanization, which generally correlates with increased wealth, suggest [illegible] increasingly dominate. By 2025, almost six out of ten people on earth are likely to live in urban centers, and over half of these will live in the cities of [illegible] urban dwellers in the developing world, compared [illegible] respectively. This represents a shift in numerical [illegible]

[8] In economics parlance the demand for many animal source food products is 'income elastic', meaning that income growth increases demand. Indeed, some animal source foods can even be considered luxury goods, meaning that a 1 % increase in income will lead to an increase in demand of more than 1 %.

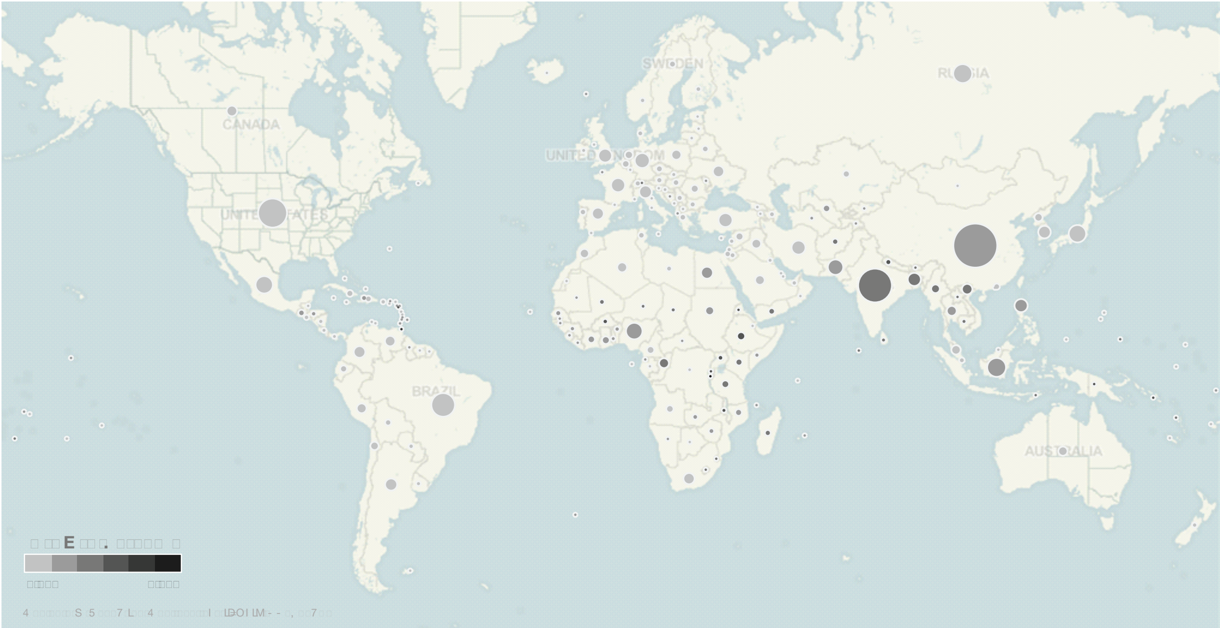


Figure 4.1: EVS SZOlbdaWhST c PO] cZOlb]a] TQ c bWSW&$$- RWOSR Pg QWZSaWSb O R bVS] XSbSR O cOZ average rate of growth in urbanization to 2050 (indicated by shading). Data extracted from UN World Urbanization A]a SQa &$$- CSdWa] F?&$%$

living in the developing world today to 80% in 2030. 3g &$)$VSb]XSQbW]a S] T) %WZZW]WbVS less developed regions and about 1.1 billion in the developed world. Figure 4.1 summarizes the current levels of urbanization and the projected annual average growth rate to 2050.

A G7A7 IDGH7C EGD I 7IIG I H

Fish product attributes must also be considered in the context of other foods. Growing recognition of bVS VSOZbVPS Sba]T waV Q] ac[bW] T Sf Q ZS can alter patterns of demand relative to meat products for some consumers, although the overall importance of health information may be relatively limited (Shroeter and Foster, 2004). Conversely, Q] QS a OP b [SQcg ZSdSZaQ W]d]c awV such as salmon and tuna, have depressed demand in some markets (Oken et al., 2003).

Product issues for other foods, also affect demand. For example, Egypt has experienced a substitution effect, in part a result of what happened to the]c Zbg SaQb]cAZbg Zba WUWQOb OYSbaVOS OTS &$$ SQPaS]TSDa]T OdWOx eVWQ caused some 30 deaths in the country (WHO, &$%$ W[WZg WWWSVS b OdWO]c bP SOY led to a shift in consumer preference away from]c Zbg]eO Ra SST] Y OR aV OgSZc &$$ Future zoonotic or other animal health issues,

widely anticipated by experts due to increasing WbS aWQOW]]T]R cQbW] [Sb]R a OR ORS liberalization, may have dramatic effects on markets for animal derived foods. Depending on where disease strikes this may either stimulate or reduce RS[O R]T aV

In the coming years we can expect demand side processes such as seafood awareness, food safety, quality convenience, sustainability and ethics to become even more important. Trends will be driven not only by developed country consumers, but also by the growing middle class in the developing e] ZR WZS baUWQO QS]TaQV aWSa] bY decades to appear among developed world consumers it seems likely that the attitudes of wealthier consumers in the developing world will evolve much faster. Consumer trends in major Asian markets, particularly China and Southeast Asia, are currently poorly understood, but will have a major WxcS QS] Q_OQZb S]R cQbW] S Ra

For developed countries, while overall demand seems unlikely to change markedly, the value of purchases is expected to rise through value addition 4SaSg &$$-R Q_OQZb S]R cQa WZZ continue to substitute for both expensive and cheap eWZRaV]R cQa SSa] T S[ZS SdSWRSSbOZ 2010). The rise of supermarket chains in Asia, and elsewhere in the developing world, will also have major implications for the many small producers currently engaged in aquaculture production (Reardon et al., 2010).

OECD countries represent a relatively small but nonetheless important sector of the global market for aquatic foods in view of their purchasing power and demand. Increasingly, they not only consume their own farmed aquatic foods but also those of many developing countries (OECD, 2008, 2010). Much of the production of farmed GWSb[Sa S baWSR QQab] TS[ZS OWaSR at EU member states where it has gained rapid market penetration as a cheap substitute for the WQSOaWUZgf S aWdS[WS eV WboaV bORWb]OZZg ac ZWSR R][Sa bWQaVSWSa bWSR QQab Wa often promoted by supermarkets and sold as highly]wbOPZS QS WSQS]R cQb aQV OaSO]R WSa SOR]b Q]]Y RORSR ZSab SH QO QZa expect other inexpensive farmed species such as tilapia to penetrate wealthy western markets provided the following conditions are met:

- Fish continues to be considered as a healthy option to other animal food sources
- EORS]ZWQWSab ORQbOT[SR aW Q]bWcS to be liberalized
- Developing country aquaculture producers can continue to meet wealthy country food safety standards
- Dc S[O YSa Q]bWcS]b QQbc S aUWQO b SQ]][WQ PSvb]T bVS dOZcQWa R thus continue to develop and market value-added convenience products
- Farmed aquatic foods can be produced and brought to markets in environmentally sound ways
- Pricing continues to make aquaculture a competitive animal source food.

Price

5S[O R]T aW R S Ra]VS WQS VS]R cQb b]aRS aW]R cQb S eOb VS economists term own-price elastic, meaning that when the price falls, people buy more. However, WbWab]Zg QVUSa WS WQS aW VOb matter, but also the changes in the prices of competing (substitute) food products. The trend in prices over the past 15-20 years has been for T]R aW WQSab WS VOZbV]b]T SdSOZ aquaculture products, such as salmon. In contrast, red meat prices have fallen by approximately 50% over the same period. Although data are scant, it would appear that the prices for capture waVS WSa]R cQb OdS QSOaSR cbPVa S]T aquaculture products have decreased. Salmon and shrimp for example, previously considered VWUV dOZc]R cQb SO]e aWUWQOb Zg Z]eS W price, and have broadened their consumer base tremendously.

Although predicting how absolute and relative WQSa]T [SOb aVw OR [WZY eWZZ Sd]ZdS b O Q] ac[S QWQS WR QZb][Sa _cO bWObWdS projections have been attempted. The Fish to 2020 analysis by Delgado et al. (2003) provides perhaps the most comprehensive recent attempt. This analysis concluded, as one would expect given urbanization and economic growth trends, that China and India will lead the global growth in S QOWb Qac[bW] VW% R $O - S year, respectively. Other developing countries of Southeast Asia and Latin America are in the middle rank with 0.4 and 0.5% growth respectively. The rest of the world is likely to see static or declining per capita consumption. Supported by the World Bank, efforts are now underway by to update these projections and forecast trends out to 2030.

Environmental constraints to sector growth

The last decade has seen a dominant narrative arguing that aquaculture growth will be constrained by local environmental factors and the carrying capacity of the environments where production]QQc a 9S[Z %-- :/ H% --, Wa dWSe has been re-enforced by evidence from several intensive production sectors. We have seen major disease outbreaks in the prawn and salmon WRcabWSa ZS7USZ %-WeQOH &$$)/ baYQc et al., 2000), evidence of genetic pollution and transmission of parasites and disease to wild salmon stocks (Pearson and Black, 2001), and habitat destruction, eutrophication and antibiotic]ZZbW] W[O g gabS[a [S6 a] %---

However, while these concerns are undoubtedly legitimate, there are signs that such problems OS Q][[ ]Zg Q]y SR]b VS SZg bOUSa]T WS aWQQW] OR QO SP]dSQ][S Oa VS SQb matures (Asche, 2008). Reduction in pollution eWb]UO WQ tSa S]b S]TaV]R cQSR in the Norwegian salmon industry, for example, appears to be related to industry growth (Tveterås, 2002). With the development of new vaccines, the absolute volume of antibiotics used in Norwegian salmon production also declined markedly despite continuing production increases (Figure 4.2). i

In most cases there are two drivers that stimulate an aquaculture sector to address environmental Q] abOWa aQVS &$$, S abEWVS SRcQbW] W]R cQbWgWbR SY QS]wb VObSacZb]T the negative feedbacks from the effects of a RSbS W]ObWU]R cQbW] SdW [S b] aW health and increased risk of disease outbreaks.

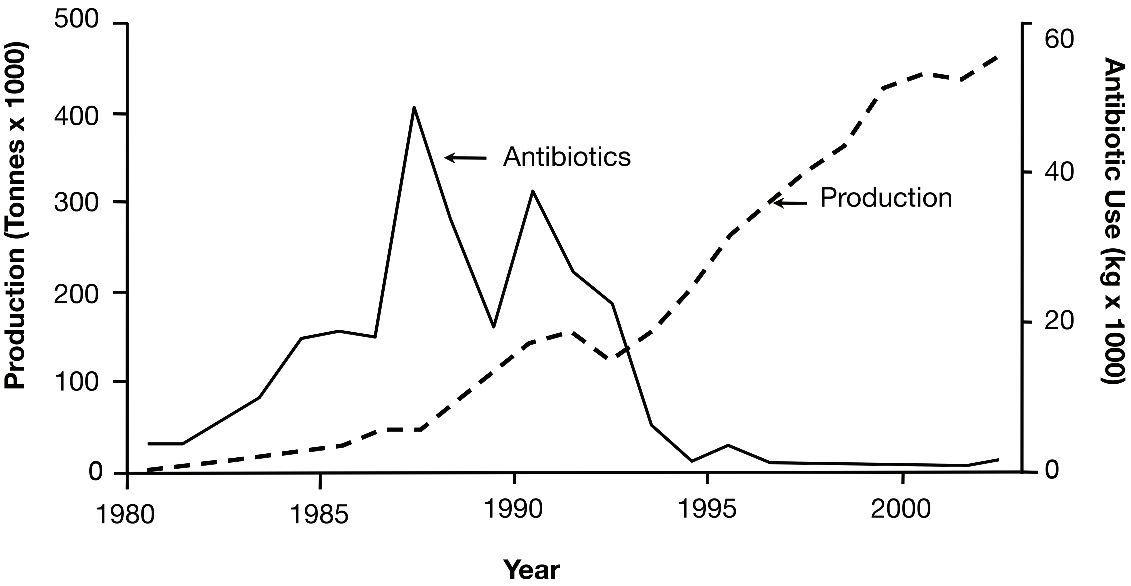


Figure 4.2: The rise and decline of antibiotic use in the Norwegian salmon industry compared to the trend of rising production (adapted from Asche, 2008).

The second is government regulation, which is essential for limiting the impact of those effects that do not affect the productivity of the industry WbSZT S UZW[WbZZO ba W$TS ba WR driver, currently favored by NGOs such as WWF in western markets, is to move the sector towards environmental improvements by raising retailer and consumer awareness of environmental impacts.

5 WdS P]wb bSWaWQW] Oa]Zg SB possible because prevailing economics have allowed increased reliance on nutritionally complete feeds and energy-intensive technologies, such as aeration and oxygen injection. These production innovations have depended largely on private sector investment. This trend is likely to continue. For many parts of the industry, we are likely to aSS QjWROPZS QSOa WS aWQW] WS coming decades and new approaches for handling environmental concerns.

S WdObW] VOb Wa Qb UZQS ObWQZZg attractive from an environmental standpoint, is the development of Recirculation Aquaculture Systems (RAS). Such systems offer a high degree of control over environmental variables, and high levels of biosecurity and waste treatment. They are of particular interest for locations close to consumer markets. However, while the virtues of urban RAS have been promoted for some time (Costa Pierce Sb OZ V&$$)OdS b g$bdZZVSW]bS bWO RAS are highly complex with high capital and operational expenditure and have not always] SObSR SZWZP]wbOPZg SgV QZWdSWU energy demands and carbon footprints although these could be reduced by use of non fossil fuel energy sources (wind energy, solar, etc). With little take-up of the technology, there is minimal incentive or revenue stream for suppliers to invest in the necessary development and manufacturing capacity for standard mass-produced low-cost systems.

HVWZSW aWQQWO]]TVS QS bZg]R O b systems will undoubtedly continue, there is also interest in using the abundant areas off-shore to reduce environmental pressure. Cage (synonymous with ‘pen’) systems dominate the production]T WU dOZc [OWS aW aSQWSa SQWOZZg W Europe, North and South America. As a result of climate change, and competition for near-shore coastal areas (with accompanying concerns about their local environmental impact in some parts of the world), some investment has been made in the design of offshore cage systems able to withstand the extreme wave and wind climates associated with more exposed environments. Such systems rely on stronger materials, more robust designs and integrated cage and mooring systems that allow cages to be submerged below the water surface to avoid hostile weather conditions (Beveridge, 2004; 8 pbbc[O R SdSWRS &$$ Zb]c UV VSaS technologies will continue to be developed they OS ZWYSZgSab Zb WQg VaUWQOb SfO aW]]T production in view of the high capital and operating costs and the limited market for the high value TO[SR aV VOb QO S]R cQSR WaQV gabS[a

Feeds

5Sa VSbVS S R W S aWQQWO]]T]R cQbW] methods the majority of aquaculture production is still derived from extensive and semi-intensive aquaculture of omnivores and herbivores. There are powerful economic incentives to intensify production, however, and we can expect to see increasing dependence on feeds. This brings with it concerns about the resultant demands on biophysical resources and impacts on food security.

The bulk of aquaculture feedstuffs are of crop] WUW WhS]ga SVbO R Q]R cQbW] makes substantial demands on ecosystem services (Tilman et al., 2002). Using such materials b SSR aV OR VaW[[Og ZS bRQ][SbWb] for use of the same materials for human food or bio-fuels, with consequent implications for prices and affordability. It may also lead to changes in crop production (e.g., change in land use from growing human food staples to production of aquaculture feedstuffs). Demand on ecosystem services may be further exacerbated by the global trade in the feeds and feedstuffs that sustain aquaculture production. For example, the Egyptian aquaculture industry uses an estimated 1 million tonnes of aquaculture feed per annum. All feedstuff ingredients are imported, primarily from North America, which may add to the overall environmental cost of production.

Other important aquaculture feedstuffs include ubOaVv aW aV[SOZ OR aV]WZ SWdSR]T WRcabWOZR ObWa OZ aWS WSa RO eSZg caSR]b abOW VaW[OR QOWd]c a aV production (Tilman et al., 2002). Fishmeal and oil are particularly important for these species groups because they require long-chain fatty acids that are only found in high amounts in these feed sources. EVS S S QQS a VOb VSaS SSRaV aVS WSa aggravate food security in parts of the world by RWdSWU aW]T RWSQb VO Q]ac[bW]]b aquaculture. It appears, however, that, while there is considerable scope to increase the proportion of TSSRaV]T VO Q]ac[bW] WebW S WQO the situation is more ambiguous in Asia where use of such feedstuffs in small-scale aquaculture disadvantages some but has considerable ZWd SZWVS Swba]T]VS a 9bVUb OR Hasan, 2010).

Notwithstanding these concerns the track record of innovation to deal with these resource constraints is impressive in those parts of the aquaculture sector where industry competition has driven STQWSg QSOSa WaWab SdSR WS salmon industry where production costs have declined dramatically. In Norway, for example, production costs have decreased by 60% in the last 20 years. Although reductions in labor demand account for a substantial proportion of this, technical innovation to improve, for example, TSSRWU SQWSWSaWZaWUWQOb cRO aWUVS Sb OZ &$$SOaWU WSSQ aW[SOZ OR aV oil inclusion in aquaculture feeds and limiting their caS]b aObS]]R abQY OR uWS v SSRa are among the most immediately implementable abOSUWSa]T cTbVS SQWSQg W[dS[S ba (Tacon and Metian, 2008). This may in time be complemented by selective breeding. Fish have the ORWgZOZPSWbZWS b] S Oab OS OR SZUOS lipids, which varies not only among species but also families. Identifying the genes that control this and determining the heritability of the trait may facilitate selective breeding of strains with reduced RS S RS QS] aV]WZa c2OQZb S ?Sea &$$-

Last, long promised microalgal based technologies capable of producing commercial quantities of OT ROPZS [GbWOZObbQO cPaWbdbS] T aV[SOZ O R aV]WZaWOc_OQZbS STSRabcTa [Og SP beginning to become commercially viable (Durham, 2010).

Aquaculture will increasingly have to compete with other animal production sectors for use of feedstuff crops and agricultural by-products. The sector will be able to continue to secure access only if it can afford to pay the going rate and if the roles of aquaculture in food security and economic RSdSZ][S b O caWQWSZgSQ]U WhSRb VdS resulted in an enabling policy environment.

C I HHA I G C 7C C I 7AM D O G7CHBH

Aquaculture production is almost entirely comprised of plants and animals derived from broodstock that have been in captivity for only a few generations. As a result, growth of farmed aquatic organisms is similar to, or because of poor management of captive breeding systems, worse than that of their wild counterparts (Brummett et al., 2004). Domestication, in which life history traits are altered through selective breeding to meet human needs, affords the possibility to develop more productive (i.e., fast growing, disease SaWbO b WUVSaV gWSZRWa EVSRSdSZ][S b of faster growing strains reduces demands on some ecosystem services, such as land and water. However, although yet to be thoroughly studied it is probable that the development of faster growing strains, as being pursued at present, will have only little effect on the demand for feed. In essence Qc S b RSRWU]U O[a W[OWZgSZSOQbT aV bVOb SOb] S]b SfZWQWbTaV VOb Q]dSb T]R [] S QWWSZg bW SaV b [Og]eSVdS SP possible to widen breeding objectives to select for both faster growth and better feed utilization.

7O[W U]dWBaVS]] bc Wb] b WcS QS SdS aspect of the life cycle of an animal, including many of the attributes that might appeal to consumers: color, size, shape, nutritional composition. The relative importance of genes in determining many of these attributes, however, is as yet unknown as is our understanding of the genes involved or the heritability of these traits. Powerful new tools, such as genetic markers, are expected to increasingly assist us in identifying these genes and gene complexes.

At present, genetic improvement programs are underway for a dozen or so widely farmed species, including both marine shrimps and freshwater prawns, common and Indian major QO a WZOWOaTW2QO R OV SZ WaVb OWP]e trout and Atlantic salmon. Results from such selective breeding programs can be impressive: the selectively bred Jayanti strain of Labeo rohita ('rohu'), for example, widely used by Indian farmers, USe c]b % OTbS S USOW]]dS oS generations compared with local strains, across a range of production environments (Ponzoni et al., &$$-

EVS ab USbWQOZZg WSR 8O[SR T aVWa a strain of Atlantic salmon that grows twice as fast as other domesticated strains. Produced by AquaBounty Technologies, it is currently awaiting approval for commercial production by the U.S. Food and Drug Administration (USFDA). The animal has a single copy of a DNA sequence that includes code for a Chinook growth gene as well as regulatory sequences derived from Chinook salmon and ocean pout (Marris, 2010). Several other aquaculture species await permission for commercial use, including common carp in China (Aldhous, 2010). The permitting process has until SQSbZgOYS [Og gSO cbP W&$$-VSbFD752 announced that they intended to treat GM traits in farmed animals as veterinary drugs, potentially speeding up the licensing process. Nevertheless, strong public concern about the potential for ORdSaS SW [S bOZ TSSQa Vc ZR aV SO S O R RSR eWbeWZR WZWYSZWcSbQS licensing arrangements. GM technology will only be adopted in aquaculture if it results in lower]R cQbW] Qa SOS]wba OR SfO RSR markets. Market size will, however, ultimately depend on the perceived safety of the product to consumers and, indeed, with the brand image of GM foods in general.

Another issue with respect to genetics concerns non-native species. A precautionary approach would, of course, severely restrict the use of alien species in aquaculture and rely instead on the development of native stocks. Currently, however, a considerable proportion of aquaculture production comes from non-natives (Figure 4.3). Even in China, where native carps dominate production, 12% of production comes from non-natives.

Recognizing that the current incentives for use of alien 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]T 4]RcQb]T Sa] aWZS WZS WSa %--)R O the ICES Code of Practice on the Introductions and Transfers of Marine Organisms (2005), IUCN provides a useful series of recommendations for national governments to implement responsible use of alien species in aquaculture (Hewitt et al., 2006). Tools for risk analysis associated with introductions of aquatic animals are also available (Kapuscinski, &$$ /bZc SbOZ &$$-

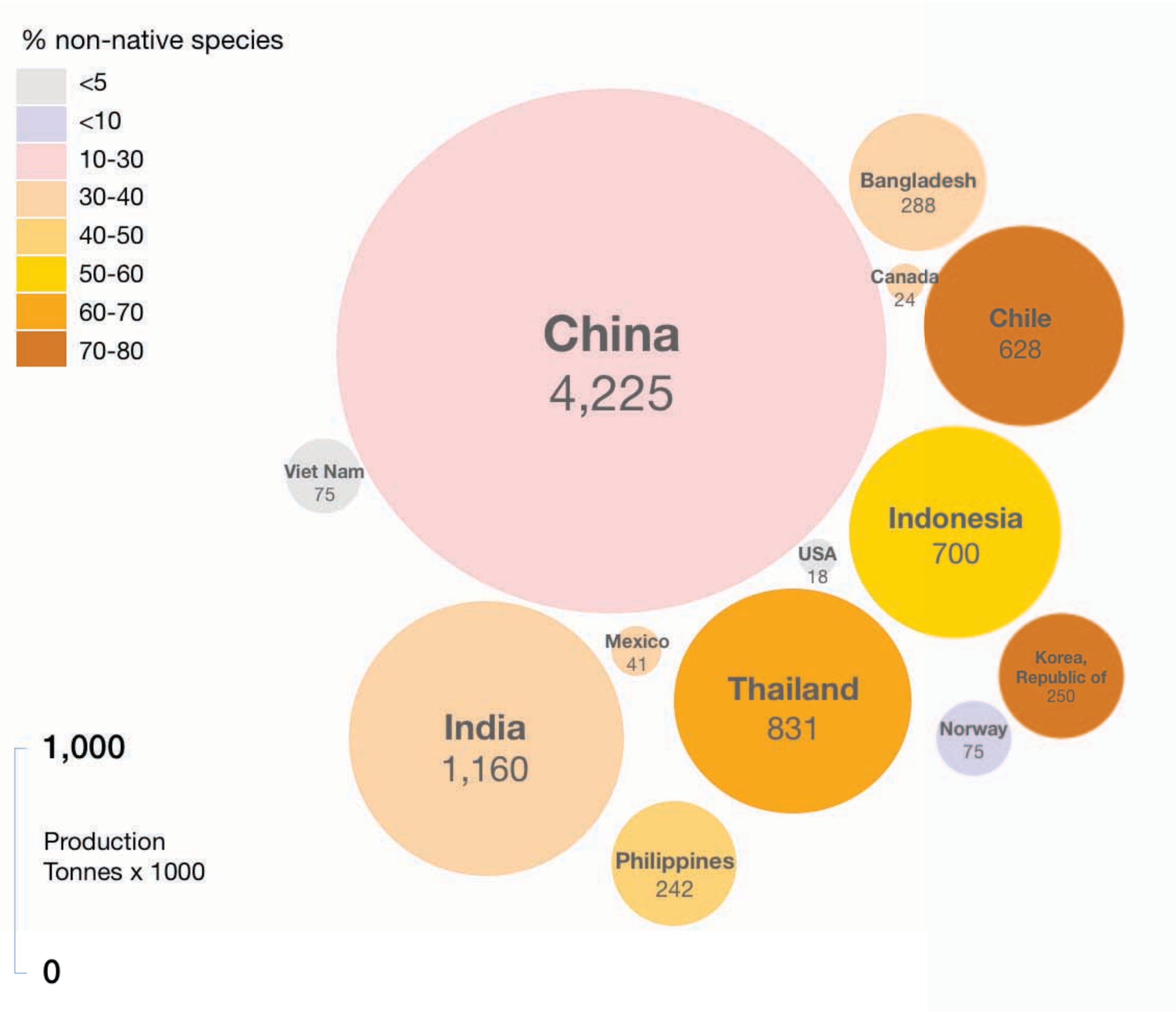


Figure 4.3: Summary of non-native species production for the systems modeled in this study. This calculation
SfQZBSaaSOeSSRaO ROQQ]cba T -$]TUZ]POZ]R cQbW]W&$$, GOZSa c RS SOQV Q c bgOS] RcQbW]
(x 1000 t).

H. 7A

Aquaculture production methods are increasingly intensifying and farms are getting larger and more spatially concentrated. Because of this, there is a growing concern about increasing risks from the spread of pathogens and infectious aquatic animal diseases and the increased movement of aquatic animals. Inter-regional trade and the introduction of new species and strains to meet economic and [O YSb $[O Ra]eV]a S VaUWQOb Wya S caS ITOaV aV WaIZaOWYa OQb WS ObaTS of pathogens. Current estimates suggest that PSbeSS]S VdR]b O OZT]TaV OR VaW[a put into cages or ponds are lost to poor health management before they reach marketable size (Tan et al., 2006).

Although technologies and measures for aquatic animal disease prevention, control and treatment VOdS W[dSR VaUWQObZg WQSb gSO caS of antimicrobials and other veterinary drugs and associated environmental and human health risks remain a major concern. Antimicrobials and other medicines are of particular concern given their importance for human health. Uneaten feed provides a source of these contaminants to the environment, while ingested medicines are metabolized, excreted or voided in feces.

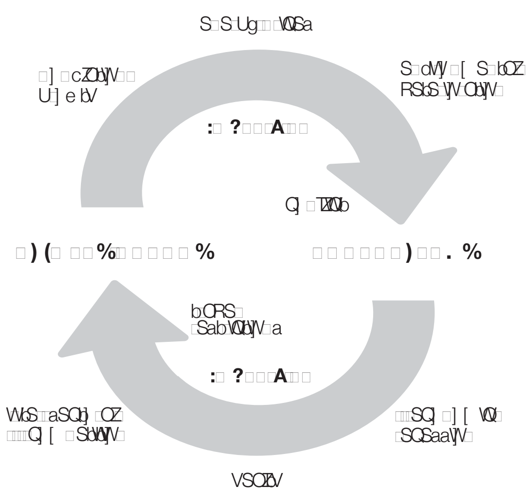
Accumulation of residues from these sources can WQSOaS OWIWR WOZaWb QS WTSR aV Impaired decomposition of organic material in the SdW IS b $QOaS ITSQZWa WPQS WOZ C can also occur. Disease prevention often proves RWQcZb OR [Og OT[S a QS bZg]QTa]S on treatment than prevention, but increased use of antimicrobials as prophylactics and as growth promoters is possible in future. This will further increase the risks of developing new, drug-resistant strains of pathogens. Developing vaccines is one route to reducing use of veterinary drugs, but research in this area is currently restricted to relatively few species (e.g., salmon, trout, grouper) and vaccines are only effective against certain types of disease.

Environmental stressors, such as poor water quality, acting alone or in conjunction with other stressors such as over-crowding, poor handling or inadequate nutrition, compromise the immunity of farmed aquatic animals, increasing their susceptibility to attacks by pathogens present in the farmed environment. Increasingly, bVS OQOZb S RcabgOR]VS ar ObW]Q U]dS [S ba VSb27 VS b 6r: SQ]U WhbVOt effective biosecurity measures are needed to reduce the spread of pathogens. Adequate welfare standards are also required to minimize stress and reduce the incidence of disease and its consequent W[OQb]]R cQbW] OR]wba e] E]bVS factors are also important. First, environmental standards have been developed for many of the compounds used as medicines by aquaculture, and have been widely disseminated, if perhaps less widely enforced. Second, food safety standards, designed to protect consumers from exposure to potentially harmful medicinal and other chemical residues, are driving more responsible use. Such standards are more widely used by developed countries, and for products from developing countries for export to them, but many developing countries will need to apply the same or similar regulations to protect their domestic consumers. Industry codes of practice may help, but legislation and its implementation, combined with capacity building, are also needed.

AB 7I 7C

Climate change – aquaculture interactions are two-way: climate change affects aquaculture, and aquaculture contributes to climate change WUS ((S UES SZ]e WZZbSa VObbVS impact of climate change on the sector and those who depend on it and vice versa is moderated by a range of other external factors which may be occurring at the same time (Beveridge and Phillips, 2010).

Figure 4.4: The relationship between aquaculture and climate change. (From Beveridge and Phillips, 2010)



Climate change is likely to increase global seawater temperatures. Combined with sea level rises, changes can be expected in inshore salinities, currents and seawater mixing patterns, and in wind speeds and direction. The changes in the physico-chemical environment will impact on ecosystem abcQbc S OR cTQbW]rb VS RaWPW]]T aSQWSa aquatic productivity and the incidence of harmful algal blooms. Coastal areas and estuaries are likely to experience the greatest changes in biophysical conditions and ecology. Inland, changes in the levels and pattern of precipitation are likely to WQSOaS VS QWSRQS]TR WU W[S OSOa and drought in others and impact on groundwater and surface water reserves. Temperature rises will increase evaporative water losses, change abObWQOW] OR [WU ObS a]T ZOYSa O_bWQ community composition and aquatic productivity (for reviews see Handisyde et al., 2006; Allison et OZ $$-/ &3WZSg RO UaT R &$$-/ Sc4U bS OZ $$-/ &3dSWBS SbOZ &%$

Temperature changes can be expected to impact not only on the aquatic environments that support aquaculture production but also on the farming operations themselves. Temperature increases will increase productivity especially in areas where anthropogenic nutrient inputs are increasing. The incidence of harmful algal blooms, however, is also likely to increase, limiting bivalve and other types of culture. Moreover, above some critical point elevated temperatures stress farmed aquatic O W[OZa aTWQWSZg] bO YSRZg WQbadWdOZ S] RcQbW]]ebV]RcQbW] RO]wba

Climate change will thus directly affect aquaculture production through choice of species, location, technology and production costs. Development of heat tolerant strains is likely to be limited given the complex interactions between temperature and physiology. In short, adaptation strategies to climate change are likely to be limited. Instead, we can expect geographic winners and losers. Aquaculture production will disappear from areas that become too hot, dry or stormy while areas presently considered as excessively cold may PS Swb OaWaWQOSR WQ]OaZ ?Og

With respect to the impact of aquaculture on QZW[Ob QVUS SVO a VS]ab aSQWw effect concerns the use of wetlands and coastal mangroves . These habitats sequester high levels of carbon, and efforts are needed to ensure that any aquaculture should be sited in areas which such areas does not compromise such natural carbon sinks.

Production projections

RIM DMJ JGHM AGF IGAFM DD GNLAHI JGB AGF F L J ADAL GF LG : DA N L AIOADGD FGAFM GLG G S3 2006)

4 AD 7AE I G

Notwithstanding our historic tendency to under-estimate the rise of aquaculture, several projections of future production are available. We have drawn on these to examine likely future trends. Figure 4.5 shows actual aquaculture production up to 2008 (excluding seaweeds) against the values projected under various scenarios from published studies summarized in an analysis for the FAO (Brugère and Ridler, 2004). The various projections have been made under somewhat different assumptions OR O]OQVSa e]E]T VS]TSQOa SJ %---/ HWXbra[&$$ ac[SOaQ] abO b aW WQSaOR are based solely on demand driven by population growth and per capita consumption. In contrast, both supply and demand considerations and their effects on prices are included in the analysis by IFPRI (Delgado et al., 2003), which disaggregated T]R aW bW WUVOR Z]e dSZQSOb WSa] VS basis of their markets and price elasticities.

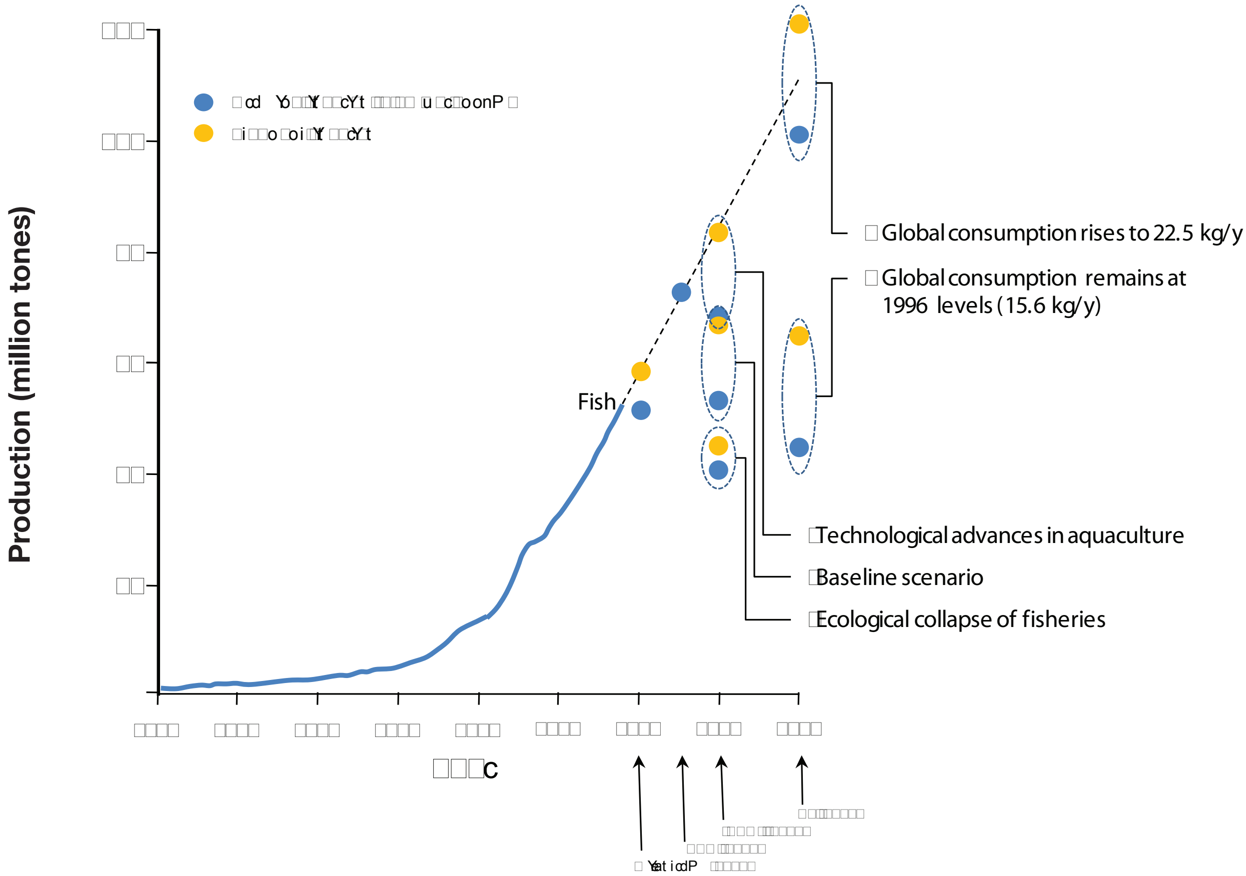


Figure 4.5: 4][OWja]TWtja WQOZ Rab W] RcQtW]jT TO[SRwaV eWtbaSdS OZ] XSbW]a] TTcbc SO_cOQcZbcS production. Circles denote projections based on supply and demand considerations under various assumptions, as summarized in Table 3 of Brugère and Ridler (2004). Historical production data are from FAOStat.

EVS baRWSagP 5SZUJORSb OZ &$$S %O-- consider alternative scenarios for the future. The IFPRI study explored six scenarios, three of which are considered here: a baseline scenario that embodied the authors "most plausible" set of assumptions, an extreme scenario where QObc S aWS WSa]R cQbW] QZWWU aW[SOZ waVS WSa Q]ZZaS eWbO dW % OcOZ]eb V in production, and an aquaculture development scenario where technological progress increases production growth by 50% relative to the baseline aQS OW] S J %--- aW SR eb aQS OW]a bVS ab Qa[SR S QWb Qac[bW] e]cZR S[OW Ob%-- ZSdSZaQ] R VOb We]cZR Wa to 22.5 kg/y, based on a combination of historical time trends and modeled relationships between GDP growth and consumption. Further richness to these predictions was added by Brugère and Ridler (2004) who considered how these projections might be affected by either no growth in wild QObc S aWS WSa] gP O [SRab $ Ue bV

Examining these various projections in relation to observed trends in production we derive an uncertainty envelope for total aquaculture production out to 2030 in the following way (Figure 4.6). Because the three projections up to 2015 fall broadly on the current growth trajectory for production, there is consensus among the studies that global production growth will continue along a aW[WZOXSQbg] bVS SQSb Oab] T VS Sf bwdS years or so.

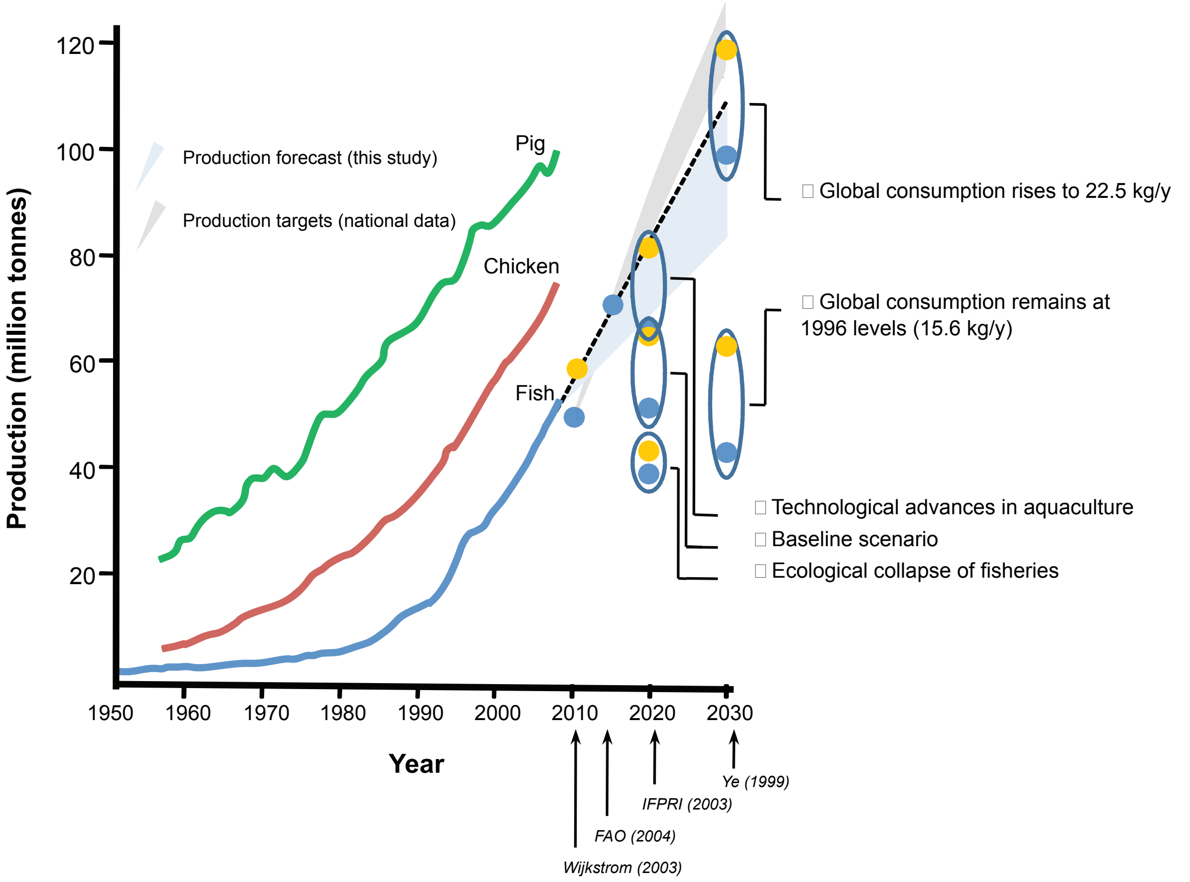


Figure 4.6: 4][OWja]T Wa WOZbS Ra WTO[SR waV WO R QWYS [SOb]R cQbW] bVS ZWZS] RcQbW] bOXSQ-tory envelope and the combined aquaculture production targets envelope for nine countries (Bangladesh, India, China, Indonesia, Philippines, Thailand, Vietnam, Brazil, Chile, Canada, Egypt). Historical production data are from FAOStat,]R cQbW] ObUSb RbO S][T EOPZS -[UI S RCWZS &$$(2_cOQcZb S] RcQbW] SRWbQ]a T][7WcS 4.5 are also shown.

Predictions for the latter half of the decade are variable, but if continued growth to 2015 holds we will have surpassed all but the most optimistic of the IFPRI scenarios to 2020. Thus, assuming that we do not see the catastrophic collapse of eWZRaVS WSa Qa[SR P VS]ab SaaW[WbWQ scenario, but that we also see no growth in this sector (Mills et al., 2010), the envelope for production by 2020 is between 65 and 85 million tonnes. The lower bound of this range corresponds to the IFPRI baseline scenario under a stagnant waVS WSa Qa[bW] OR VS c S]P R SxSQb VS QbWcObW]]TVS QS b]R cQbW] trend and the prediction for IFPRI technological W]dObW] QS OW] RS ObOaO b aVS WSa assumption.

The bounds of uncertainty become even greater as we look out to 2030. For this time horizon, and in the absence of a new modeling effort, a Q] aS dObWdS dSZ] S WP OPZg SbSS -RO 110 million tonnes. The lower bound represents a growth pattern that continues the trajectory for the IFPRI baseline scenario prediction for 2020. The upper bound represents the continuation of the current production trend and the IFPRI technological innovation scenario under a stagnant waVS WSa Qa[bW] b QZaQ] Sa] Ra] b VS midpoint between the two projections by Ye for global consumption of 22.5kg.

One indication of the reasonableness of this likely envelope for the aquaculture production trajectory comes from a comparison with the targets for

Zbjc UV eS aQ[S] Ueb V WS SOZc a Zg]aV]T bVS eWZRO S SQ) eS R] S dWQUSO WQSOaS WbVS ac ZgS] bSR W]TwQWZabObWbaWQ[WUgSOaW OlbWQZO OaPbS RO] [QZZ QaOZSaVSWSaRQ][Sa OdOWZOP SWZZa$%$ &

]R cQbW] VOb eSS SVBWSR WVS ObW]OZ ZOa of nine countries (Brugère and Ridler, 2004, Table -WUB (Q]Sa VS SSZ]Sa]T VSaS projections and shows that our estimated range falls below the collective ambitions of these nine countries. The envelope for production targets eOa QOBSR OaSR]ep aQS OW]aO OcOZ growth rate for China of 3.5%, or a more modest rate of 2% (Brugère and Ridler, 2004). Although national targets are often over-optimistic there is little to indicate that the aquaculture sector as a whole will be unable to meet demand should it eventuate.

It is also interesting to examine how pig and chicken meat production has evolved and to observe the remarkably similar growth rates for production over the last decade (Figure 4.6). This suggests, perhaps, that all three sectors have been driven by similar demand drivers during this period and that all three production systems have been able to meet this demand.

D G'E HG I DC

The global distribution of production described here for 2008 is likely to still hold in 2010, moderated somewhat by some recent large changes (e.g., marked declines in Chile; marked increases in some sub-Saharan African states). For the next wdS gSO VSbST S eS [ObST Oa[S bVOb the present global pattern of production will remain largely unchanged: i.e. that Asia will account for [] SVO -$]T]R cQbW] c6 S]T QcR 3–4% and South America, North America and Africa for 2% each, and Oceania for a fraction of a percentage point. Indeed, one can expect Asia to further consolidate its position by a few percentage points at the expense of the rest of the world.

The regional distribution of aquaculture production U]eb V Sg] R VS Sfb dS gSO W[S WRQZb b SRWQb SSV OQb a S ObWZZg WaVWOb First, the industry is now a major global provider of food which increasingly must compete for markets with other sources of animal-derived foods, all of which are changing too in response to market globalization. Second, like other food production sectors, aquaculture depends on a range of scarce] WSbSa]c QSa]T eWQVW]ab QSOaWZg Q][SbS eWbVSa VEV VSbSQb WaOZZg beginning to be taken seriously at policy level; governments are starting to develop and apply incentives and penalties to facilitate or regulate sectoral growth, the methods by which it is achieved, and trade. They are doing this to ensure that the sector makes appropriate contributions to social, economic and environmental objectives. Given these considerations and the complicated relations these factors will have with production costs and price to consumers one must be QOW]a eWbSw WdSbOa[S ba QP b]e bVS sector will evolve geographically.

There are, however, several conclusions that are probably robust. First, despite the investment, aquaculture production in Europe and North America has remained largely static over the past decade and is unlikely to grow substantially. This is primarily due to lack of available sites, competition from other producing countries and substitution of comparatively expensive, domestically produced waV aQV OaQ]R gP SVO S]R cQa]T]bVS Oba]TVS e]ZR bVaSR QWab]T GWSb[tilapia from China). Marine production in the United States remains constrained by lack of an enabling legal framework, competition for coastal resources and competition from overseas producers (e.g., Latin America and Asia for shrimp). Similarly, freshwater production in the United States is limited by overseas producers able to produce identical (tilapias, carps) or substitute products (striped QOwaV QWbZg Q][SbWdSWQSa

Second, production in Africa is very low but is growing fast in some countries, unconstrained by resources that are often underutilized. Despite bVS OQbVOb aV WaS]ab W[bO b]a QS]T animal protein per capita for many countries in this region and provides several essential vitamins O R cbWSa aVw Q]ac[bW] WaS Z]eSabW the world. Here it is projected that simply to keep pace with population growth a further 1.6 million b SaOZ[]a b %$V[SaVS QS b]R cQbW] ZSdSZaWZZ SPSSFSR gP &$% SdSWBSSbOZ 2010). Growth in sub-Saharan Africa is increasingly being driven by investors in countries such as Uganda, Nigeria and Ghana, keen to develop enterprise type operations that target both domestic and regional markets (OECD, 2010). However, because of the very low production base O R SQOaS]T SWQWS OR]] Zg SBSZ]SR value chains, it is likely to take at least a decade before substantial increases in production in sub-

Saharan Africa are realized. If this is correct, local [illegible] over the next decade. Despite this overall picture, however, there will be large local increases in some countries and this will likely bring with it substantial resource demands.

Third, the current trends indicate that the majority of increases in global production to 2030 will come from South and Southeast Asia and China, with a continued drive by major producer countries such as China and Vietnam towards export to the strong European and North American markets. Increased import taxation, such as that currently being imposed by the United States against Vietnamese [illegible] and Aquaculture, 2010), but the general trend is clear. The principal constraint to growth in production in the region, other than markets, is likely to be availability of resources (land, water) and environmental change.

Finally, of the countries in the Asian region, it is China where biophysical constraints seem most likely to slow the rate of production growth. While China is likely to further consolidate its position as the world's largest producer and consumer of farmed aquatic products, the resource base upon which this production depends will come under [illegible] to imagine how current production growth rates can be maintained in the longer term. Balanced against this, however, will be considerable pressure to satisfy internal demand through domestic aquaculture production. While domestic production will meet some of this need, increasing imports can also be expected, some of which may be supplied by Chinese overseas aquaculture investments.

[illegible]

To explore and illustrate the consequences of current production practices for future biophysical demands of aquaculture might develop we have constructed a scenario in which production from our modeled systems (excluding seaweeds) will reach 100 million tons by 2030. We chose 100 [illegible] it falls on approximately the upper quartile of our uncertainty envelope. Given the tendency of previous work to under-estimate aquaculture [illegible] range seems reasonable. We also made two other assumptions to avoid projecting forward trends that we believe are unlikely to persist and which have high leverage on the predicted environmental demands:

1. [illegible] production in Vietnam will slow faster than in other countries owing to pressure on natural resources[10].

2. [illegible] than other forms owing to increasing demand for this product category.

To estimate the distribution of global production, a scaled estimate of the recent (2003 – 2008) compound annual production growth rate was used to project forward production from the 2008 starting value for each production system. For all production systems the same scaling factor of approximately 0.42 was used for all years and systems. For China, we reduced production growth [illegible] growth rates by 20%.

[illegible]

[illegible] distribution of overall production between 2008 and 2030 under our growth scenario. The key feature of this result is the continued dominance by Asia, but the emergence of several other countries (India, Indonesia and Thailand) as key players. For Asia as a whole, this conclusion is almost certainly robust, although how production will be distributed across countries is far less certain given the dynamic nature of the sector. The spectacular [illegible] in recent years is a testament to how quickly things can change.

[10] [illegible]

Figure 4.7: Projected change in production distribution between 2008 and 2030 for the systems modeled in this study, which produced 82% of world production in 2008 (data exclude seaweeds). Blue circles: 2008 production; orange circles: 2030 production.

Table 4.1 summarizes the change in overall environmental impact for each of our six categories. Increases [illegible] from aquaculture were offset at current market price of \$15 per tonne of CO_2, the cost would rise from US\$ [illegible] attention to issues of waste disposal. Of course, these projections assume current (2008) practices, whereas improved technologies, regulatory regimes and production practices should modify this trend; see [illegible]

Table 4.1: Projected change in total environmental impact between 2008 and 2030 for the systems modeled in this study, which produced 82% of world production in 2008 (data exclude seaweeds, and assumes current production practices).

Year	Eutrophication (Mt PO_4 eq)	[illegible] (Mt SO_2 eq)	Climate Change (Mt CO_2 eq)	Land Occupation (Mha)	Energy Demand (Tj eq)	Biotic Depletion (Mt)
2008	[illegible]	2.54	[illegible]	50.61	3,358,468	15.11
2030	[illegible]	5.05	[illegible]	113.63	[illegible]	[illegible]
% Change	168%	--	132%	125%	[illegible]	151%

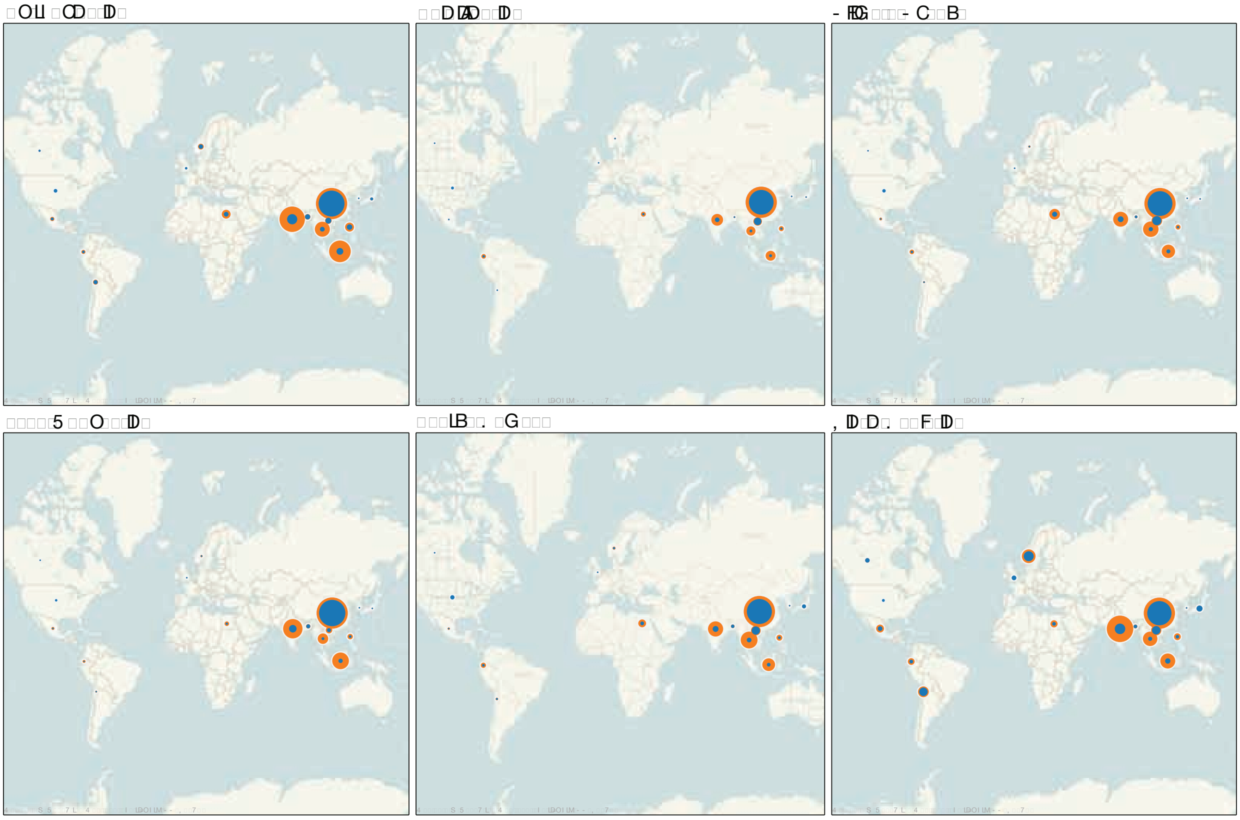


Figure 4.8: Projected change in distribution of environmental impact between 2008 and 2030 for the systems modeled in this study (data exclude seaweeds). Blue circles: 2008 production; orange circles: 2030 production.

Figure 4.8 shows the distribution of impact for each of our impact categories in 2008 and 2030. As we e]c ZR SfSQbVSaS WaWPW]a [O RZg] dSOZZ]R cQbW] ZSdSZa oTW U VS W[bO QS]T focused support to Asian producers to mitigate the environmental impacts of aquaculture.

Conclusions

In this section we have explored the drivers of demand for aquaculture products and the environmental constraints to meeting this demand. We then examined published projections of future growth. These suggest that aquaculture production is likely to increase at a rapid pace. Finally, we explored the future environmental demands of aquaculture if it reached 100 million tonnes (excluding seaweeds) and in the OPaS QS]TaUWQOb WdObW] OR W[dS[S ba WbQVW_Sa OR bQV]Z]Ug RS VbWaQS OW] we estimate that the environmental demands will be between 2 and 2.5 times greater than 2008 levels by 2030 for all the impact categories studied.

Photo by Stevie Mann
MALAWI

PHOTO CREDIT: The WorldFish Center

5. POLICY

5. Policy Implications and Recommendations

Understanding, quantifying and explaining the environmental impacts of aquaculture is essential for sound decision making. Policy-makers need this information to establish evidence based and fair environmental regulations. Fish farmers need it to implement better management practices and understand and comply with environmental regulations. And retailers and consumers need it to make informed choices and drive appropriate policy and farming practices.

In this section we distill the results of our LCA study [illegible] recommendations for action. Following this we offer a more general conclusion and recommendations regarding the future of aquaculture. We then combine and further amplify our recommendations for key stakeholder groups (Table 5.1) before considering the future research investments that are needed to support sector development.

[illegible]

[illegible]

The absolute levels of environmental impact revealed by this study indicate those regions and production systems where efforts to regulate and reduce global environmental demands are best [illegible] agencies and institutions should:

- Develop approaches to encourage and support China and other Asian and Latin American countries to analyze impacts and better manage the sector towards improved environmental performance.

- Focus especially on improving production practices in inland pond, pen and cage aquaculture because these dominate global production.

- Focus especially on carps, shrimps and prawns as these are among the sectors which have the largest overall impacts in absolute terms.

[illegible] sector has high aggregate impact. Unfortunately this sector comprises many species, making a [illegible] comparative analyses of impacts in the marine [illegible] issue apart (Volpe et al., 2010).

[illegible]

The highly regulated nature of the salmon farming industry in some countries has led to considerable technical innovation that has both driven down costs and reduced environmental impact. This sector offers some lessons for the rest of the industry, as do many of the traditional systems of aquaculture in Asia with their low environmental impacts.

[illegible] cross-sector and cross-country learning deserves close attention as one of the most effective means for driving improvement. In view of this international agencies and regional bodies and government agencies should:

- Support or develop national and regional learning networks and innovation platforms for both policies and technologies that bring together government, the private sector, NGOs and research agencies to jointly identify and implement solutions that will overcome problems, establish and share best practices, and improve sector wide environmental performance.

- [illegible] develop practical measures for implementing the Ecosystem Approach to Aquaculture that has recently been developed by the FAO.

- Support emerging aquaculture sectors to understand cost drivers as a means to stimu- [illegible] production practices.

- Facilitate private sector investment in improving environmental performance.

[illegible]

[illegible] aquaculture feeds is a high priority for intensive and semi-intensive systems. This is true for traditional [illegible] and shrimp. A range of largely complementary strategies based on the following principles and recommendations is needed to reduce feed constraints on sector development:

- Use locally sourced feedstuffs, including agricultural by-products (oil cakes, rice bran), and develop pre-treatment and processing methods to increase digestibility and nutrient availability and reduce anti-nutrients.

- [illegible] to improve the nutritional value of the product for consumers.

- [illegible] high quality marine lipids and protein.

- [illegible] such as carps and tilapia that will not rely on [illegible]

- Develop high quality protein and lipid sources from plants and microorganisms.

- Develop feeding technologies and management systems to optimize the conversion of feeds into aquatic animal biomass.

[illegible]

[illegible] aquaculture sector. There are, however, many steps that the sector can take that are more generic in nature. Our analysis shows, for example, that reducing the sector's impact on climate [illegible] value chain. In view of this government agencies should:

- Facilitate energy and other resource use audits (e.g., water) across aquaculture value chains [illegible] cost savings.

- Where practicable, help make available to producers energy and other resource use data for their operations on a daily basis. This [illegible] if combined with comparative data for other producers.

- Facilitate cross-sectoral dialogue on industry best practice in the food and agriculture sector.

[illegible]

[illegible] relative to several other animal source foods are clear. For many regions, an increase in the [illegible] use of available resources. These products are especially suited to meeting the demand of growing urban populations (including the urban poor) through local peri-urban production.

In view of this national planning agencies should:

- [illegible] various animal production sectors and consider policy drivers that can shift towards a more [illegible]

Recommending an aquaculture species choice [illegible] picture that emerges is somewhat mixed. Eels are particularly demanding in relative terms, albeit

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with very low overall production, and shrimps and [illegible] Yet they all perform favorably in terms of resource demands compared to meat. Bivalve and mollusk farming is the least ecologically demanding of the animal source foods and provides an ecological service by removing nutrients. These groups are a particularly nutritious and environmentally sustainable option for consumers.

[illegible]

[illegible] security will become increasingly important in the developing countries. This is particularly true for African and Asian countries where there is growing domestic and regional demand, especially from the growing urban populations, including the urban poor. In view of this, governments and industry in these countries will need to pay particular attention to:

- Stimulating the private sector to invest in commercial aquaculture where there is access to strong demand in domestic and regional markets.
- Evaluating research and policy development needs along the entire value chain from inputs to consumer markets.
- Supporting development of aquaculture production that will deliver sustained supplies at affordable prices for poor consumers.
- Supporting aquaculture both as a household livelihood and food and nutrition security support strategy in areas where production is feasible, but markets are weak.

[illegible]

Without further and more wide ranging analysis it [illegible] change will affect global aquaculture production. To more fully assess climate change impacts on the sector, a value chain approach must be adopted in which not only production but also essential upstream and downstream activities (e.g., seed and feed supply, transport and processing) are included. To make matters even more complex, climate change will interact with other factors such as population growth, changes in markets, trade barriers and energy prices to impact on aquaculture and aquaculture-related food security.

Aquaculture also affects climate change; although it is a relatively small contributor to greenhouse gas generation. To sustain present and future markets, especially in developed countries, the sector must minimize its potential for climate change impact. Certain key principles should be universally applied:

- Avoid use for aquaculture of sites high in sequestered carbon (mangroves, seagrass, forests).
- [illegible] potentially important source of methanogenesis, must be carefully dealt with, preferably for producing other foods.
- Energy consumption associated with pumping and post-harvest processing, transport and marketing must be minimized.

Tools such as Life Cycle Analysis (LCA) can help identify the most energy-consuming steps in value chains and evidence from other sectors suggests that often mitigation may not be that costly. But [illegible] to encourage changes, and ultimately it may be consumers who, through exercising choice in what they eat, play the most important role in promoting mitigation.

General conclusion

The trends in many of the drivers of demand for aquaculture products suggest that the aquaculture sector will continue to grow to meet increasing [illegible] impacts of such growth can be managed through innovation, strengthened policy, capacity building and monitoring.

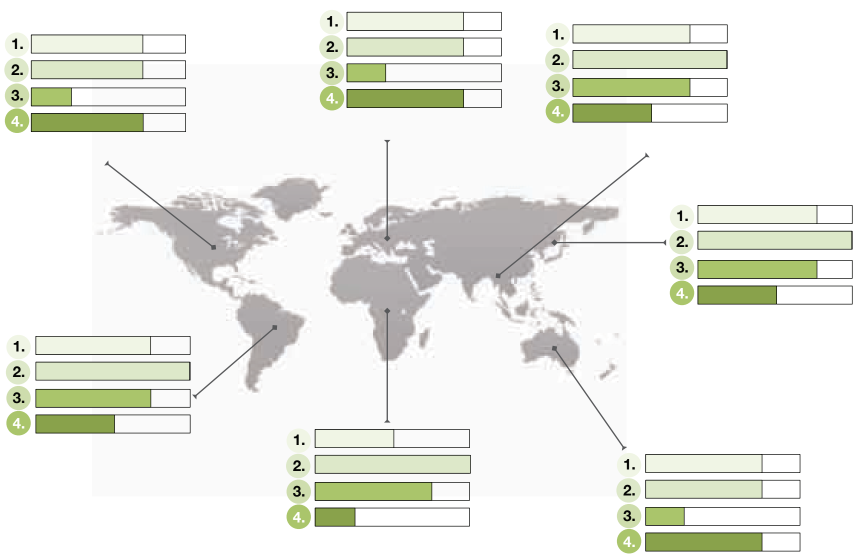
Increasing wealth and urbanization will result [illegible] decades. At a global scale, there is every indication that the aquaculture sector will be capable of meeting this demand. This will occur through both expansion of areas under cultivation and

WbS aWQQW]]T]R cQW] cb3]b OQWSdSSaS increases in ways that limit environmental impacts we offer four core recommendations to government and industry in all producer countries:

1. 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. Ensure that the regulatory environment keeps pace with sector development and support policy analysis and development that internalizes into aquaculture enterprises the costs of its environmental impacts.
3. Develop capacity in national agencies for supporting the development of sector regulation and for monitoring and compliance.
4. Monitor carefully how supply and demand T aV WSd]ZdW b Sac S Vb a] k and investment is appropriate to the market opportunity.

These core recommendations apply globally, but there are regional differences in their relative importance for attention over the next three to wdS gSO OaSR] VS RWUa]TWWabRg literature review and our own experience, Figure 5.1 summarizes our view of these differences.

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	edaeh hM o en i l f f o d c d Mhpi á me mdR e di l h i l f f eh d admi c d á appropriate to the market opportunity.



KEY			
Maintain current emphasis	Warrants increased attention and investment	gl ah i i Rdap d ad h i attention and investment	A top priority for attention and investment

Figure 5.1: Core recommendations for government and industry in all producer countries and their relative importance for each region.

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Table 5.1: Recommendations summarized for key stakeholder groups.

Stakeholder Group	Recommendations
Policy makers	• Use audits of energy and other ecological resources across aquaculture value chains as a guide for management decisions. • OYS TWObW]] SUg O]bS SQ]ZUWQOZ QS WQOb OR SQWSg measures accessible to producers. • CSdWSe RO W[]dS QSWQOW] bO ROROa 8]]R 2cOZObS AOQWQS S4]RT Practices and other industry management codes and guidance documents to ensure bVSg SxSQb SQ]UWQOZ gWSTO]OQVSa]bO[[O OUS[Sb OR dOZc OVWa • Facilitate cross-sectoral comparisons and dialogue on best practices in food]R cQbW] eWW VS ZWQOSYa aVSWSa OR OWQZbS SQb a • 6f O[WS Vb]c UVZg VSbSZOWdSS Sba]TVS dWO]a OW[OZ]R cQbW] SQb a OR Q]aWR]ZWORgWdS VOb QO VObT]dO Ra O $ SQ]ZUWQOZZgS ST]R cQbW] portfolio. • Avoid siting 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. •]Wb ST[OQS]TQSWQOW] WS QOQZbS SQb RO SSY eOgb 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	• OYS SBS aS]TQOQS B QbZg aWSOZ OR aV]WZ ZWSa • 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. • 3 SSR aV VObVOdS []S ZWSRVS[O R]T WUVcQZWb[OWS ZWR OR]bSW • 5SOZ QCZZgWe]UOWQOZZgVQSR aV] R SRW[S ba • Minimize energy consumption on-farm and in the following value chain.

Photo by Mark Prein
BANGLADESH

Research needs

Acting on the above recommendations should be guided by sound science and implementing many [illegible] that we think are most important.

[illegible]

The analysis presented here indicates major differences in environmental resource demands within and between countries, species and farming systems. This indicates major opportunities for improving ecological performance. Research is needed to identify the better performers, combined [illegible] investments that will drive improvement.

Life Cycle Analyses, the methods of Volpe et al. [illegible] Approach to Aquaculture are being used in various ways to measure performance and encourage improvement. Further work is needed, however, to improve the consistency and comparability [illegible] to provide practical guidance to farmers and regulators. The research needed includes:

- Developing a common and comprehensive analytical framework to facilitate comparisons of animal source food production systems that captures impacts on key planetary boundaries, such as the nitrogen cycle, biodiversity and climate change.
- Developing cost-effective LCA-based indicators for measuring ecological performance status and improvements that can be applied across scales, from farm to global levels.
- Developing LCA indicators for use with integrated farming systems and identifying incentives (e.g., economic, policy, markets) to improve the ecological performance of integrated aquaculture and agriculture at farm and landscape levels.
- Improving the LCA database on systems that are currently poorly covered by global datasets [illegible] in major producing countries (e.g., carps in China, Bangladesh; products for domestic markets).
- [illegible]
- Determining how emerging supermarket chains in Asia and other entry points can be used to improve the environmental performance of aquaculture products for domestic or regional markets.
- Carrying out more in-depth LCA studies on [illegible] cies, system design and management practices, to understand entry points for improvement and costs.
- Identifying the present frontiers of environmental performance and what can be done to support their adoption.
- Identifying which investment strategies, incentives and institutional arrangements best facilitate environmental improvement among small- and medium-sized enterprises.

[illegible]

While there is strong evidence that the aquaculture sector will continue to grow to meet the anticipated increasing demand for farmed aquatic products, policy makers, producers and retailers need to [illegible] This will require improved quantitative models [illegible] initiative that is currently being supported by the World Bank, is particularly welcome in this regard. Research is also needed to ensure that policies designed to help meet demand for aquaculture produce are consistent with policy objectives for other sectors, such as environment, energy, food and nutritional security, and poverty and that policies are consistent at national and regional levels.

1 GD 7C ID Æ G C GDCB CI7AB E7 I C EGD I DC DB 7 CH

Research is needed to help China and other Asian and Latin American countries better manage the aquaculture sector towards improved environmental performance. Because carp and shrimp and prawn aquaculture have among the largest overall impacts in absolute terms and pond and cage production systems dominate global aquaculture, efforts should focus on these commodities and systems. Attention should be paid to both technological and management interventions, and the incentives (e.g., policies, legislation, taxation, market) that produce the USOSab SdW [S bOZ S PSvba

Work in this area should also build on the recent efforts of Volpe et al. (2010) to further disaggregate bVS sVS waVt QSb] g WQVOa WUV aggregate impact, to help identify the species and systems to focus on.

-CCD 7I C I H IDGIDG E C C MDC OH B 7A7C OH DAH

Feed contributes a high proportion of the ecological footprint in many aquaculture systems, including impact on biodiversity. Further nutritional research is required to reduce dependency on wild waVS WSa OaWSRWSba WO_OQZb S SSRa b YS same time, replacement by other ingredients (e.g., internationally sourced plant ingredients) can lead to ecological resource demands that could offset Og SdW [S bOZ WdS[S ba]T waV[SOZ] oil replacement. Further research on aquaculture feeds using the LCA tool would be useful to identify feed and feed management strategies leading to genuine improved environmental performance.

II GCI GI AB 7I 7C DCH GI DCH CIDI 7F 7 A G H IDG

The specter of climate change demands that we better understand how it will affect food security, at national, regional and global scales and whether this will affect demand and supply of aquaculture produce. Work is also needed to determine how the impacts of aquaculture on climate change can be mitigated and whether emerging funding mechanisms for climate change mitigation and adaptation can be used to support environmental improvements in developing country aquaculture.

The bottom line

Aquaculture is one of the most environmentally STQWS eOga]b]R cQS VS OW[OZ c aQSTJR a that a growing and urbanizing world population needs. It is one of the fastest growing food production sectors in the world and demand for aquaculture production will most likely continue to grow with rapid pace. But increasing production will have increasing environmental costs unless developed in a way that minimizes the demand on the environment.

EWWab Rg WS ab]b]dWB O OZ]WQ S]T bVS SR]O Ra aV OT[W U [OYSa] SdW[S bOZ resources using Life Cycle Analysis. It shows that there are huge opportunities for improvement in ecological performance across countries, regions and species groups. But we will only capture these opportunities if governments, businesses, non-government actors and researchers take steps together to improve production systems and techniques, invest in innovation, especially bj SRcQS SZWQS]aV [SOZ RO]WZaRO strengthen regulation including improving monitoring and compliance.

If we do these three things we can make aquaculture a more sustainable endeavor that uses biophysical resources prudently so that it can play Wb]ZS cZZg WSbU]c cb S SSRa]T waV

Systems modelled in this study

Country	Habitat	Species Group	Production System	Intensity	Feed Regime	Production 2008
Bangladesh	Inland	Carps	Ponds	Extensive	Natural	%□ □)&%
				Intensive	Pellet	,□)(□
				Semi-Intensive	Mash	385602
Canada	Coastal	Salmonids	Cages & Pens	Intensive	Pellet	□ □ &□ $
Chile	Coastal	Salmonids	Cages & Pens	Intensive	Pellet	□ &□ ,□ ,
China	Coastal	Bivalves	Bottom culture	Extensive	Extractor	3348250
			Off-Bottom Culture	Extensive	Extractor	)□ %□ ($□
			Ponds	Extensive	Extractor	□)$%%&
		Crabs and Lobsters	Cages & Pens	Extensive	Trash	%-□ □))
		Gastropods	Off-Bottom Culture	Extensive	Natural	&&(-□ □
		□ bVS□ □waV	Cages & Pens	Intensive	Trash	□ ,%(%
				Semi-Intensive	Trash	(□ $%□)
		Other Invertebrates	Ponds	Semi-Intensive	Mash	%-□)□)
		Aquatic Plants	Off-Bottom Culture	Extensive	Extractor	-□ $□ $$)
		Shrimps and Prawns	Ponds	Intensive	Pellet	-)&□)
				Semi-Intensive	Pellet	)□ -,-□
	Inland	Bivalves	Ponds	Extensive	Extractor	,-□ -&
		Carps	Ponds	Extensive	Natural	□ □ &))-□
				Intensive	Pellet	1801363
				Semi-Intensive	Mash	,□ &-□ ,&
		4ObaV	Ponds	Extensive	Natural	□ □ □ □ □ (
				Semi-Intensive	Mash	□ □ □ □ □ (
		Crabs and Lobsters	Cages & Pens	Semi-Intensive	Pellet	)%,□)□
		Eels	Ponds	Intensive	Paste	(%□)(
		Gastropods	Off-Bottom Culture	Extensive	Natural	-□ □ &-
		□ bVS□ □waV	Cages & Pens	Semi-Intensive	Mash	&&&)-□ □
		Other Vertebrates	Ponds	Intensive	Pellet	286010
		Shrimps and Prawns	Ponds	Extensive	Natural	124004
				Intensive	Pellet	62002
				Semi-Intensive	Pellet	1054041
		Tilapias	Ponds	Intensive	Pellet	%%%$&-,
Ecuador	Coastal	Shrimps and Prawns	Ponds	Semi-Intensive	Pellet	150000
Egypt	Coastal	□ bVS□ □waV	Ponds	Semi-Intensive	Pellet	58650
		Tilapias	Ponds	Intensive	Pellet	(□)□)
				Semi-Intensive	Mash	283238
	Inland	□ bVS□ □waV	Ponds	Semi-Intensive	Pellet	150663

Country	Habitat	Species Group	Production System	Intensity	Feed Regime	Production 2008
India	Inland	Carps	Ponds	Extensive	Natural	,□ □ &□
				Intensive	Pellet	(%)-□)
				Semi-Intensive	Mash	%-%-,□ -
Indonesia	Coastal	□ bVS□ □weV	Ponds	Semi-Intensive	Pellet	&□ □ $$&
		Aquatic Plants	Off-Bottom Culture	Extensive	Extractor	%-□)-%
		Shrimps and Prawns	Ponds	Extensive	Natural	113431
				Intensive	Pellet	%(%□ ,-
				Semi-Intensive	Pellet	&,□)□
	Inland	4ObweV	Ponds	Intensive	Pellet	86556
				Semi-Intensive	Mash	%&-,□)
		Tilapias	Ponds	Extensive	Natural	□ &□),
				Intensive	Pellet	%((□ %
				Semi-Intensive	Mash	202603
Japan	Coastal	Bivalves	Off-Bottom Culture	Extensive	Extractor	416000
		□ bVS□ □weV	Cages & Pens	Intensive	Trash	&&-□ $$
		Aquatic Plants	Off-Bottom Culture	Extensive	Extractor	□ □ □ -$$
Korea, Dem. Rep.	Coastal	Aquatic Plants	Off-Bottom Culture	Extensive	Extractor	444300
Korea, Rep.	Coastal	Bivalves	Off-Bottom Culture	Extensive	Extractor	□ %□ (%,
		Aquatic Plants	Off-Bottom Culture	Extensive	Extractor	□ ,%$□ □
Mexico	Coastal	Shrimps and Prawns	Ponds	Semi-Intensive	Pellet	121601
Norway	Coastal	Salmonids	Cages & Pens	Intensive	Pellet	,%, &-&
Philippines	Coastal	□ bVS□ □weV	Ponds	Extensive	Natural	&() %%□
				Intensive	Pellet	□ $□ □ -
				Semi-Intensive	Mash	□ $□ □ -
		Aquatic Plants	Off-Bottom Culture	Extensive	Extractor	%(&&□ -%
	Inland	Tilapias	Ponds	Extensive	Natural	&(%-□
				Intensive	Pellet	&(%-□
				Semi-Intensive	Mash	%-□)(□
Thailand	Coastal	Bivalves	Bottom culture	Extensive	Extractor	□)(□ -
			Off-Bottom Culture	Extensive	Extractor	&□ --(□
		Shrimps and Prawns	Ponds	Intensive	Pellet	485800
	Inland	Tilapias	Ponds	Intensive	Pellet	&□ &□)
				Semi-Intensive	Mash	182536
UK	Coastal	Salmonids	Cages & Pens	Intensive	Pellet	%&,□ ((
USA	Inland	4ObweV	Ponds	Intensive	Pellet	233564
Viet Nam	Coastal	Shrimps and Prawns	Ponds	Extensive	Natural	&, , , - (
				Intensive	Pellet	- □□,
				Semi-Intensive	Pellet	&&□&&
	Inland	4 ObweV	Ponds	Intensive	Pellet	1250000

Glossary

:G:

A process that happens when compounds like ammonia, nitrogen oxides and sulphur dioxides are Q]dSbSR WO SQWQOZOQW] W OQWRcPalO QSa SEV2WRQOW]]AS bWOZA 2WSaSaSR relative to the acidifying effect of SO_2.

Algal bloom

A sudden and rapid increase in biomass of the plankton population. Seasonal blooms are essential for the aquatic system productivity. Sporadic plankton blooms can be toxic.

Alien species

A species occurring in an area to which it is not native.

Aquaculture

The farming of aquatic organisms in inland and coastal areas, involving intervention in the rearing process to enhance production and the individual or corporate ownership of the stock being cultivated.

Benthic

Of or relating to or happening on the bottom under a body of water.

Biodiversity

The variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are a part: this includes diversity within species, between species and of ecosystems.

Biophysical resources

Resources such as soil, nutrients, water, plants and animals.

Biotic depletion

EVS d][Sc]T eWZR S_cWSR]b a]b]aS dSR O_OQZcbS]R cQbW]

Bivalves

4][[O[S]T O QZOaT O_ObWQ []ZZa OVOQSWhSRP eb QOZOSQc a dOZdSaXSWR gP OSfWZPS ligament along a hinge line. This class includes various edible species, many of which are cultivated (e.g. mussels, oysters, scallops, clams).

Cage culture

Culture of stocks in cages. Cages are rearing facilities enclosed on the bottom as well as on the sides by wooden, mesh or net screens. They allows natural water exchange through the lateral sides and in most cases below the cage.

Coastal aquaculture

The cultivation of aquatic organisms where the end product is raised in brackish and marine waters; earlier stages of the life cycle of these species may be spent in fresh waters or marine waters.

Cumulative energy demand

It represents the direct and indirect use of industrial energy required throughout the production process.

Dissolved oxygen

The amount of oxygen (mg/l O2) in solution in the water under existing atmospheric pressure, temperature and salinity. Sometimes also expressed as parts per million (ppm) or as percent of saturation level.

Ecological services

[illegible] water, maintenance of biodiversity, decomposition of wastes, soil and vegetation generation and renewal, pollination of crops and natural vegetation, groundwater recharge through wetlands, seed dispersal, greenhouse gas mitigation, and aesthetically pleasing landscapes.

Ecosystem

A natural entity (or a system) with distinct structures and relationships that liaise biotic communities (of plants and animals) to each other and to their abiotic environment. The study of an ecosystem provides a methodological basis for complex synthesis between organisms and their environment.

Ecosystem approach to aquaculture

An ecosystem approach to aquaculture (EAA) strives to balance diverse societal objectives, by taking account of the knowledge and uncertainties of biotic, abiotic and human components of ecosystems [illegible] ecologically and operationally meaningful boundaries.

Eutrophication

[illegible] subsequent reduction of dissolved oxygen. The Nutriphication Potential (NP) is set at 1 for phosphate (PO_4 [illegible]

Fatty acid

Organic acid composed of carbon, hydrogen and oxygen that combines with glycerol to form fats.

Feed conversion ratio (FCR)

[illegible]

Feedlot

[illegible] Feedlots are associated with both the provision of high energy feedstuffs and the generation of considerable amounts of high moisture content wastes.

Feedstuff

Any substance suitable for animal feed.

Fish oil

WZbOSSR]T b]bOZaVw]R g]]T waV eOaS Wa]WZS aSR WS [OcTOQbS]TaV SSRa
edible fats and industrial products.

Fishmeal

A]bSW WQV[SOZS RdSR]T]QSaaWU]WZW SaaWU gRU WBWU]ZS aW acOZZgOZa
SZOUWQ]w gROQbV OeSZZ SaWSa OR gP]R cQa]T waV]QSaaWU ZOa aVw]TOZ SR Fa
mainly as agriculture feeds for domestic livestock (poultry, pigs, cattle, etc.) and as aquaculture feeds for carnivorous aquatic species. It must contain not more than 10 percent moisture. If it contains more than 3 percent salt (NaCl), the amount of salt must constitute a part of the brand name, provided that in no case
[c ab VS OZbQ]S b]TWa]R cQb SSSR SQS b

Gastropods

A member of the largest class of phylum Mollusca. Characteristics generally include: a foot upon which the rest of the body (called the “visceral mass”) sits, a well-developed head, a protective one-piece shell, and body “torsion” - where most of the visceral mass is normally twisted anticlockwise 180 degrees so that the back end of the animal is positioned over its head. The class includes the snails, slugs, sea hares, sea slugs, limpets, conches and abalone.

Inland aquaculture

Aquaculture that takes place in freshwater.

Life cycle analysis

Life Cycle Assessment (LCA) is a method developed to evaluate the mass balance of inputs and outputs of systems and to organize and convert those inputs and outputs into environmental themes or categories relative to resource use, human health and ecological areas.

Mollusk

Invertebrate animal belonging to the phylum Mollusca with a soft unsegmented body and covered by a calcium carbonate shell, of 1 to 8 parts or sections. In some species the shell is lacking or reduced. The surface is coated with mucus and cilia. Major cultured mollusks are mussels, oysters, scallops, cockles, clams (bivalves) and abalone (gastropod).

Nitrogen

2]R ZSa USQa SZS[S VOb [OYSa c ,SQS b]TVS SOa Qb VS S RO WQ aWS b]T
all living tissue. It is almost inert in its gaseous form.

Pelagic

Relating to living or occurring in open water areas of lakes or oceans.

Pen culture

[illegible] free water exchange; in the intertidal zone, it may be solid-walled; the bottom of the structure, however, is always formed by the natural bottom of the water body where it is built; usually coastal e.g. in shallow lagoons, but also inland e.g. in lakes, reservoirs. A pen generally encloses a relatively large volume of water.

Poikilothermic

[illegible]

Recirculating system

[illegible] system is treated to enable its reuse.

[illegible]

[illegible] its low market value. Usually part of a (shrimp) trawler's bycatch. Often it is discarded at sea although an increasing proportion is used as human food or as feed in aquaculture and livestock feed.

Zoonotic

[illegible] disease that normally exists in animals but that can infect humans.

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