FAO FISHERIES AND AQUACULTURE TECHNICAL PAPER

583

ISSN 2070-7010

On-farm feeding and feed management in aquaculture

Cover photographs:
Left top to bottom: Feeding grow-out striped catfish (*Pangasianodon hypophthalmus*) with farm-made aquafeed from a feeding station, Mekong delta, Viet Nam (courtesy of FAO/T.P. Nguyen). A farmer feeding black tiger shrimp (*Penaeus monodon*) with commercially produced pelleted feed from levee during first month of rearing (courtesy of FAO/Umesh N. Ramasawamy).
Right: Feed distribution using automatic feeder for cage culture of Atlantic salmon (*Salmo salar*) near Bodo in Norway
(courtesy of Trevor Telfer).

Cover design:
Mohammad R. Hasan

On-farm feeding and feed management in aquaculture

FAO
FISHERIES AND
AQUACULTURE
TECHNICAL
PAPER

583

Edited by

Mohammad R. Hasan
Aquaculture Officer
Aquaculture Branch
FAO Fisheries and Aquaculture Department
Rome, Italy

and

Michael B. New
FAO Consultant
Marlow, Bucks
United Kingdom of Great Britain and Northern Ireland

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2013

ISBN 978-92-5-107978-2 (print)
E-ISBN 978-92-5-107979-9 (PDF)

Preparation of this document

This technical paper was prepared by a group of experts under the leadership of Dr Mohammad R. Hasan as a part of the Food and Agriculture Organization of the United Nations (FAO) Aquaculture Service's (FIRA) ongoing regular work programme on "Studies, reviews, guidelines and manuals on use of feed and nutrient in sustainable aquaculture development", under the organizational output "Aquaculture practices and technologies that comply with the Code of Conduct for Responsible Fisheries (CCRF) are developed and promoted".

This technical paper reviews the current status of on-farm feeding and feed management in aquaculture. It contains a) ten case studies on feeding and feed management practices carried out in seven selected countries of Asia (i.e., Bangladesh, China, India, Thailand, Viet Nam) and Africa (i.e., Egypt, Ghana) for eight species belonging to four major farmed species of freshwater finfish and shellfish: shrimp and prawns, Nile tilapia, striped catfish and Indian major carps; b) an analysis of the findings of these ten case studies and a case study for Indian major carps in India (published separately[1]); c) ten invited specialist reviews on feed management practices from regional and global perspectives and d) an overview of the current status of feed management practices with information drawn from the case studies, the invited reviews and other related publications. In addition, a targeted workshop entitled "On-farm feeding and feed management in aquaculture" was convened in Manila, the Philippines, from 13–15 September 2010 where all the above case study reports, analysis of case studies and invited review papers were presented. The workshop was organized by the Fisheries and Aquaculture Department Aquaculture Service (FIRA) and was hosted by the Southeast Asian Fisheries Development Center Aquaculture Department (SEAFDEC/AQD), Iloilo, the Philippines. The report of the workshop was published as a FAO Fisheries Report (www.fao.org/docrep/013/i1915e/i1915e00.pdf).

Before editorial work, the manuscripts in this technical paper were reviewed for technical content, FAO house style and linguistic quality by Dr Richard Arthur for the invited reviews and synthesis paper and by Dr Thomas Shipton for the case studies. For consistency and conformity, scientific and English common names of fish species were used from FishBase (www.fishbase.org/search.php).

Much gratitude is due to the authors of the invited reviews and case studies, who faced an enormous task and showed tremendous patience with the editors. Ms Tina Farmer and Ms Marianne Guyonnet are acknowledged for their assistance in quality control and FAO house style. Mr Koen Ivens prepared the layout design for printing, and Ms Danielle Rizcallah provided miscellaneous assistance. The publishing and distribution of the document were undertaken by FAO, Rome. Finally, Jiansan Jia, Chief of the Aquaculture Branch of the FAO Fisheries and Aquaculture Department is acknowledged for providing the necessary support, advice and insight to initiate the study and to complete the publication.

This publication is organized in three sections: a) Overview and Synthesis, b) Case Studies, and c) Invited Reviews. The publication is printed with the first section "overview and synthesis" while the whole volume is available on a CD–ROM accompanying the printed part of this publication.

[1] Ramakrishna, R., Shipton, T. & Hasan, M.R. 2013. Feeding and feed management of Indian major carps in Andhra Pradesh, India. FAO Fisheries and Aquaculture Technical Paper No. 578. Rome, FAO. 90 pp.

Abstract

This technical paper provides a comprehensive review of on-farm feeding and feed management practices in aquaculture. It comprises of a) ten case studies on feeding and feed management practices carried out in seven selected countries of Asia and Africa for eight species that belong to four major farmed species of freshwater finfish and shellfish; b) an analysis of the findings of the above ten case studies and a separately published case study for Indian major carps carried out in India; c) ten invited specialist reviews on feed management practices from regional and global perspectives; and d) an overview of the current status of feed management practices. The country-specific case studies were carried out for Nile tilapia (*Oreochromis niloticus*) in China, Thailand, the Philippines, Egypt and Ghana; Indian major carps [rohu (*Labeo rohita*), catla (*Catla catla*) and mrigal (*Cirrhinus cirrhosus*)] in India and Bangladesh, giant river prawns (*Macrobrachium rosenbergii*) in Bangladesh, striped catfish (*Pangasianodon hypophthalmus*) and whiteleg shrimp (*Litopenaeus vannamei*) in Viet Nam and black tiger shrimp (*Penaeus monodon*) in India. The broad thematic areas that were addressed in these case studies and invited reviews are: i) current feed types (including fertilizers) and their use in semi-intensive and intensive farming systems; ii) on-farm feed production and management; iii) feeding and feed management strategies, feed procurement, transportation and storage; iv) environmental, economic, regulatory and legal frameworks of feeding and feed management practices; and iv) identification of research needs. Based on the information presented in the eleven case studies, ten specialist reviews and from other relevant publications, an overview paper presents concluding remarks and recommendations on some of the major issues and constraints in optimizing feed production, use and management.

Hasan, M.R. & New, M.B., eds. 2013.
On-farm feeding and feed management in aquaculture.
FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 67 pp.
Includes a CD–ROM containing the full document (585 pp.).

Contents

Abbreviations and acronyms

ABW	average body weight
ADB	Asian Development Bank
AI	active ingredient
AIT	Asian Institute of Technology
ARI	Animal Research Institute, Ghana
BAFPS	Bureau of Agriculture and Fisheries Products Standards, Philippines
BAI	Bureau of Animal Industries, Philippines
BCR	benefit-cost ratio
BDT	Bangladesh taka
BFAR	Bureau of Fisheries and Aquatic Resources, Philippines
BFDC	Bangladesh Fisheries Development Corporation
BMP	better management practices
BOD	biochemical oxygen demand
BW	brackishwater
BWD	body weight per day
C	carbon
CAAC	Certification and Accreditation Administration of China
CAA	Coastal Aquaculture Authority, India
CAAP	concentrated aquatic animal production systems
CCRF	Code of Conduct for Responsible Fisheries
CFU	colony forming units
CIBA	Central Institute of Brackishwater Aquaculture, India
CIFA	Central Institute of Freshwater Aquaculture, India
CIFE	Central Institute of Fishery Education, India
COD	chemical oxygen demand
CP	crude protein
CSIR	Council for Scientific and Industrial Research, Ghana
CSIRO	Commonwealth Scientific and Industrial Research Organization, India
DAP	diammonium phosphate
DM	dry matter
DOC	days of culture
DoF	Directorate of Fisheries
EAN-UCC	European article numbering-uniform code council
ECAA	Extension Service Centre for Agriculture and Aquaculture, Viet Nam
EFS	extensive farming system
EIA	Export Inspection Agencies, India
EIC	Export Inspection Council, India
EM fungi	Ectomycorrhizal fungi
FAO	Food and Agriculture Organization of the United Nations
FaST	freshwater aquaculture centre selected tilapia
FBMA	Fisheries Bureau of Ministry of Agriculture, China
FCR	feed conversion ratio
FHS-BFAR	Fish Health Section of the Bureau of Fisheries and Aquatic Resources
FW	freshwater

g	gramme
GAFRD	General Authority for Fisheries Resources Development, Egypt
GAP	good aquaculture practices
GDP	gross domestic product
GIFT	genetically improved farmed tilapia
GST	genomar supreme tilapia
ha	hectare
HACCP	hazard analysis and critical control points
hCG	human chorionic gonadotropin
hrs	hours
ICAR	Indian Council of Agriculture Research
ICS	internal control system
IFN	international feed number
IMC	Indian major carps
INR	Indian rupee
IU	international units
kg	kilogramme
m	metre
MA	Ministry of Agriculture, China
MALR	Ministry of Agriculture and Land Reclamation, Egypt
MAR	Ministry of Agriculture and Rural Development, Viet Nam
MBV	Monodon baculovirus
MDCP	monodicalcium phosphate
MEFS	modified extensive farming system
mg	milligramme
mm	millimetre
MoFA	Ministry of Food and Agriculture, Ghana
MoFI	Ministry of Fisheries, Viet Nam
MP	muriate of potash
MPEDA	Marine Products Export Development Authority, India
MRP	maximum retail price
MSL	mean sea level
MT	million tonnes
mu	unit used for land measurement in China (1 mu = 666.7 square meters)
N	nitrogen
NACA	Network of Aquaculture Centres in Asia-Pacific
NaCSA	National Centre for Sustainable Aquaculture, India
NAFIQUAVED	National Fisheries Quality Assurance and Veterinary Directorate, Viet Nam
NFDB	National Fisheries Development Board, India
NFE	nitrogen free extracts
NPK	nitrogen, phosphorus and potassium
NR	net return
OM	organic matter
P	phosphorus
PG	pituitary gland
PL	postlarvae
ppm	parts per million
ppt	parts per thousand
RGCA	Rajiv Gandhi Centre for Aquaculture, India
RMA	rapid market appraisal
SEAFDEC	Southeast Asian Fisheries Development Center

SEERAD	Scottish Executive Environment and Rural Affairs Department
SIFS	semi-intensive farming systems
SIS	small indigenous fish species
SPF	specific-pathogen-free
SSP	single superphosphate
t	temperature
TBCAPMPA	Tilapia Branch, China Aquatic Products Marketing and Processing Association
TC	total costs
TFC	total fixed costs
TFS	traditional farming system
TGR	total gross revenue
TP	triple phosphate
TSP	triple super phosphate
TVC	total variable costs
US$	United States dollar
USAID	United Sates Agency for International Development
VASEP	Vietnam Association of Seafood Exporters & Producers
VAT	value added tax
WHO	World Health Organization
WLS	whiteleg shrimp
WRI	Water Research Institute, Ghana
WSSV	white spot syndrome virus
WWF	World Wildlife Fund
YHV	yellow head virus

SECTION A
OVERVIEW AND SYNTHESIS

An overview of the current status of feed management practices

Thomas A. Shipton[1a] and Mohammad R. Hasan[2]
[1]FAO Consultant
Grahamstown, South Africa
[2]Aquaculture Officer
Aquaculture Branch
FAO Fisheries and Aquaculture Department
Rome, Italy

Shipton, T.A. and Hasan, M.R. 2013. An overview of the current status of feed management practices. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture.* FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 3–20.

ABSTRACT

This paper presents an overview of the current status of feed production and on-farm feed management practices. It reviews some of the major issues and constraints in optimizing feeds and on-farm feed management practices. The analysis is based on the findings of the country- and species-specific case studies, regional, and specialist subject reviews that are presented in this technical paper. Providing farmers with well-balanced feed at cost-effective prices is a prerequisite to profitable production. Formulation issues, and in particular the provision of species-specific feeds that address the nutritional requirements of the different life stages of the farmed animal (larval, fry, grower, finisher and broodstock) remain important topics for both commercial and farm-made feed production sectors. Much of the aquafeeds used in Asia and Africa are either produced on-farm or by small-scale semi-commercial feed manufacturers, and improvements to the quality and preparation of these feeds are likely to bring about improved productivity and cost savings. The small-scale production sector is currently constrained by a number of factors including inadequate access to finance, a lack of technical innovations, an absence of feed formulation and processing knowledge, and training. The potential to develop public-private partnerships with farmer groups or associations to share resources and improve access to improved manufacturing capacity should be considered. The majority of the case studies revealed that farmers across many countries and sectors were unaware of the importance of appropriate feed handling and storage techniques. The importance of feed management practices in optimizing production parameters needs to be conveyed to farmers. The use and efficacy of automated feeding systems needs to be established, and the use of feed tables, feed and production records needs to be promoted. Farmers need to be provided with simple tools to monitor farm production indices (e.g. feed conversion efficiency and growth rate) and training on how to take corrective actions. In extensive and semi-intensive production systems, there is a need to establish the qualitative and quantitative relationships between natural pond productivity and the impact that the use of supplemental and farm-made feeds have on nutrient cycling and

[a] Present address: Department of Ichthyology and Fisheries Science, Rhodes University, Grahamstown, South Africa.

retention in the farmed species. Developing a better understanding of these dynamics is central to optimizing feed formulations and reducing feed costs. The implications of feed type, formulation and feed management practices on the environmental footprint and economics of the farming operation are important issues that farmers need to take into consideration when planning their farming activities. If farmers understand and can quantify the economic interrelationships between feed type and costs, performance and feed management, they can significantly improve their profitability. Economic tools for this purpose to assist farmers need to be developed. Poor regulatory control and a lack of standards throughout the aquafeed value chain are constraints to feed supply, quality and use. Appropriate aquafeed policy, regulatory frameworks, and feed standards need to be developed in those countries that do not already have them, and institutional capacity needs to be strengthened in those agencies responsible for monitoring and compliance. Training and the dissemination of information to farmers, particularly small-scale farmers that have limited access to the latest technological and management developments, are issues that need to be addressed. Weak extension and information dissemination networks result in low adoption rates of new feed production technologies and management practices. Consideration should be given to promoting programs that use the local media to provide farmers with extension messages, including, amongst others, up-to-date feed ingredient availability, quality, price and supplier information, feed formulation and ingredient inclusion rates.

1. INTRODUCTION

In semi-intensive and intensive aquaculture systems, feed costs typically account for between 40 and 60 percent of production costs (De Silva and Hasan, 2007). In order to ensure profitability, it is imperative that farmers have access to good quality feeds at reasonable prices, and that they optimize their feed use by instituting appropriate on-farm feed management practices. This paper presents an overview of the current status of feed production and on-farm feed management practices, and provides a review of some of the major issues and constraints to optimizing them. The analysis is based on the findings of the species-specific country case studies, regional reviews, and specialist subject reviews that are presented in this technical paper.

These case studies and regional reviews focused on feed and feed management practices for Nile tilapia (*Oreochromis niloticus*) in China, Egypt, Ghana, the Philippines, Thailand, and sub-Saharan Africa, the Indian major carps (*Catla catla, Labeo rohita, Cirrhinus cirrhosus*) in Bangladesh and India, striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam, North African catfish (*Clarias gariepinus*) in sub-Saharan Africa, whiteleg shrimp (*Litopenaeus vannamei*) in Viet Nam, black tiger shrimp (*Penaeus monodon*) in India and giant river prawns (*Macrobrachium rosenbergii*) in Bangladesh. The analysis also draws on selected reviews that focused on specific aspects of feed management, including environmental, economic, regulatory and manufacturing perspectives. Finally, it considers the outcomes of an FAO Expert Workshop on on-farm feed and feed management in aquaculture that was held in Manila, the Philippines, on the 13–15 September 2010 (FAO, 2010)[2].

2. SYNOPTIC REVIEW OF FARM-MADE AND COMMERCIAL FEED USE

As feed represents one of the highest operating costs in aquaculture systems (Hasan, 2007; Hasan *et al.*, 2007), feed choice and feed management practices have a significant impact on the economic performance of a production system. The type and value of feed inputs that farmers select is dependent upon a number of factors including

[2] http://www.fao.org/docrep/013/i1915e/i1915e00.pdf

the market (local, export) and the value of the fish, the financial resources available to the farmer, the species, the culture system and intensity of production. In general, inputs for low-value species that are grown for local consumption are usually limited to fertilizers, farm-made feeds or locally produced small-scale commercial feeds comprising one or more ingredient sources. Examples of these systems would include the Indian major carps cultured under extensive or semi–intensive conditions in India and Bangladesh (Ramakrishna, Shipton and Hasan, 2012; Sarder, 2013). In contrast, commercially manufactured pelleted feed inputs are used for high-value species that are cultured in intensive systems. Examples would include the salmonids in Europe and the Americas (Kaushik, 2013), and, increasingly, the high-value marine finfish (e.g. groupers, barramundi and snappers) that are increasingly produced across southeast Asia (Hasan, 2012a).

Rising competition for land and water resources is increasing pressures to improve productively through intensification. A move towards intensification of farming systems requires the adoption nutritionally complete feeds and is increasing the demand for both farm-made and commercially produced feeds (De Silva and Hasan, 2007; Rana, Siriwardena and Hasan, 2009). The case studies revealed this gradual shift towards intensification. For example in Egypt, the intensification of pond culture practices for Nile tilapia (*Oreochromis niloticus*) and the adoption of intensive cage culture technology have manifested as increased demand for commercially manufactured feeds, which now account for 60 percent and 100 percent of the feed used in these sectors respectively. This increase in demand has seen commercial feed manufacturing capacity in the country grow from 20 000 tonnes/annum in 1999 to 420 000 tonnes/annum in 2010 (El-Sayed, 2013). Likewise, a move towards intensification in black tiger shrimp (*Penaeus monodon*) production in India (Ramaswamy Mohan and Metian, 2013), Nile tilapia (*Oreochromis niloticus*) in the Philippines (Romana-Eguia, Laron and Catacutan, 2013), and striped catfish (*Pangasianodon hypophthalmus*) in Viet Nam (Nguyen, 2013) have also resulted in increases in the demand for commercially manufactured feeds.

Commercially manufactured feeds were reported to be available in all eight countries (Bangladesh, China, Egypt, Ghana, India, the Philippines, Thailand, and Viet Nam) where case studies were conducted and, with the exception of Ghana, all the countries reported commercial manufacturing capacity. Hecht (2007) noted that locally produced commercially manufactured feeds were only available in five sub-Saharan countries indicating that, in contrast with other producer regions (Europe, Asia and the Americas), sub-Saharan Africa generally lacks access to locally manufacturing capacity, and primarily relies on farm-made feeds or imported commercially produced feeds.

While commercially manufactured feeds are usually formulated to satisfy the nutritional requirements of specific species and their life stages, farm-made feeds typically comprise simple ingredients that, depending on the culture systems, are fed as simple mixtures, doughs or compressed pellets. While the quality of the farm-made feeds is dependent upon the formulation applied, the quality and availability of ingredients and the manufacturing processes, they are generally more affordable than commercially manufactured feeds, and remain the primary feed source for many semi-intensive farmers. For resource poor farmers, the relatively low cost of farm-made feeds enable them to procure small amounts of feed at any one time, promoting affordability and enabling them to better manage their on-farm cash flows.

The intensification of farming systems and the concomitant growth in demand for good quality, cost-effective farm-made feeds makes them increasingly important to sustaining sectorial growth, and it has been noted that one of the ways to improve aquaculture production is to improve the quality of farm-made feeds (De Silva and Davy, 1992; De Silva and Hasan, 2007).

Some production sectors have already seen significant improvements to the quality of farm-made feeds. For example, farmers in Viet Nam that use farm-made feeds for striped catfish production have improved their feed formulations and manufacturing techniques. Formulations now contain up to six ingredient sources, and the feeds are extruded to form semi-moist pellets with improved water stability (Nguyen, 2013). In Bangladesh, the development of farmer associations has improved farmers' access to information (e.g. formulations, ingredient supplies and costs), and enhances their buying power and access to production technologies. The associations enabled the farmers to negotiate better ingredient prices and purchase them in bulk; increasingly, these farmers also have access to small-scale commercial feed manufacturers that are willing to produce feed batches in relatively small quantities, thus providing a level of manufacturing technology and feed quality that would otherwise be unattainable (personal observation of the authors). In this regard, the potential to promote public/private partnerships between small-scale feed manufacturers and farmers/farmer associations as a mechanism to improve access to cost-effective quality feeds needs to be investigated further.

3. FEED MANAGEMENT – ISSUES AND CONSTRAINTS

3.1 Feed production and handling

3.1.1 Feed formulation

Providing farmers with nutritionally balanced feeds is a prerequisite to cost-effective production. Formulation issues, in particular the provision of species-specific feeds that address the nutritional requirements of the different life stages of the farmed animal (larval, fry, grower, finisher and broodstock) remain issues for both commercial and farm-made feed production sectors.

Many of the commercially manufactured formulations that are available to farmers are based on laboratory formulations using high quality ingredients; few are conducted under commercial farming conditions. Formulations based solely on laboratory experiments do not always translate well to commercial conditions, where lower quality feed ingredients and least-cost formulae are applied. Likewise, the formulations are not always supported by rigorous scientific research, are poorly formulated, and sold to farmers who may be unaware of the nutritional requirements of their farmed species. Hasan (2012a) cited this problem in the expanding marine finfish sector in Southeast Asia where farmers were being encouraged to use the same commercial formulation for barramundi (*Lates calcarifer*) and grouper culture – two species groups that have different nutritional requirements. Indeed, the use of inappropriate formulations was found to be a common problem across a wide number of sectors. For example tilapia farmers in China were reported to use commercial grow-out formulations that contained a higher level of dietary protein than required (MoA, 2005) and tilapia farmers in Thailand were reported regularly to use commercial grow-out feeds that were designed for catfish and carps (Bhujel, 2013). In Viet Nam, striped catfish farmers reported using grow-out feeds that contained protein levels that were sub-optimal for the larger size classes (Nguyen, 2013). Despite the availability of manufactured feeds designed for the whiteleg shrimp (*Penaeus vannamei*), farmers reported using feeds that were designed for black tiger shrimp (*Penaeus monodon*); these have a higher protein level than is required by the species (Hung and Quy, 2013). The use of poorly formulated feeds that fail to satisfy the nutritional requirements of the species and their various life stages will inevitably result in feed inefficiencies and raised production costs. Evidently there is a need to inform farmers, feed suppliers and unregulated feed manufacturers of the importance of selecting and supplying appropriate species and size-specific formulations.

Some commercial formulations designed for specific life stages (e.g. fry, fingerling and grower) are so similar in terms of their nutrient content as to be virtually indistinguishable. This raises a number of issues including the nutritional rationale behind the formulations, the relationship between the nutrient inclusion rates and cost differentials, and the ability of the manufacturers to maintain such small differences reliably in the nutrient levels in the feed. Resolving these issues and ensuring that farmers are supplied with appropriate formulations at cost-effective prices should be viewed as a priority, and will without doubt improve the economic performance of the farming operations.

While a significant amount of research has been undertaken to establish the nutritional requirements of many of the species groups, much of this has not been communicated to the farmers producing farm-made feeds or to small-scale feed manufacturers. Evidently, many farmers producing farm-made feeds are often unaware of the nutrient requirements of their farmed species, notably dietary protein and energy levels and how these change over the production cycle (White, 2013). Formulations are often based on past experience (what the farmers themselves have found to work), feed ingredient availability and cost, and advice from other farmers and feed ingredient suppliers. For example in Thailand, tilapia farmers indicated that they lacked basic information that they could use as formulation templates (Bhujel, 2013). The provision of simple training manuals focusing on the nutritional requirements of the farmed species, the availability, quality, composition, and cost of local feed ingredient sources, and methods to formulate feeds that satisfy specific nutritional requirements would significantly improve the quality of their formulations; it would also improve the economic efficiency of their farming operations. Training and information dissemination requirements are addressed in detail in Section 3.6.

3.1.2 Manufacturing technologies

Much of the aquafeeds used in Asia and Africa are either produced on-farm or by small-scale semi-commercial feed manufacturers (De Silva and Hasan, 2007; Hecht, 2007). Improvements to the quality and preparation of on-farm feeds are likely to bring about improved productivity and cost savings (Hasan *et al.*, 2007). Notwithstanding the quality of the feed ingredients used and the formulations applied, the manufacturing processes and type of feed produced can significantly affect feed performance. While farmers generally recognize the need to use quality feed ingredients, they often appear unaware that feed processing has a significant effect on feed quality and utilization. For example in China many of the feed ingredients that are used in farm-made tilapia feeds are poorly milled and fail to conform to the feed process standards as outlined by the national feed guidelines (Liu *et al.*, 2013; MoA, 2005). Presenting feeds as simple dry or moist mixtures or as moist mixed feeds leads to much of the feed being dispersed in the water column, resulting in low ingestion rates and high economic feed conversion ratios (eFCR). Feed efficiencies can be improved by encouraging farmers to use simple extruders and compressing their feed ingredients into dry pellets. Likewise, improving milling and the binding characteristics of the pellets reduces the amount of fines, improves pellet hardness and water stability, improves eFCR, and results in cost savings to the farmer (Rana and Hasan, 2013).

Focusing on improving efficiencies in the farm-made and small-scale feed manufacturing sectors is likely to bring significant gains to on-farm feed efficiencies. These sectors are currently constrained by a number of factors including inadequate access to finance, technical innovations, feed formulation and processing knowledge, and training. The potential to develop public-private partnerships with farmer groups and associations to share resources and improve access to improved manufacturing capacity should be considered.

3.1.3 Feed transport, storage and handling

The majority of the case studies revealed that farmers were generally unaware of the importance of applying appropriate feed transport, handling and storage techniques. Imported commercial diets are particularly vulnerable to spoilage during shipping because sea freight storage conditions are sometimes suboptimal and, depending on the route, delivery times can be significant. Likewise transporting feeds in open trucks, motorbikes and bicycles can also result in long transit times and, on poor roads, this can result in the pellets being damaged, and a concomitant increase in fines (Rana and Hasan, 2013). In the Philippines, the majority of tilapia farmers were found to be unfamiliar with feed storage issues, and tended only to learn about appropriate storage practices after experiencing feed storage problems (Romana-Eguia, Laron and Catacutan, 2013). Poor feed storage practices manifest as a range of malpractices, ranging from the surveyed tilapia farmers of Ghana that stored their feeds in the open or under tarpaulins at night, exposing them to moisture, pests and inclement weather (Awity, 2013), to Indian shrimp farmers that were storing their feeds in metal containers and exposing them to the sun and excessive heat (Ramaswamy, Mohan and Metian, 2013). Inappropriate feed storage conditions can result in nutrient loss, feed spoilage, lower yield and poor economic returns. Prolonged exposure to unfavorable storage conditions and exposure to light, heat, humidity, air and water, or microbial/ pest infestation (bacteria, fungi, insects and rodents) negatively impacts feed quality (Tacon, Jory and Nunes, 2013). Feeds should be stored in cool ventilated areas that are not exposed to the elements and extremes of heat and humidity and are protected from pests; feeds should also be used on a first in: first out basis. Hecht (2007) reported that small-scale feed producers and fish farms usually have small facilities that do not allow the bulk purchase of raw materials when prices are low, adding to feed costs. Where necessary, better management guidelines focusing on feed storage and handling issues need to be developed and communicated to the farmers (FAO, 2010; Section 3.6).

3.1.4 Top dressing and feed additives

The addition of chemicals to feeds by the farmers, known as "top dressing", usually requires the finished feeds to be sprayed with materials that are absorbed into the feeds. This process is generally used to add therapeutants, probiotics or nutrients that the farmers believe to be deficient or absent in the feeds or that act as feed attractants to stimulate consumption. This practice has been reported across a number of sectors. For example, 75 percent of the Indian shrimp farmers reported using probiotics and feed additives, adding US$39/tonne to the feed cost (Ramaswamy, Mohan and Metian, 2013).

The major concerns related to the practice of top dressing include the source and quality of the chemicals that are applied and their cost and efficacy. Of particular concern is the control and use of therapeutants such as antibiotics and hormones. In addition to the possible legality of using these chemicals, if applied incorrectly their use may result in animals being dosed at sub-optimal levels impacting their efficacy, possibly promoting disease resistance, and negatively impacting the environment. In addition, if farmers purchase their medicines from unscrupulous traders, they may end up using inappropriate chemicals that are either illegal, adulterated or of poor quality with low levels of active compounds, or not fit for purpose (Robb and Crampton, 2013). Additional concerns include worker exposure to active chemicals, and consumer safety because of farmers not applying the correct withdrawal periods. While many countries have developed regulations to control the use of veterinarian medicines in aquafeeds, compliance is often lacking, and regulatory authorities are often ill equipped to monitor their distribution and use.

A further issue is the cost and the efficacy of the chemicals that are being applied. It is evident that many farmers are using additives in the belief that they are improving their production parameters but few of these products have been empirically tested in terms of their efficacy and their cost effectiveness. It remains unclear whether the farmers are simply adding to their production costs, or whether there are real and demonstrable advantages from their use.

Depending upon the sector and the country, addressing these issues will probably require a number of interventions including farmer education; the development of better management practices to inform farmers when and how to top dress their feed and of the legal status of the therapeutants and chemicals; improvements in regulatory controls and compliance; and research to establish the efficacy and cost effectiveness of the various additives chemicals that are in use.

3.2 Feed monitoring and on-farm feed management

3.2.1 Optimizing feed management strategies

The profitability of a commercial farming operation is of paramount importance to the farmer. Adopting appropriate feed management strategies is instrumental in ensuring that feed use is optimized and that the highest economic returns are available to the farmer (FAO, 2010). While maximum growth rates will be attained by feeding to satiation, over- or under-feeding will result in feed inefficiencies (Kaushik, 2000) and, in the case of over-feeding, increased levels of farm effluents. Underfeeding manifests itself in lowered growth rates and increases in size heterogeneity in the population as hierarchies develop (Jobling, 1983; Houlihan, Boujard and Jobling, 2001). Optimization of feeding strategies requires farmers to calculate appropriate ration sizes and feeding rates, feeding frequencies, and feeding times that take into consideration the endogenous feeding rhythms of the farmed species. The case studies reported in this document revealed that farmers that are using commercially manufactured feeds are often but not always supplied with feeding tables, and are provided with technical support to assist them in determining ration sizes and feeding schedules. In many respects it is in the interest of the feed manufacturing company to ensure that their feeds are used appropriately - it promotes good production outcomes for the farmers and enables them to develop long term commercial relationships. Farmers that perceive that they are getting poor growth responses from a feed will quickly change their supplier. Those farmers that are using farm-made feeds and purchase feed ingredients from suppliers are less likely to have access to the information that they need to determine how they should design their feeding regimes. In the absence of this information, farmers will find it difficult to determine appropriate feed rations, and in many respects, they are more likely to adopt inappropriate feeding strategies.

Nevertheless, even when feed tables are available, the surveys carried out in the case studies revealed that many farmers do not use them, or apply them inappropriately. In China, Liu *et al.* (2013) found that the majority of tilapia farmers did not feed their fish according to the prescribed rates suggested by their feed tables, and failed to take into consideration ambient temperature, body mass and pond biomass when determining feed rations. Perhaps not surprisingly, the one survey farmer that maintained feed records and adjusted feed rates according to the prescribed feed tables reported the best feed conversion ratios, attesting to the importance attached to optimizing feed management practices. Likewise, the Indian major carp farmers surveyed in Bangladesh did not generally monitor their feed use, or use FCR to determine feed efficiencies (Sarder, 2013), probably resulting in farmers feeding sub-optimally. While the use of farm records to monitor feed use and efficiency was variable across the case studies, it was evident that many farmers were not keeping adequate production records; relatively simple farm data such as stocking rates, mortality, feed use and water quality were not always being recorded. In the absence of this data it is difficult for farmers to assess and monitor the efficacy of their production systems and to determine whether changes to their management strategies have demonstrable improvements on production efficiencies. There is a clear need to train farmers in feed management practices, promote the use of feed tables and ensure that farmers maintain adequate feed and production records.

An aspect of feed management that is often overlooked is the human dimension. Tacon, Jory and Nunes (2013) noted that on the larger shrimp farms, feeding is often the remit of those workers who often lack technical understanding of the importance of optimizing feed management, are poorly paid, and are seldom incentivized to improve feed management and efficiency. Unsurprisingly, feed management under these conditions is often far from optimal. Indeed on some commercial tilapia farms in Malaysia, it was reported that hired farm workers tended to overfeed the fish in the mistaken belief that feeding more produced higher growth rates (Ng *et al.*, 2013). Tacon, Jory and Nunes (2013) further drew attention to the fact that feed management regimes in shrimp culture are often designed to suit the farmer or farm worker, and have little regard to the behavioral preferences of the farmed species. As shrimp feeding activity is highest during the night, feed regimes should focus on delivering feed at night - not during the daylight hours when it is convenient for those presenting the feed.

In many instances innovative farmers have reported developing their own feeding strategies to optimize feed use. For example, in Andhra Pradesh, India, the majority of Indian major carp farmers reported that they spread their farm-made feeds at fixed points in their ponds (Ramakrishna, Shipton and Hasan, 2013). Simply placing their mash feeds in this manner resulted in much of it being dispersed in the water column and being wasted. More innovative farmers employed a “bag feeding” method in which the feed mixtures were placed in bags that were located throughout the pond. This method, also reported by the Indian major carp farmers of Bangladesh, promotes demand feeding and results in higher growth rates, improved feed ingestion rates, and higher retention rates because less feed is lost to the water column (Sarder, 2013). Other innovative feed management practices reported by the carp farmers in Andhra Pradesh included the development of restrictive feeding regimes, in which the fish are left unfed for one day in every ten days – a practice that is designed to reduce feed costs and stimulate compensatory growth. A similar restrictive feeding practice was reported by some of the striped catfish farmers in Viet Nam (Duong, Le and Nguyen, 2010). While the potential for restrictive feeding regimes has been demonstrated experimentally in the North African catfish (*Clarias gariepinus*) in Africa (Hecht, 2013), it has yet to be adopted as a farming strategy (Ali, 2001; Ali and Jauncey, 2004); carp farmers in Andhra Pradesh have also developed “break feeding schedules” in which feed rations are split into two rations, delayed by 20 minutes (Ramakrishna, Shipton and Hasan, 2013). The practice allows the dominant fish to be fed to satiation during the first round, and the smaller fish to reach satiation during the second feed round. As the practice improves satiation levels across the entire culture population, it promotes minimal size variations at harvest. Additional strategies include: 1) the use of feeding enclosures to make it easier to apply floating feeds and prevent feed wastage, and 2) cooking selected mash feed ingredients that are high in starch (e.g. broken rice) to promote gelatinization, increase digestibility and nutrient availability (Nandeesha, Sentilkumar and Antony Jesu Prabhu, 2013). Evidently, the role that the innovative farmers play in improving on-farm feed management practices is an important one, and mechanisms need to be developed to promote and communicate these innovations to other farmers (Section 3.6).

3.2.2 The role of natural productivity and the implications for feed management

Promoting natural productivity to provide a feed source for low trophic feeders such as tilapia, carp and shrimp is a common practice that was widely reported in the case studies. The use of inorganic and organic fertilizers in extensive and semi-intensive production systems is a well-established practice; however, considerable differences exist in the type of fertilizers used and in their availability, cost, and application rates. While many farmers were able to maintain natural productivity adequately in their culture systems, others, most notably in Africa, were reported to fertilize at sub-optimal levels resulting in lower levels of production (Hecht, 2007; Pouomogne, 2007; Abban, 2005). In such cases, training farmers to use simple indicators to measure the levels of natural productivity in their ponds and providing information to enable them to manage their phytoplankton, zooplankton, benthos and periphyton production through appropriate fertilizer use would improve their production efficiencies.

The need to establish the qualitative and quantitative relationships between natural productivity and the impact that the use of supplemental and farm-made feeds have on nutrient cycling and retention in the culture may be also be pertinent to improving production efficiencies in extensive and semi-intensive production systems. The comparative role of feeds versus natural productivity on the nutrition of the farmed animals is poorly understood. Feeds often play a dual role by providing nutrition to the animals being farmed and as a nutrient source to stimulate natural productivity. Developing a better understanding of these dynamics is central to improving nutrient retention in the farmed species and the culture system, improving feed formulation, reducing feed costs and improving the efficacy of feed management systems.

3.2.3 The use and efficacy of feeding devices

Kaushik (2013) presented a review of the feeding devices that have been developed for salmonids and are increasingly being applied to other species groups. The case studies demonstrated that small-scale farmers generally rely on hand feeding; only selected sectors have embraced automated feeding devices. For example, while the majority of tilapia farmers in China use automated feeding systems (Liu *et al.*, 2013), they were only reported on selected farms in Thailand and Malaysia and were absent from the Philippines, Ghana and much of the rest of sub-Saharan Africa, where the majority of small-scale farmers still rely on hand feeding. A similar situation was found with the Indian major carp producers; with the exception of some feeding strategies such as the "bag feeding" technique, which is effectively a simple form of demand feeding, farmers also tended to rely on hand feeding. Shrimp production is also primarily based on hand feeding and the use of feeding trays to monitor consumption.

While hand feeding has the advantage of enabling farmers to monitor feeding behavior and adjust rations accordingly, automated feeders can be cost effective, reduce labor requirements, and allow large volumes of feed to be fed efficiently. In the case of demand feeders, they have the advantage over hand feeding in that they take into consideration the behavioral rhythms of the farmed species, return of appetite, and the nutritional quality of the diet. The choice and complexity of the automated systems required is dependent on the farmed species, the size of the fish and the design of the culture system (Kaushik, 2013). For example, simple belt feeders can be used in hatcheries to supply low quantities of feed to fry which often require feed on a near continuous basis. In grow-out systems, more complex systems such as static demand feeders and movable mechanical systems based on compressed air can be applied. In those species where feeding hierarchies develop, computer controlled automated feeders using video or infrared sensors to monitor consumption can be particularly effective in ensuring that all the fish are fed to satiation. For example, while dominant Atlantic salmon feed voraciously at the surface and reach satiation rapidly, the subdominant fish eat lower in the water column and take longer to reach satiation. Linking feed monitoring systems to automated feeders ensures that both the dominant and subdominant fish are fed to satiation (Robb and Crampton, 2013).

While many of the more complex systems require electricity and a relatively high level of technical expertise, they would also be costly to install and operate making them unsuitable for small-scale rural producers. However, there are alternatives, such as simple mechanical demand feeders that could be used by small-scale farmers to improve their on-farm feed management. The use and efficacy of these systems needs to be established and, where appropriate, their adoption encouraged.

3.3 Feed management and the environment

Feed quality and feed management practices play a significant role in the environmental impacts that add to a farming operation. Inappropriate feeding strategies, and in particular those that result in overfeeding are a major cause of excess nutrients entering the environment. Overfeeding causes reduced feed efficiencies (Talbot, Corneillie and Korsøen, 1999), increased feed wastage (Thorpe and Cho, 1995) and in many cases increased environmental degradation (Cho and Bureau, 1998). Depending upon the efficiency of the feed formulation and the feed management practices, approximately 15–25 percent of the nitrogen in the feed is retained by the culture animals with the remainder entering the surrounding environment in either soluble or particulate form (Boyd and Clay, 2002). Likewise over 75 percent of the total carbon and phosphorus that is provided in the feed is excreted via the gills or released as particulate matter (Holby and Hall, 1991; Hall *et al.*, 1992). The negative environmental impacts associated with nutrient and organic enrichment include increases in the biochemical oxygen demand in the water bodies and sediments (anoxic sediments), changes to community structures and eutrophication (Barg and Phillips, 1997).

Optimizing feed formulation, quality and feed management practices can play a key role in limiting nutrient inputs into the aquatic environment, and minimizing the environmental impacts of farming operations. The high feed conversion ratios that are associated with poor quality feeds and/or poor feed management practices manifest as increased nutrient loadings, and an increased potential to impact the receiving environment negatively. The case studies reported large variations in FCR that were attributed to both feed type and feed management. For example, in semi-intensive striped catfish pond culture in Viet Nam, Nguyen (2013) reported FCR of 1.6:1 and 2.9:1 when commercially manufactured and farm-made feeds were used respectively. While the nutritional composition and feed management practices would have differed between the two feed types, the result suggests that commercially manufactured pellets were more efficient than the farm-made feeds, and the commercially manufactured feeds would have probably resulted in lower effluent loadings. Likewise in India, in semi-intensive pond culture of the Indian major carps, Ramakrishna, Shipton and Hasan (2013) reported FCR of 1.8–3.4:1 and 2.3–4.1:1 using commercially manufactured pellets and farm-made feeds respectively. Despite differences in feed formulations and feed management practices, it is reasonable to suggest that the commercial feeds would generally have produced lower emissions.

A common theme across the case studies was the quality, availability (temporal and spatial) and high costs associated with many of the feed ingredients used in farm-made feeds. Often the quality of farm-made feeds depends on ingredient availability, cost and farmers' perceptions of the correct quantities to use. As nutritional imbalances lead to reduced production performances and increased effluent, there is often a need to improve the on-farm feed formulations that the farmers apply. The use of cost-effective formulations that are water stable, palatable, have a nutrient composition that targets the specific developmental stage of the fish and, where appropriate, take into consideration the endogenous availability of natural food organisms (e.g. shrimp culture, semi-intensive Indian major carps and tilapia culture) will improve production parameters (growth and FCR), improve the economic efficiency of the operations, and have a positive effect on the environmental impact of the farming operation.

Similarly, poor feed handling, storage and spoilage prior to ingestion will result in poor feed efficiencies and increased environmental degradation. Sub-optimal feed management strategies, and the need to develop and promote better feed management practices were cited as priority interventions in many of the case studies presented. Improving feed management practices would improve production economics and reduce the environmental impacts associated with the farming operations.

3.4 The economics of feed management

The implications of feed type, formulation and feed management practices on the economics of the farming operation are important issues that farmers need to take into consideration when planning their farming activities. While these economic interrelationships are often difficult for farmers to assess, they can have a profound effect on the profitability of the farming operation (FAO, 2010; Shipton and Hecht, 2013).

These relationships are most evident in highly competitive sectors where feed costs represent a high percentage of the production cost, the farm-gate prices are low, and profitability is marginal. Nguyen (2013) demonstrated that when striped catfish farmers in Viet Nam used commercially manufactured feeds, their feed costs accounted for 82.9 percent of total production costs. When a mixture of farm-made feeds and commercially manufactured feeds were used, this percentage was reduced to 79.0 percent, and further reduced to 77.4 percent when farm-made feeds were used as the sole food source. While using farm-made feeds appears to be the cheaper option, and switching to them reduces investment costs, they are less efficient in terms of growth and FCR; thus, in terms of real production costs (cost/kg fish produced), they are more expensive to use. This study demonstrated that the total cost of production using farm-made feeds was US$0.88/kg fish, whereas it was US$0.79/kg fish for farmers using commercially manufactured feeds or a combination of commercially manufactured and farm-made feeds. Feeding commercially manufactured feeds or in combination with farm-made feeds thus increased profits by US$0.09/kg compared to the exclusive use of farm-made feeds. This represents a significant cost saving – which is of critical importance when farm gate prices are so low. Nguyen (2013) noted that the high cost of commercially manufactured pellets had forced some resource poor farmers to revert to farm-made feeds, or to use them when farm-gate prices were low. While there is some scope for substitution with farm-made feeds, the economic analysis suggests that while reverting to farm-made feeds may reduce feed costs, farmers need to recognize that there will be a concomitant reduction in profits. Evidently, resource poor farmers resort to the cheaper farm-made feeds when they are unable to afford the more expensive but ultimately more productive and profitable commercially manufactured feeds. In some sectors, credit schemes between feed manufacturers, dealers and the farmers have been developed. These types of micro-lending models need to be encouraged and novel ways to fund feed purchases sought, possibly through the development of farmer groups and associations, bulk buying schemes, the involvement of banks and micro-lending institutions, and the development of public-private partnerships.

The relationship between feed management practices and the economic efficiency of the farming operation is an important consideration for farmers, and provides them with the rationale for choosing one feed management practice over another. Using a bio-economic model of an intensive re-circulation system for culturing the Japanese meagre (*Argylosomus japonicus*), Shipton and Hecht (2013) demonstrated how deteriorating feed management practices, manifesting as a reduction in FCR, impacted the economic viability of the farming operation. As a simple example, on a 600 tonne per annum farm it was established that a increase in FCR from 1.0:1 to 1.6:1 increased feed costs as a percentage of total production costs from 36.2 percent to 46.1 percent, and increased annual farm operational costs by 22.9 percent. The analysis highlighted the economic importance of optimizing those feed management practices that impact FCR – and, ultimately, profitability. Amongst others, these include optimizing feeding frequency, ration and rearing temperature. In tilapia culture in Thailand, Bhujel (2013) also considered the use of feed and their effect on culture periods and production costs; he concluded that, as well as the factors outlined above, additional factors such as land, water and pond excavation costs also need to be considered. In those cases in which the cost of land rental or purchase was expensive then higher density fed-lot type systems become a more economically viable option.

Farmers need to consider a large number of parameters that affect on-farm feed utilization, and ultimately profitability. Principal amongst these are: systems design (e.g. extensive versus intensive farming systems); operational parameters (e.g. temperature, water quality); feed type and formulation; and feed management practices (e.g. feeding schedules). In general, farmers do not have access to this information, and there is a need to develop economic tools to assist farmers to understand the implications of their feed choices and management strategies.

3.5 Aquafeed policy, regulations and governance

In many case studies, poor regulatory control and a lack of standards throughout the aquafeed value chain were cited as constraints to feed supply, quality and use. Major issues reported were: the use of poor quality or adulterated ingredients; a failure to use appropriate product labeling; and the misrepresentation of products and/or a lack of standard feed specifications, resulting in inappropriate formulations being sold to farmers. As there has been limited assessment of the quality of the feeds that are available (Kader, Hossain and Hasan, 2005), farmers are usually reliant on feed ingredient suppliers and manufacturers to provide quality products. This issue is particularly pertinent to resource-poor, small-scale farmers who, on purchasing poor quality or sub-standard feeds and feed ingredients, have little practical recourse to the supplier or manufacturer. In the light of these issues, the role of aquafeed regulation and governance in ensuring the quality of feed and feed ingredients and optimizing production becomes pertinent (FAO, 2010).

A review of the governance mechanisms and the role that legal, policy and regulatory instruments play in ensuring feed quality revealed that there were significant regional variations in the regulatory instruments that are used to control the sector. It was evident that the quality of commercially manufactured feeds is generally high in developed countries where the sector is characterized by large-scale industrial production and fewer feed manufacturers (a more consolidated feed manufacturing sector). In these countries, the regulations relating to feed manufacturing, use and management are designed to ensure feed quality and to limit the environmental impact of their use (Shipton and Hecht, 2013). In contrast, in less developed regions such as Asia, many production sectors are dominated by small-scale farmers using farm-made feeds or commercially manufactured feeds procured from a pool of small-scale feed manufacturers. Arguably, in these areas, regulations are more focused on regulating feed quality and ensuring that farmers have access to good quality feeds, with less emphasis on the environmental impact of their use. In practice, few countries in Asia have the regulatory measures in place to check ingredient and feed quality on a regular basis (De Silva and Hasan, 2007); regulatory measures are certainly less available in other regions such as sub-Saharan Africa (Hecht, 2007; El-Sayed, 2013).

Nevertheless, there are positive signs of appropriate feed regulatory frameworks starting to be developed and adopted in less developed producer countries. For example, Bangladesh and Viet Nam have recently introduced new regulatory frameworks for the manufacture and trade of aquafeeds (Hasan, 2012b; Nguyen, 2013). In Viet Nam, these new dispensations require feed mills to be registered, feed standards to be applied, and regular product monitoring to be carried out (Nguyen, 2013). In contrast, in India, there are currently no feed regulations in place for freshwater aquaculture. However, in saline and brackishwater systems, the Coastal Aquaculture Authority (CAA) has limited powers to review feed mill registration, and the aquafeed manufacturing industry is currently subject to voluntary codes of practice. The CAA is planning to introduce a legally binding framework in the near future (Ramaswamy, Mohan and Metian, 2013). In sub-Saharan Africa, no regulatory standards exist in terms of feed composition, feed performance, feed use, effluent treatment or levels, and no codes of conduct or better management practices have been developed or adopted (El-Sayed, 2013).

Traditionally, government agencies provide the legal, policy and regulatory frameworks under which aquaculture and aquafeed use is controlled. In recent years, the emergence of certification bodies such as the Aquaculture Stewardship Council (ASC), the Aquaculture Certification Council (ACC) and the Global Aquaculture Alliance (GAA) has seen a new approach to governance. In many respects these "non-state, market-driven" systems (Vandergeest, 2007) now compete with traditional governmental regulators, in what some authors have termed "the privatization of governance" (Gereffi, Garcia-Johnson and Sasser, 2001). Increasingly, market access, and in particular export orientated markets to the developed world, are being driven by certification programs and compliance standards. Feed and feed use are major components of these standards, and from a market access perspective, it is becoming increasingly important that governments put in place regulatory measures to control and monitor feeds and feed ingredient quality to ensure compliance.

The development of regulatory frameworks to control the quality of feeds available to farmers needs to be accompanied by institutional capacity to enforce the regulations and ensure compliance. Monitoring feed production and quality is a complex and expensive undertaking, and the case studies suggest that many of the countries that have developed appropriate regulatory frameworks lack the institutional capacity to enforce them. The role that non-government actors such as the national feed industry associations can play in facilitating the sustainable development of the aquafeed manufacturing sector also needs to considered (Tacon and Hasan, 2007).

3.6 Training and developing information networks to improve feed management

Training and the dissemination of information to farmers and particularly small-scale farmers that have limited exposure to the latest technological and management developments is an issue that needs to be addressed (FAO, 2010). Most farmers using farm-made feeds operate at the household level and have relatively limited education; thus the transfer of complex technical messages is problematic and requires continuous attention (Hasan *et al.*, 2007). Weak extension and information dissemination networks result in low adoption rates of new feed production technologies and better management practices.

Farmer clusters and associations have proved an effective platform for information dissemination and promoting farmer to farmer training. Farmer clustering is becoming increasingly prevalent across Asia, and is more recently being adopted in some African countries. For example in Kenya, tilapia farmers are now being encouraged to form farmer associations (AquaFish CRSP, 2009), and across Asia, small-scale shrimp farmers in India, Indonesia, Bangladesh and Viet Nam are increasingly becoming organized into groups/clusters. In addition, the identification and training of key innovative farmers to train other farmers, and farmer field schools have proved successful and need to be promoted further. While training needs are sector specific and are described in more detail in the case studies, it is clear that they generally focus on the need to improve feed formulations; formulate species- and life-stage specific diets; and improve the understanding of ingredient quality, nutrient composition and selection, manufacturing processes, storage, and on-farm feed management practices.

Access to up-to-date market information for small-scale feed manufacturers and farmers producing farm-made feeds is an issue that needs to be addressed. While large-scale manufacturing operations generally have access to, and are aware of the cost, availability and nutrient composition of the ingredients that are on the market, this is not always the case for the farmers and small-scale feed manufacturers. Contemporary market information including sources, suppliers, quality and cost is a prerequisite to the development of cost-effective farm-made feeds. Furthermore, the use of appropriate local and seasonally available feed ingredients that can be incorporated into farm-made feeds also needs to be encouraged. Farmers and small-scale feed manufacturers need to be made aware of the availability of these ingredient sources, and how they can best be incorporated into their formulations. Currently, information networks are either inefficient or lacking, and there is a need to promote programs that use local media to supply farmers with up-to-date feed ingredient availability, quality, price and supplier details. In addition, farmers require access to information pertaining to species-specific feed formulations and ingredient inclusion rates. Area-specific databases containing feed ingredient supply and cost information that are easily accessed by farmers and small-scale feed manufacturers could also be considered.

4. RECOMMENDATIONS

The following recommendations are based on the issues and constraints highlighted in the case studies and reviews in this technical paper. Improvements to the nutritional quality, methods of preparation and on-farm management of aquafeeds will bring about productivity gains and cost savings to farmers; thus the majority of these recommendations pertain to the quality of the aquafeeds and on-farm feed management practices. Recommendations relating to the broader issues of training needs, information dissemination and regulatory frameworks are also provided.

1. Initiate research and development programs that focus on improving the nutritional quality of farm-made aquafeeds. Provide farmers and small-scale feed manufacturers with species and life-stage specific feed formulations that take into consideration existing knowledge, ingredient quality and seasonal availability, processing technologies, performance and price.
2. Improve on-farm and small-scale feed manufacturing technologies, feed handling and storage techniques. Technical and financial support to this manufacturing sector will improve feed quality, reduce feed costs and increase farm productivity. The potential to develop public-private partnerships with farmer groups and associations to share resources and facilitate access to improved manufacturing capacity should be considered.
3. Determine the extent and efficacy of "top dressing" procedures. Establish the dose, efficacy and cost-effectiveness of the chemicals and materials used. Characterize the environmental impacts associated with their use. Where appropriate, develop policy, regulations and guidelines to control and monitor their use.
4. Teach farmers about the importance of feed management practices in optimizing production parameters. Establish the use and efficacy of automated feeding systems and promote the use of feeding tables and maintaining feed and production records. Provide farmers with simple tools to monitor farm production indices and training on how to take corrective actions.
5. Establish the roles that natural productivity, feed and fertilizer use have on nutrient recycling and retention in extensive and semi-intensive production systems. Develop appropriate feed formulations that take into consideration the role of natural productivity in providing nutrition to the culture animals.
6. Develop monitoring protocols to assist farmers to optimize natural productivity in their extensive and semi-intensive production systems.
7. Identify and optimize new feed management practices and develop better management practices (BMPs) that can be communicated to farmers through farmer groups/associations, extension networks and the media.
8. Develop and disseminate economic tools to assist farmers to understand the implications of their feed choices and optimize their feed management strategies.
9. Develop appropriate aquafeed policies, regulatory frameworks, and feed standards in those countries that do not already have them. Poor regulatory control and a lack of standards along the aquafeed value chain are constraints to feed and

feed ingredient quality. Farmers must be assured of the quality of the feeds and feed ingredients that they are purchasing. Enhance and develop capacity at those institutions responsible for monitoring and compliance.

10. Provide up-to-date market information for small-scale feed manufacturers and farmers producing farm-made feeds. Promote programs that use local media to provide farmers with up-to-date feed ingredient availability, quality, price and supplier information, feed formulation and ingredient inclusion rates.

REFERENCES

Abban, E.K. 2005. *Study and analysis of feed and nutrients including fertilizers for sustainable aquaculture development in Ghana* (unpublished report of the Water Research Institute, Council for Scientific & Industrial Research). 24 pp.

Ali, M.Z. 2001. *Dietary protein and energy interactions in African catfish* Clarias gariepinus (Burchell, 1822). PhD Thesis. Stirling, University of Stirling, 273 pp.

Ali, M.Z. & Jauncey, K. 2004. Evaluation of mixed feeding schedules with respect to compensatory growth and body composition in African catfish *Clarias gariepinus. Aquaculture Nutrition*, 10: 39–45.

AquaFish CRSP. 2009. *Fish farmers association models success.* AquaFish CRSP: Sustainable aquaculture and fisheries for a secure Future Newsletter No. SS-1. (Available at http://aquafishcrsp.oregonstate.edu/Documents/Uploads/FileManager/Success%20Story-Baitfish_final_072011.pdf).

Awity, L.K. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Ghana. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 191–211. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Barg, U. & Phillips, M.J. 1997. Environment and Sustainability. *Review of the State of the World Aquaculture.* FAO Fisheries Circular No. 886, Rev.1. Rome, FAO. 163 pp.

Bhujel, R.C. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Thailand. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 159–189. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Boyd, C.E. & Clay, J.W. 2002. *Evaluation of Belize Aquaculture Ltd: A superintensive shrimp aquaculture system.* Report prepared under the World Bank, NACA, WWF and FAO Consortium Program on Shrimp Farming and the Environment. Work in Progress for Public Discussion. Washington DC. Published by the Consortium. 17 pp.

Cho, C.Y. & Bureau, D.P. 1998. Development of bioenergetic models and the Fish-PrFEQ software to estimate production, feeding ration and waste output in aquaculture. *Aquatic Living Resources*, 1: 199–210.

De Silva, S.S. & Davy, F.B. 1992. Strategies for finfish nutrition research for semi-intensive aquaculture in Asia. *Asian Fisheries Science*, 5: 129–144.

De Silva, S.S. & Hasan, M.R. 2007. Feeds and fertilizers: the key to long term sustainability of Asian aquaculture. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 19–47. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Duong, H.T., Ly, T.M. & Nguyen, T.P. 2011. Effects of restricted and alternative feeding methods on the growth of the striped catfish (*Pangasianodon hypophthalmus*) fingerlings. In T.P. Nguyen, Q.P. Truong & T.T.H. Tran, eds. Proceedings of the 4th Aquaculture and Fisheries Conference, pp. 178–190. Can Tho, Viet Nam, Can Tho University. 543 pp. (In Vietnamese).

El-Sayed, A-F.M. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Egypt. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 101–129. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

FAO. 2010. *Report of the FAO Expert Workshop on on-farm feeding and feed management in aquaculture. Manila, the Philippines, 13–15 September 2010.* FAO Fisheries and Aquaculture Report No. 949. Rome, FAO. 37 pp. (also avallabile at www.fao.org/docrep/013/i1915e/i1915e00.pdf).

Gereffi, G., Garcia-Johnson, R. & Sasser, E. 2001. The NGO-industrial complex. *Foreign Affairs*, 125: 56–65.

Hall, P.O.J., Holby, O., Kollberg, S. & Samuelsson, M.O. 1992. Chemical fluxes and mass balances in a marine fish cage farm. IV. Nitrogen. *Marine Ecology Progress Series*, 89: 81–91.

Hasan, M.R., ed. 2007. *Economics of aquaculture feeding practices in selected Asian countries.* FAO Fisheries Technical Paper No. 505. Rome, FAO. 205 pp.

Hasan, M.R. 2012a. *Transition from low-value fish to compound feeds in marine cage farming in Asia.* FAO Fisheries and Aquaculture Technical Paper No. 573. Rome, FAO. 198 pp.

Hasan, M.R. 2012b. Bangladesh: seed and feed production and management. *FAO Aquaculture Newsletter*, 49: 32, 47.

Hasan, M.R., Hecht, T., De Silva, S.S. & Tacon, A.G.J., eds. 2007. *Study and analysis of feeds and fertilizers for sustainable aquaculture development.* FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Hecht, T. 2007. Review of feeds and fertilizers for sustainable aquaculture development in sub-Saharan Africa. In M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 77–109. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Hecht, T. 2013. A review of on-farm feed management practices for North African catfish (*Clarias gariepinus*) in sub-Saharan Africa. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 463–479. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Holby, O. & Hall, P.O.J. 1991. Chemical fluxes and mass balances in a marine fish cage farm. II. Phosphorus. *Marine Ecology Progress Series*, 70: 263–272.

Houlihan, D.F., Boujard, D. & Jobling, M. 2001. *Food intake in fish.* Oxford, Blackwell Science. 259 pp.

Hung, L.T. & Quy, O.M. 2013. On-farm feeding and feed management in whiteleg shrimp (*Litopenaeus vannamei*) farming in Viet Nam. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 337–357. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Jobling, M. 1983. Effect of feeding frequency on food intake and growth of arctic charr, *Salvelinus alpinus* L. *Journal of Fish Biology*, 23: 177–185.

Kader, M.A., Hossain, M.A. & Hasan, M.R. 2005. A survey of the nutrient composition of some commercial fish feeds available in Bangladesh. *Asian Fisheries Science*, 18: 59–69.

Kaushik, S.J. 2000. Feed allowance and feeding practices. *In* B. Basurco, ed. *Recent advances in Mediterranean aquaculture finfish species diversification.* Proceedings of the Seminar of the CIHEAM Network on Technology of Aquaculture in the Mediterranean (TECAM). *Cahiers Options Méditerranéennes*, 47: 53–59.

Kaushik, S.J. 2013. Feed management and on-farm feeding practices of temperate fish with special reference to salmonid. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 519–551. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Liu, J., Li, Z., Li. X. & Wang, Y. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in southern China. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 71–99. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

MoA (Ministry of Agriculture of China). 2005. Formula Feed for Tilapia (SC/T 1025-2004). Beijing, Ministry of Agriculture. 7 pp.

Nandeesha, M.C., Sentilkumar, V. & Antony Jesu Prabhu, P. 2013. Feed management of major carps in India, with special reference to practices adopted in Tamil Nadu. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 433–462. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Ng, W.-K., Teh, S.-W., Chowdhury, K.M.A. & Bureau, D.P. 2013. On-farm feeding and feed management in tilapia aquaculture in Malaysia. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 407–431. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Nguyen, T.P. 2013. On-farm feed management practices for striped catfish (*Pangasianodon hypophthalmus*) in Mekong River Delta, Viet Nam. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 241–267. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Pouomogne, V. 2007. Analysis of feeds and nutrients for sustainable aquaculture development in Cameroon. *In* M.R. Hasan, T. Hecht, S.S. De Silva & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 381–399. FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Ramakrishna, R., Shipton, T.A. & Hasan, M.R. 2013. *Feeding and feed management of Indian major carps in Andhra Pradesh, India.* FAO Fisheries and Aquaculture Technical Paper No 578. Rome, FAO. 90 pp.

Ramaswamy, U.N., Mohan, A.B. & Metian, M. 2013. On-farm feed management practices for black tiger shrimp (*Penaeus monodon*) in India. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 303–336. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Rana, K.J. & Hasan, M.R. 2013. On-farm feeding and feed management practices for sustainable aquaculture production: a synthesis of case studies from selected Asian and African countries. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 21–67. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Rana, K.J., Siriwardena, S. & Hasan, M.R. 2009. *Impact of rising feed ingredient prices on aquafeeds and aquaculture production.* FAO Fisheries and Aquaculture Technical Paper No. 541. Rome, FAO. 63 pp.

Robb, D.H.F. & Crampton, V.O. 2013. On-farm feeding and feed management: perspectives from the fish feed industry. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 489–518. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Romana-Eguia, M.R.R., Laron, M.A. & Catacutan, M.R. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in the Philippines. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 131–158. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Sarder, M.R.I. 2013. On-farm feed management practices for three Indian major carp species (rohu *Labeo rohita*, mrigal *Cirrhinus cirrhosus* and catla *Catla catla*) in Bangladesh: a case study. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 213–239. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Shipton, T.A. & Hecht, T. 2013. Economic, regulatory and legal review of feed management practices. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 565–585. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Tacon, A.G.J., Jory, D. & Nunes, A. 2013. Shrimp feed management: issues and perspectives. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 481–488. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Tacon, A.G.J. & Hasan. M.R. 2007. Global synthesis of feed and nutrients for sustainable aquaculture development *In* M.R. Hasan, T. Hecht, S.S. De Silva, & A.G.J. Tacon, eds. *Study and analysis of feeds and fertilizers for sustainable aquaculture development*, pp. 3–17. FAO Fisheries Technical Paper No 497. Rome, FAO. 510 pp.

Talbot, C., Corneillie, S. & Korsøen, O. 1999. Pattern of feed intake in four species of fish under commercial farming conditions: implications for feeding management. *Aquaculture Research*, 30: 509–518.

Thorpe, J.E. & Cho, C.Y. 1995. Minimizing waste through bioenergetically and behaviorally based feeding strategies. *Water Science and Technology.* 31 (10): 29-40

Vandergeest, P. 2007. Certification and Communities: Alternatives for Regulating the Environmental and Social Impacts of Shrimp Farming. *World Development*, 35 (7): 1152–1171.

White, P. 2013. Environmental consequences of poor feed quality and feed management. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 553–564. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

On-farm feeding and feed management practices for sustainable aquaculture production: an analysis of case studies from selected Asian and African countries

Krishen J. Rana[1a] **and Mohammad R. Hasan**[2]
[1]*FAO Consultant*
Stirling, United Kingdom of Great Britain and Northern Ireland
[2]*Aquaculture Officer*
Aquaculture Branch
FAO Fisheries and Aquaculture Department
Rome, Italy

Rana, K.J. and Hasan, M.R. 2013. On-farm feeding and feed management practices for sustainable aquaculture production: an analysis of case studies from selected Asian and African countries. *In* M.R. Hasan and M.B. New, eds. *On-farm feeding and feed management in aquaculture.* FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. pp. 21–67.

ABSTRACT

Aquaculture production reached some 79 million tonnes in 2010. During the period from 1998–2010, production from feed-dependent aquaculture increased more than twofold from 20 to 45 million tonnes, largely through intensification. The use of exotics with established technologies such as tilapias, carps, shrimps and salmonids provided firm market opportunities for increasing production and driving production efficiency.

This review considers changes in feed and feed management practices in selected countries (Bangladesh, China, Egypt, Ghana, India, the Philippines, Thailand and Viet Nam) that contributed to this increase. Four major farmed species groups of freshwater finfish and shellfish: tilapias, catfishes and Indian major carps, and shrimps and prawns are considered. These groups showed a phenomenal growth in production, increasing from 1.6 million tonnes in 1988 to 16 million tonnes in 2010, with a single species within each species group dominating production. The contributions of these species to production are presented. Ponds (1–5 ha) continued to be the predominant production system but the use of cages in countries such as Egypt, the Philippines and Ghana is on the increase. The types and changes in farming practices are discussed. The key trigger for change in culture practices was market opportunities, combined with the need for increased production and productivity to reduce costs.

[a] Present address: University of Plymouth, Drake Circus, Plymouth PL4 8AA, United Kingdom of Great Britain and Northern Ireland.

Two fundamental changes in farming practices that contributed to this increase are evident and discussed: the increase in the use of formulated farm-made and commercial aquafeeds and the concomitant aeration of ponds/tanks. In India the introduction of stocking large fish, together with supplementary feeding, was a notable shift in farming practice. For tilapia, intensification through the introduction of stocking larger fish, aeration, increased feed inputs and a shift to culture in cages characterized the changes in farming practices in countries such as the Philippines, Egypt, and Ghana. The high international prices and availability of hatchery reared postlarvae encouraged many small to medium-sized farmers in Bangladesh and India to change culture practice to focus only on freshwater prawns and shrimps in larger ponds (0.2–0.4 ha) using supplementary feeds and aeration, pushing shrimp yields up to 3–5 tonnes/crop. Such developments and their associated challenges and approaches for improving production and production efficiencies and reducing feed costs for the selected countries are detailed in the review. Additionally, the implications of fish mortality on feed utilization efficiencies and cost are modelled using case study scenarios.

1. OVERVIEW OF GLOBAL PRODUCTION

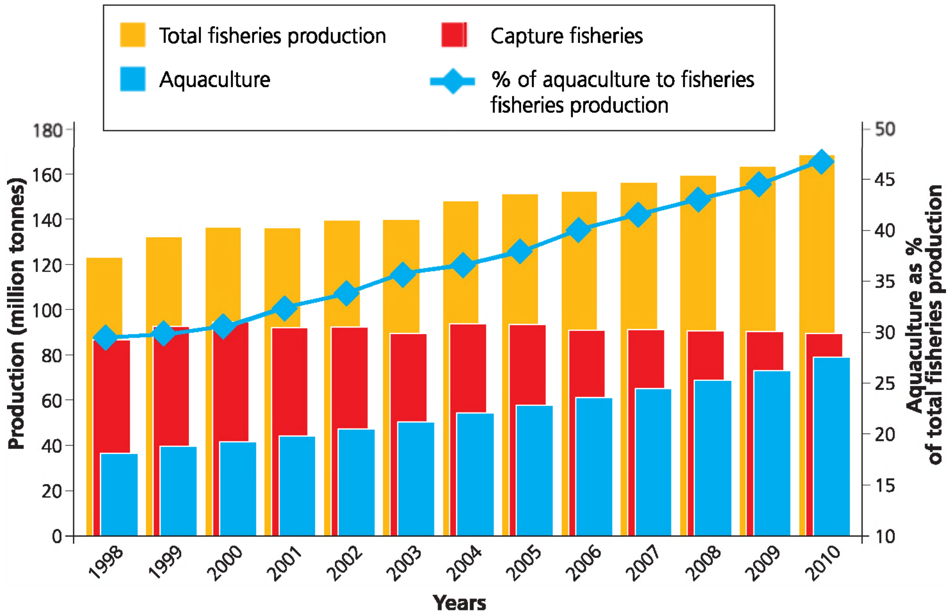
1.1 Global aquaculture production

It is now internationally accepted that the increased supply of fish products required to meet global demand cannot be sourced from wild fisheries, which are either stagnant or declining (FAO, 2012a). To meet their national and international demand, nations around the world have continuously developed and improved technologies and management, especially feed and feed management practices, to increase production volumes and efficiencies for a range of aquatic organisms in an environment of limiting natural resources.

Although there are large intercountry differences in sector growth, aquaculture has collectively achieved the highest average growth rate among the animal production sectors. In 2010, global aquaculture production reached 79 million tonnes, growing at an annual rate of 9.7 percent since 1998, while technological advances in equipment and feed and greater areas under culture have led to an increase in its proportional contribution to total fisheries (Figure 1). In 1988, aquaculture contributed only 15 percent of total global fisheries production; by 2010, however, this had risen almost threefold to 47 percent. This increased contribution, however, is largely an Asian phenomenon, as Asia accounted for 72 million tonnes or 91.5 percent of total world aquaculture production in 2010, while the Americas, Africa and Europe contributed only 3.3, 1.8 and 3.2 percent, respectively. Global production was valued at US$125 billion, with the share of the Asian region being US$102 billion, or 81 percent of total world aquaculture value. This increasing trend is projected to continue in future decades; consequently, the aquaculture sector is expected to play a significantly greater role in contributing to food security, poverty alleviation and economic improvement for the poor.

Over the past 15–20 years, more than 60 countries have engaged in farming over 200 species or species groups of aquatic animals and plants in a vast range of production systems, ranging from low-input extensive to high-input intensive aquafarms using ponds, caged enclosures and tanks. In broad terms, aquaculture systems used for the production of these aquatic animals and plants can be divided into feed-dependent systems or "fed aquaculture" (e.g. finfish and crustaceans) or non-fed aquaculture systems, where culture is predominately dependent on the natural environment for food and nutrients (e.g. aquatic plants and molluscs).

FIGURE 1
Global trends in contribution of aquaculture to fisheries production, 1988–2010



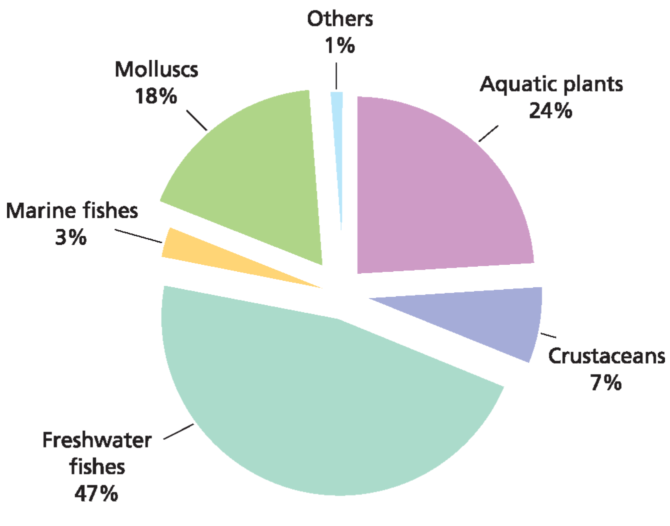
Source: Adapted from FAO (2012b).

1.2 Global and country profiles of species and species group utilization in aquaculture

Although more than 200 aquatic species or species groups are farmed, the majority of production stems from a few species and species groups that are cultured with minimum impact on the environment when compared with other food production sectors such as agriculture and livestock, while still maximizing benefits to society.

In 2010, freshwater fish accounted for 47 percent of global production, while the remaining 53 percent was of marine origin (Figure 2). Of this 53 percent, about 92 percent comprised aquatic plants and shellfish (except abalone), which are not dependent on feed and, as such, actually remove nutrients such as nitrogen and phosphorus originating from anthropogenic activities, especially agriculture and sewage disposal. Seaweeds and algae utilize these nutrients for growth, and shellfish filter the resultant algae as food. Similarly, freshwater and marine fish species that filter algae and zooplankton can also have the same positive impact. This removal of nutrients from the water can reduce the risk of coastal algal blooms and ameliorates the negative impacts of the agriculture sector, which is a significant contributor of these nutrients through the use of

FIGURE 2
Global output of aquaculture by species group, 2010



Source: Adapted from FAO (2012b).

fertilizers. Indeed, in 2007, more than 200 million tonnes of fertilizers (nitrogen-potassium-phosphorus [NPK]) were used globally in agriculture; much of this eventually entering the aquatic environment, both through runoff and via groundwater.

1.3 Range of species and species groups used globally in aquaculture

In 2010, only about a dozen species and species groups accounted for almost all global finfish production, with a few species dominating each region (Table 1). In Asia, carps (Chinese, Indian major and common), tilapias, catfishes, milkfish, shellfishes including crustaceans and seaweed predominate in regional production. In the Americas, salmon, trout and catfish predominate, accounting for 43 percent of total regional production. In Chile, salmonids, destined for export markets in the United States of America, Japan and Europe, dominate aquaculture production, while in the United States of America catfish are predominately produced for the domestic market. In Europe, almost half (46 percent) of the total regional production originates from just two species (salmon and trout) and, in both cases, most is exported, but largely within the European region. Species diversity within Africa is also narrow, with more than 77 percent of regional production originating from three species – Nile tilapia (*Oreochromis niloticus*), North African catfish (*Clarias gariepinus*) and flathead grey mullet (*Mugil cephalus*) – all for domestic consumption, with Egypt being the focus of production. Similarly, in Oceania, two species (salmon and mussels) account for almost 80 percent of the production of the region, with mussels being mainly exported. About half of the salmon farmed in Australia and New Zealand is consumed domestically.

A global snapshot of aquaculture production in 2010 by region and key aquaculture countries is presented in Table 1. This table also provides an assessment of scale, measure of biodiversity utilized in aquaculture and key purposes of production. In addition, the production by country is ranked within each region, and the countries included represent 80–97 percent of the total aquaculture output of their region and 99.8 percent of world output. Overall, freshwater fish are by far the most widely farmed group. An understanding of the fate of national aquatic output is valuable, as it may shed some light on macro-government policy on food security and economic development, especially as pertains to feed inputs.

The main destinations of national aquatic products are colour-coded in blue and purple font in Table 1. It is noteworthy that the vast majority of species and species groups of farmed aquatic products, that are freshwater fish, are destined mainly for domestic consumption. According to (FAO, 2012b), about 994 000 tonnes of freshwater fish (aquaculture and capture fisheries including river eels) entered the export market globally in 2009. This estimation includes products in all forms (fillets, fresh frozen, etc.) and therefore whole body weight equivalent is likely to be double that level. Nevertheless, this quantity is still a small proportion of total freshwater production. In contrast, 28.4 million tonnes of marine finfish and shellfish (aquaculture and capture) were exported globally during the same period, but the proportion of farmed marine finfish and shellfish contributing to total exports is unknown. Known species of shrimps that are mainly farmed accounted for 396 000 tonnes of exports in 2009 (FAO, 2012b), but given the final product forms, the whole body weight equivalents will be higher. About 3.2 million tonnes of shrimps and freshwater prawns were farmed globally (FAO, 2012b), although Table 1 shows global production as 2.92 million tonnes because it includes only major aquaculture producing countries in the world. With rising living standards in many Asian countries, a greater share of these products will enter the domestic and regional markets.

TABLE 1

Aquaculture production (thousand tonnes) hotspots by species and species groups ranked by country within regions in 2010.
[Product destination: numbers in blue font - largely domestic; purple font - largely exports; yellow cells denote use of exotic species]

		Finfish												Shellfish									
		Salmon	Trout	Chinese carp	Indian carps	Common carp	Tilapias	Catfish	Milkfish	Grey mullet	Seabream	Seabass	Freshwater fish nei	Mitten crab	Freshwater prawns	*P. monodon*	*P. vannamei*	Clam	Oysters	Mussel & abalone	Seaweed	Country total (thousand tonnes)[1]	% of country total[2] and regional total[3] (% of world share)[4]
Asia	China	1	16	10 381		2 538	1 332	792				106	626	593	15	56	1 223		3 643	759	7 884	47 830	63
	India			146	4 076								232			96	10		3	15	3 915	4 653	98
	Indonesia					283	459	374	422				143			125	207					6 278	94
	Philippines						259	3	349							48	5		23	21	1 801	2 546	99
	Viet Nam					110	73	1 150					188			333	137				35	2 707	75
	Thailand				3	3	179	135					5			5	561		28	167		1 286	84
	Bangladesh			223	600	46	25	140					29		6	43						1 309	85
	Myanmar			36	624	23	41	25								46						851	93
Total		1	16	10 786	5 303	3 003	2 371	2 619	771	0	0	106	1 223	593	21	752	2 143	0	3 697	962	13 635	67 459	72 2033 (92.5)[4]
% of regional total		0	0	15	7	4	3	4	1	0	0	0	2	1	0	1	3	0	5	1	19	93	
Americas	Chile	247	220																	225	12	713	99
	USA	20	15				10	217									1	30	138	2		495	87
	Brazil		5			95	155	5					10				69		2	14		480	74
	Ecuador						48										223					272	99
	Canada	114	7										1						11	24		161	98
Total		380	247	0	0	95	213	218	0	0	0	0	11	0	0	0	293	30	151	265	12	2 122	2 589 (3.3)
% of regional total		15	10	0	0	4	8	9	0	0	0	0	0	0	0	0	11	1	6	10	0	82	
Africa	Egypt					92	557	10		116	15	16										920	88
	Nigeria						12	133														201	72
	Uganda						32	63														95	99
	Madagascar					3										4					4	11	99
	South Africa		1																	2		5	58
Total		0	1	0	0	95	601	206	0	116	15	16	0	0	0	4	0	0	0	2	4	1 231	1 427 (1.8)
% of regional total		0	0	0	0	7	42	14	0	8	1	1	0	0	0	0	0	0	0	0	0	86	
Europe	Norway	928	55																	2		1 008	98
	Spain		17								20	11							2	189		252	95
	France	1	33			4					1	3						2	96	77		225	97
	Italy		36								6	6								64		153	73
	UK	155	14																1	30		201	99
	Greece		3								54	31								23		113	98
	Russia	5	19	25		57																121	87
	Ireland	16	1																7	22		46	99
Total		1 104	178	25	0	61	0	0	0	0	81	51	0	0	0	0	0	2	106	407	0	2 120	2 523 (3.2)
% of regional total		44	7	1	0	2	0	0	0	0	3	2	0	0	0	0	0	0	4	16	0	44	
Oceania	NZ	13																	2	95		111	99
	Australia	32																	15	4		70	73
Total		45	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	17	99	0	180	199 (0.3)
% of regional total		22	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	50	0	91	

Notes: USA = United States of America; UK = United Kingdom; Russia = Russian Federation; NZ = New Zealand.;
[1] Total aquaculture production including all other species/species groups; [2] Percentage of aquaculture production contributed by the species and species groups shown in this table; [3] Total aquaculture production of each region/continent; [4]Value in parentheses is the percentage of world share of aquaculture production contributed by the continent.

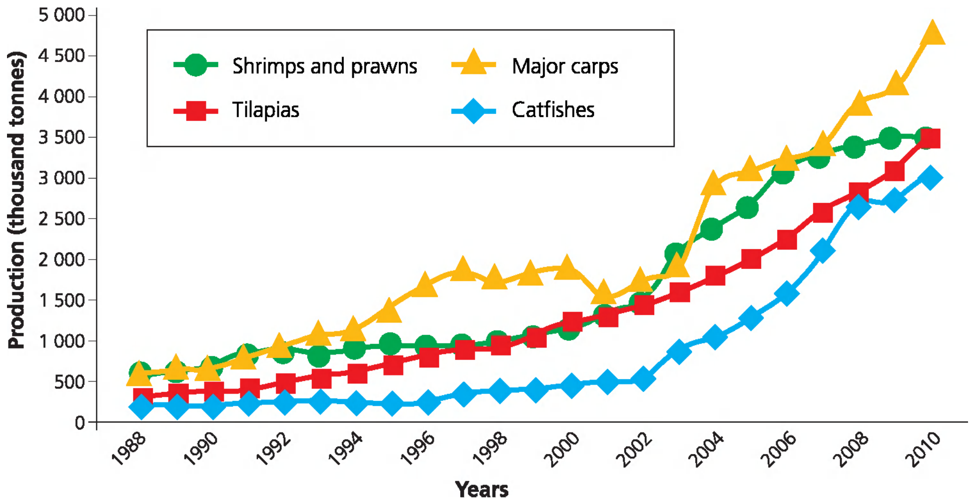
Source: FAO (2012b).

1.4 Synthesis of development trends for selected species/species-groups and countries

This review synthesizes the information derived from 11 case studies on feeding and feed management practices carried out in selected countries for eight species in four major farmed species groups of freshwater finfish and shellfish: shrimps and prawns, tilapias, catfishes and Indian major carps. These four farmed species groups totalled 14.8 million tonnes accounting for 24.7 percent of world finfish and shellfish production in 2010. For these species groups, the review focuses on country-specific case studies carried out for: Nile tilapia (*Oreochromis niloticus*) in China, Egypt, Ghana, the Philippines and Thailand; Indian major carps (rohu [*Labeo rohita*], catla [*Catla catla*] and mrigal [*Cirrhinus cirrhosus*]) in Bangladesh and India, giant river prawns (*Macrobrachium rosenbergii*) in Bangladesh; striped catfish (*Pangasianodon hypophthalmus*) and whiteleg shrimp (*Litopenaeus vannamei*) in Viet Nam; and black tiger shrimp (*Penaeus monodon*) in India.

The production of the above four species groups collectively increased from 1.6 million tonnes in 1988 to 14.8 million tonnes in 2010 (Figure 3), representing an annual average increase in production of 10.7 percent. Specific species, however, showed phenomenal growth. For example, annual production of whiteleg shrimp, increased from 77 000 tonnes in 1988 to 2 710 000 tonnes/year in 2010, an increase of more than 35 times (Figure 4). Globally, a single species within each species group dominated production. In 2010, the whiteleg shrimp accounted for 67 percent of all shrimp and prawn production, with 45 percent of world production reported from China (Table 2).

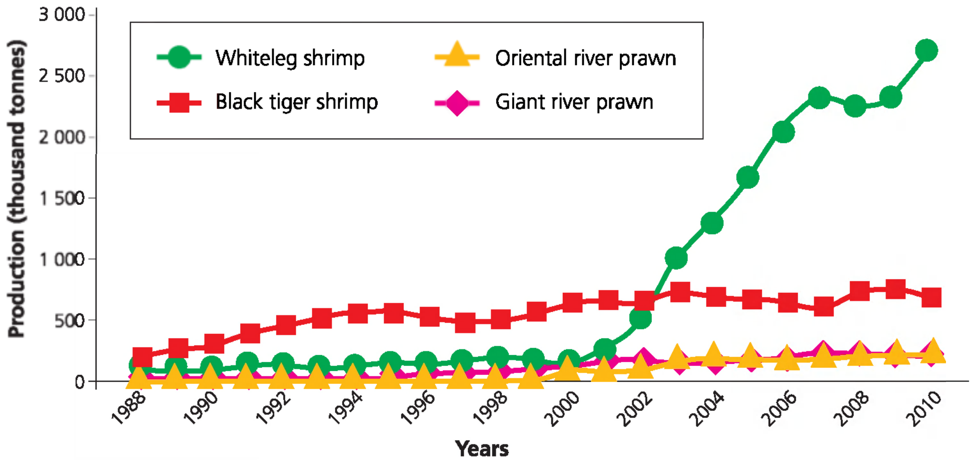
FIGURE 3
Production trends of selected species groups of finfish and shrimps and prawns, 1988–2010



Source: Adapted from FAO (2012b).

Similarly, in 2010, Nile tilapia, striped catfish and catla accounted for 73, 43 and 71 percent of production, respectively, in their species groups (Table 2). However, this dominance or ranking of preferred farmed species within species groups shows temporal variation both globally and nationally. In 1994, black tiger shrimp dominated production at 62 percent (559 000 tonnes), while whiteleg shrimp contributed only 13 percent (121 000 tonnes) of global shrimp and prawn production; however, by 2010 the trend had reversed, with black tiger shrimp production slipping to just 19 percent (685 000 tonnes) and whiteleg shrimp surging to 67 percent (more than 2 710 000 tonnes) of global shrimp and prawn production (Figure 4, Table 2).

FIGURE 4
Temporal changes in contribution of major species to global shrimp and prawn production, 1988–2010

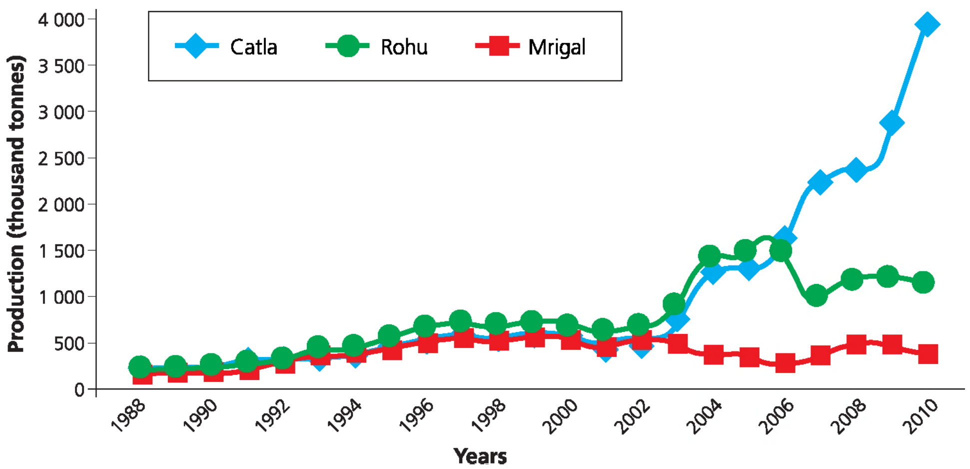


Source: Adapted from FAO (2012b).

For tilapias, there is a strong preference for farming *O. niloticus* over *O. mossambicus*. Since 1988, the contribution of *O. niloticus* to farmed tilapias has increased by more than 1.6 times, increasing from 45 percent in 1988 to 73 percent in 2010, with China and Egypt reporting 39 percent and 22 percent of world production, respectively (Table 2).

The United States of America was the main catfish (channel catfish) producer in the 1980s and 1990s, but it has been surpassed in this millennium by the phenomenal growth in striped catfish (tra or pangas) production in Viet Nam. By 2010, striped catfish production reached 1.14 million tonnes in Viet Nam, representing 37 percent of all global catfish production (Table 2), 87 percent of which was produced in Viet Nam. Channel catfish, which accounted for 80 percent of all catfish production in 1988, plummeted to just 15 percent by 2010 (Table 2) and about half (217 303 tonnes) of this was produced in China. Although China does not report any striped catfish production, it monopolizes the production of Amur and yellow catfish (Table 2).

FIGURE 5
Global production of Indian major carps



Source: Adapted from FAO (2012b).

TABLE 2

National and global aquaculture production of the selected species and species group in selected countries in 2010

Species group	Global	National production							
		China	Viet Nam	India	Bangladesh	Thailand	Philippines	Ghana	Egypt	Others
	Thousand tonnes (% of group)	Thousand tonnes [numbers in parentheses indicate % of global species production								
Shrimps & prawns										
Whiteleg shrimp	2 721 (67)	1 223 (45)	137 (5)			561 (21)				785 (29)
Black tiger shrimp	783 (19)	57 (7)	333 (43)	97 (12)	43 (6)	5 (1)	48 (6)			199 (25)
Giant river prawns	215 (5)	125 (58)	8 (4)	14 (6)	31 (14)	26 (12)				12 (6)
Others	316 (8)									
TOTAL	**4 034**									
Tilapias										
Nile tilapia	2 538 (73)	999 (39)				179 (7)	168 (7)	9 (0.4)	557 (22)	625 (24.6)
Others	959 (27)									
TOTAL	**3 497**									
Catfishes										
Pangas catfishes nei	1 307 (43)		1 140 (87)							167 (13)
Channel catfish	445 (15)	217 (49)								228 (51)
Amur catfish	380 (12)	374 (99)								6 (1)
Catfish, hybrid	117 (4)					117 (100)				0
North African catfish	191 (6)							0.570 (0.3)		190 (99.7)
Chinese long snout catfish	17 (1)	17 (100)								0
Yellow catfish	184 (6)	184 (100)								0
Others	409 (13)									
TOTAL	**3 049**									
Indian major carp										
Rohu	1 167 (22)			313 (27)	254 (22)					600 (51)
Catla	3 870 (71)			3 598 (93)	196 (5)					75 (2)
Mrigal	379 (7)			164 (43)	149 (39)					65 (17)
TOTAL	**5 416**									

Note: nei = not elsewhere included.
Source: FAO (2012b).

The Indian major carps are mainly farmed in India, Myanmar and Bangladesh, with India accounting for 75 percent of world production in 2010. Catla was the most popular major carp (Figure 5). The production of catla reported since 2003 has increased dramatically and in 2010 accounted for 71 percent of all Indian major carp production (Table 2). India produced 93 and 43 percent of all reported global catla and mrigal production, respectively, in 2010 (Table 2).

2. PRODUCTION SYSTEMS AND CHANGES IN CULTURE PRACTICES IN SELECTED COUNTRIES AND SPECIES

2.1 Types of production systems

Aquaculture practices are now driven by the basic economic criteria of income generation. However, productivity and production (and therefore subsequent income of farmers) in many parts of the world are still governed by the balance between availability and affordability of production inputs, in particular aquafeeds, which typically account for 50–70 percent of production costs (Hasan, 2007; Hasan *et al.*, 2007). The increasing competition for common resources such as land and water is dictating a global trend of intensification in aquaculture production. The degree of intensification in countries varies, being governed by species, market price and available resources. These key trends are considered for freshwater finfish and shellfish species in the selected countries shown in Table 3.

TABLE 3
Geographic scope and species considered in this synthesis

	Bangladesh	China	India	Viet Nam	Thailand	Philippines	Egypt	Ghana
Nile tilapia		X			X	X	X	X
Major carps	X		X					
Striped catfish				X				
Whiteleg shrimp				X				
Black tiger shrimp			X					
Giant river prawns	X							

For all freshwater finfish species, pond culture is the most commonly used farming method in all countries, followed by cage culture (Table 4). Cage farming of tilapias is most prevalent in the Philippines and Egypt, accounting for 32 and 21 percent of national tilapia production, respectively.

TABLE 4
Types of production systems for selected countries and freshwater finfish species

Country	Bangladesh	India	Viet Nam	China	Thailand	Philippines	Egypt	Ghana
Species	Major carps	Major carps	Catfish	Tilapia	Tilapia	Tilapia	Tilapia	Tilapia
Cages			X		X	XX (32)[1]	XX (21)	X
Pond size range (ha)	0.13–0.80		0.30–0.33	0.30–3.30	0.1–5.0	1–3	0.5–3.0	0.1–0.5
Extensive	XXX	X		X	X		X	XXX
Semi-intensive	XX	XX		XX	X	X	XX	X
Intensive		X	XXX	X	XX	XX	X	X

[1]Number in parenthesis accounts for percent of national production.

Note: X = seldom used; XX = widely used; XXX = most commonly used farming method.

Typically, all ponds used for farming these freshwater species are relatively small (0.1–5 ha). In Bangladesh and Viet Nam, ponds are considerably smaller, at less than 1 ha (Table 4). Pond depths, however, vary considerably. Although ponds are generally about 1 m deep, catfish ponds in Viet Nam are typically 3–4 m deep, facilitating high production. In the last two decades, there has been a gradual shift from extensive to semi-intensive production of the Indian major carps and tilapias in most countries. Extensive farming practices, however, are still common in Bangladesh for Indian major carps and in Ghana for tilapia (Table 4). Catfish, on the other hand, are now mainly produced intensively in small but deep ponds yielding production in excess of 100 tonnes/ha (Nguyen, 2013).

Shrimps and prawns are exclusively farmed in small ponds (0.2–2.0 ha), with all countries except Viet Nam farming extensively and semi-intensively (Table 5). Whiteleg shrimp are mainly farmed intensively in Viet Nam, with yields of 20–40 tonnes/ha. On the other hand, in Bangladesh, giant river prawns are typically farmed extensively and semi-intensively in very small ponds (0.2–0.5 ha) with correspondingly lower yields of 0.35–0.7 tonnes/ha (Table 5). In India, black tiger shrimp are farmed extensively and semi-intensively in larger ponds.

TABLE 5

Types of production systems in selected countries for selected prawn and shrimp species

Country	Bangladesh	India	Viet Nam
Species	**Giant river prawns**	**Black tiger shrimp**	**Whiteleg shrimp**
Pond size (ha)	0.2–0.5	0.5–2.0	0.3–0.6
Extensive (yield – tonne/ha)	XXX (0.35)	XX (0.5)	–
Improved extensive (yield – tonne/ha)	XX (0.5)	XX (1–2)	X
Semi-intensive (yield – tonne/ha)	XX (0.7)	XX (2–4)	
Intensive (yield – tonne/ha)			XXX (20–40)

Note: XXX = predominant type; XX = commonly used; X = seldom used.

2.2 Brief summary of change in culture practices

The trigger for change in culture practices is market opportunity combined with the need for increased production and productivity while ensuring the delivery of required environmental services for aquaculture. A varying combination of technological advances and effective knowledge transfer, access to natural resources, and state intervention in the reference countries created country-specific opportunities to change culture practices. In common for all countries, the key technological drivers and milestones significantly directing these farming practice changes were the successful closure of the Indian major carps and striped catfish breeding cycles and the mass production of seed, creating the platform for expansion and change.

2.2.1 Indian major carps (Labeo rohita, Catla catla and Cirrhinus cirrhosus)

As the largest producer of Indian major carps, India has set the pace for change and innovation in culture practices since the 1960s. The successful artificial breeding of major carps through hypophysation in 1957 transformed and facilitated expansion of Indian carp culture from small backyard ponds in the eastern Indian states of West Bengal, Orissa and Bihar to significant commercial-scale operations in states such as Andhra Pradesh, Punjab, Haryana, Karnataka and Tamil Nadu.

In addition, three prominent factors governed and facilitated the pace of change in Indian major carp culture practices and expansion:

- the concerted demonstration effort by government of the composite culture of Indian major carps and Chinese carps through Fish Farmers Development Agencies located throughout the country;
- the ease of paddy conversion to ponds using flood water and saline waters;
- the deceasing net returns from paddy crops.

Andhra Pradesh, which in 2008 accounted for 30 percent of national Indian major carp production, was the central state in developing local innovative changes to basic polyculture practices resulting in new opportunities in the production value chain. The composite culture of carps initially practised in the 1980s using small (5–10 g) Indian major and Chinese carp fingerlings and 5–7 tonnes of supplementary feed often produced undersized fish (<500 g), arising from premature harvesting owing to poor pond conditions. These fish, known as "zero fish", typically fetch less than one third to half the price of normal market-sized fish (1–2 kg). These zero fish created a new farming segment, as innovative farmers bought these as stocking material for on-growing to acceptable size in just six months, thus halving the growing period. This, together with the exploitation of compensatory growth response in fish, resulted in creating a new subsector for the semi-intensive polyculture industry using major carp juveniles of 50–125 g. Thus, composite extensive backyard carp polyculture has evolved over two to three decades into semi-intensive carp polyculture by stocking predominantly larger major carp yearlings, yielding 8–10 tonnes of fish using 23–28 tonnes of supplementary feed. Such changes in culture practices are also mirrored in Bangladesh. Market opportunities in both India and Bangladesh created impetus for further changes in culture practices as farmers introduced a larger species mix into this farming system. In India, Indian major carps have been reared in mixed semi-intensive culture with black tiger shrimp, striped catfish, giant river prawns and pirapatinga (*Piractus brachypomus*) since 1990, 1995, 2000 and 2008, respectively.

2.2.2 Nile tilapia (*Oreochromis niloticus*)

The Nile tilapia is principally farmed in ponds in China and Thailand, and in addition in cages in lakes in the Philippines, Egypt and Ghana. Intensification through the use of larger fingerlings (50 g), aeration, increased feed inputs and a shift to culture in cages have characterized the changes in tilapia culture practices in these countries. The reasons for the shift and scale of change have varied depending on the phase of national aquaculture development.

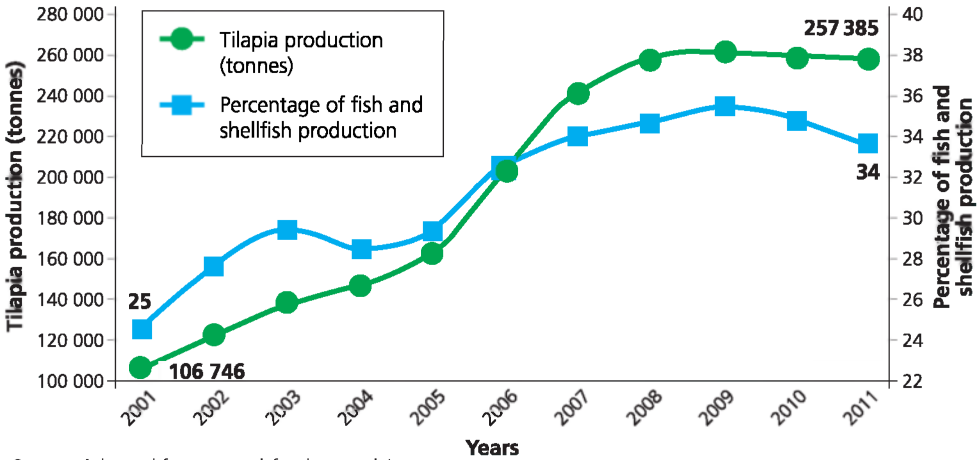
Although China has farmed Mozambique tilapia (*O. mossambicus*) since 1950 in traditional integrated production systems with carps, this species was not in high demand owing to its relatively high cost and poor growth rate. However, the open-door policy, sharply rising living standards of the 1980s and a switch to farming Nile tilapia provided the impetus for a dramatic increase in production, especially in the provinces of Guangdong and Hainan, which accounted for about 66 percent of Chinese tilapia production in 2010 (Liu *et al*., 2013). Although polyculture is still a common practice among small-scale farmers (typically 2–4 ha) with limited capital investment, tilapia farming has evolved to take advantage of increasing demand and better prices. Typically, tilapia was used as a minor component in polyculture with carps, yielding about 2 500 kg/ha tilapia, but this changed as many farmers reversed culture practice to make tilapia the major stocked fish, with yields of 7–8 tonnes/ha using in-pond aerators and pelleted feeds. This shift also created new opportunities within the production value chain for dedicated broodstock and fingerling and yearling (overwintered) seed production farms. Good prices and demand also spurred a shift from traditional polyculture to monoculture, on-growing fingerling and yearling tilapias using multiple cropping systems. Larger commercial farms (typically, 20–30 ha), with substantial local investment, local government support and attracted inward investment, began to farm tilapia intensively in the 1990s using larger, deeper ponds, aerators, automated feeders and extruded pellets, with yields of up to 15 tonnes/ha (Liu *et al*., 2013). Culture practices were further influenced by the availability of warm spring water and heated water from power stations, allowing tilapia to be farmed intensively in the colder northern provinces such as Beijing.

Tilapia did not feature in statistics for the Philippine until the 1990s, as its production from freshwater and brackishwater ponds, cages and pens increased in significance. The contribution of tilapia to total fish and shellfish production from these production systems almost doubled over the decade, increasing from 25 percent (107 000 tonnes) in 2001 to 34 percent (257 000 tonnes) in 2011 (Figure 6). The main change in tilapia farming practices in the Philippines was characterized by a shift in choice of the tilapia species farmed in the 1970s from *O. mossambicus* to *O. niloticus*. Irrespective of species farmed, the typical market size of tilapias is much smaller, at 200–250 g, compared with other regional countries such as China. From the late 1980s, increased production of Nile tilapia in the Philippines was further aided by the use of hormonally manipulated tilapias and genetically improved strains (e.g. GIFT). By this millennium, more than half of the farmers were using genetically enhanced stock. Tilapia culture using recent innovations and saline-acclimated Nile tilapia has also gained from the idle and underutilized brackishwater shrimp (and milkfish) ponds this millennium arising from disease outbreaks. Taking advantage of niche market opportunities for organic produce also further changed culture practices with the use of all-natural inputs in each phase of the operation. The eutrophic inland water bodies such as Laguna Lake made possible the use of pens and cages for tilapia culture using minimal inputs for fingerling and on-growing production. The increasing switch to higher stocking densities in cages (up to tenfold) and the use of commercial feed in the last decade has increased unit production 5–6-fold over semi-intensive culture (Romana-Eguia, Laron and Catacutan, 2013). Finally, the demand for tilapia in the export market has attracted some Philippine farmers to engage in the production of export-size tilapia. The method used normally requires stocking and feeding advanced tilapia fingerlings of 50 g (compared with the normal 10–20 g size) with complete commercial diets until the fish reach 750–800 g.

Overall, production has increased, spurred by formulated diets and larger fingerlings of improved stock; however, growth has not been linear, probably being affected by natural-resource limitations. In this millennium tilapia production increased linearly to about 2007 but has since plateaued. The greatest increase in tilapia production originated from freshwater ponds, followed by freshwater cages up to 2007 (Figure 7). Production from brackishwater and marine areas has been limited, but any further increase in tilapia production may be expected from these environments.

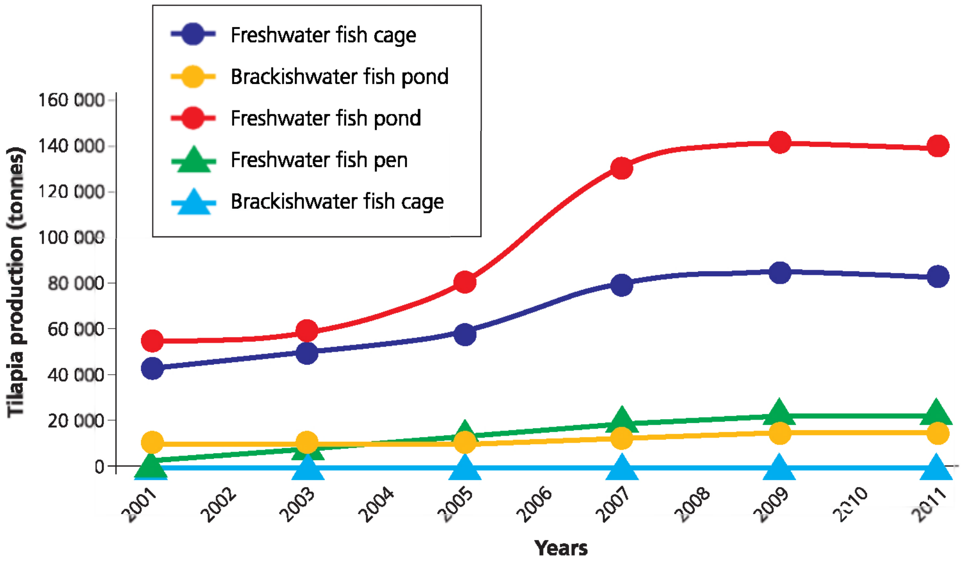
FIGURE 6

Changes in contribution of Nile tilapia to total fish and shell fish production in the Philippines



Source: Adapted from www.bfar.da.gov.ph/

FIGURE 7
Changes in contribution of Nile tilapia production from freshwater and brackishwater ponds, cages and pens in the Philippines



Source: Adapted from www.bfar.da.gov.ph/

As in the Philippines, tilapia farming in Thailand began in the late 1950s and since then, its culture has gradually moved from extensive to semi–intensive pond culture. Although a large majority of farmers still farm semi-intensively in ponds, there was a trend towards intensive farming in cages in rivers; but owing to pollution risks, some farmers, recognizing the benefits of cage culture, switched to siting cages in large ponds. Opportunities for intensification of tilapia production were made possible by feed companies that entered into contract farming, providing feed with a buy-back scheme in the late 1990s. The provision of feed by feed companies on a credit scheme made possible the sole use of commercial feed using larger fingerlings (30–50 g) to achieve two crops of fish per year with yields of 50 kg/m^3 crop of fish averaging 900–1 000 g (Bhujel, 2013).

Tilapia culture practices in Africa are also undergoing changes to meet the challenges of increasing demand. With tilapia prices rising, there is greater investment is countries such as Egypt and Ghana.

In contrast to Asia, Egypt traditionally utilizes brackishwater ponds to farm tilapia in polyculture with carps and mullets. Since the late 1990s, however, the value of tilapia has increased, and this system has been gradually replaced with semi-intensive monoculture of tilapia stocked at 12 000–40 000 fish/ha in earthen brackishwater ponds. With the advent of all-male Nile tilapia fingerlings, more than 75 percent of farmers switched over to mono-sex farming of tilapias. By 2008, more than 80 percent of tilapia were produced in semi-intensive systems (El-Sayed, 2013). By 1999, the number of fish farms utilizing intensive pond culture techniques had increased to 68, covering a total area of 1 088 ha. This created a new and growing demand for large tilapia fingerlings (especially monosex tilapia) and pelleted feed (both extruded and expanded). In less than six years, the number of fish hatcheries increased from 28 freshwater fish hatcheries to more than 350 hatcheries in 2009 (FAO, 2003–2013).

The use of ground water in the desert for integrated tilapia culture is a new feature of Egyptian aquaculture this millennium. Desert land owners rear fish in the tanks used as water reservoirs for irrigation. With continued government technical support, farmers have brought integrated fish farming into their agribusinesses, producing more than

1 000 tonnes of tilapia. With government support, this trend is expected increase to several hundred of such farms within five years. Good economic returns have also resulted in Egyptian farmers progressing to intensive tilapia farming in ponds and cages. Under intensive conditions, ponds are aerated with air compressors or paddles, stocked at 50 000–100 000 fish/ha and commercial feeds applied. The fish reach 200–250 g in 7–9 months, with a total yield of 12–25 tonnes/ha.

The use of cages of varying sizes (30–600 m^3) in rivers, especially in the northernmost branches of the Nile Delta, has also gained momentum in the last decade. While in 1993, only 355 cages were in operation, there are more than 4 500 cages in use. Annual production from cages increased 49 percent per year, rising from 12 900 tonnes in 1999 to reach 69 108 tonnes in 2008. In recent years, some farmers in Egypt have invested in intensive culture of tilapia in concrete tanks under greenhouses (Figure 8), especially in arid and semi-arid areas where freshwater or brackishwater is limited. Most tilapia farmers raise all-male Nile tilapia in aerated tanks stocked at 25–100 fish/m^3 fed on commercial floating pellets for 6–9 months with yields of 10–30 kg/m^3 of 200–400 g/fish.

FIGURE 8
Tank culture of Nile tilapia in Kafr El-Shaikh, Egypt

COURTESY OF FAO/A.-F.M. EL-SAYED.

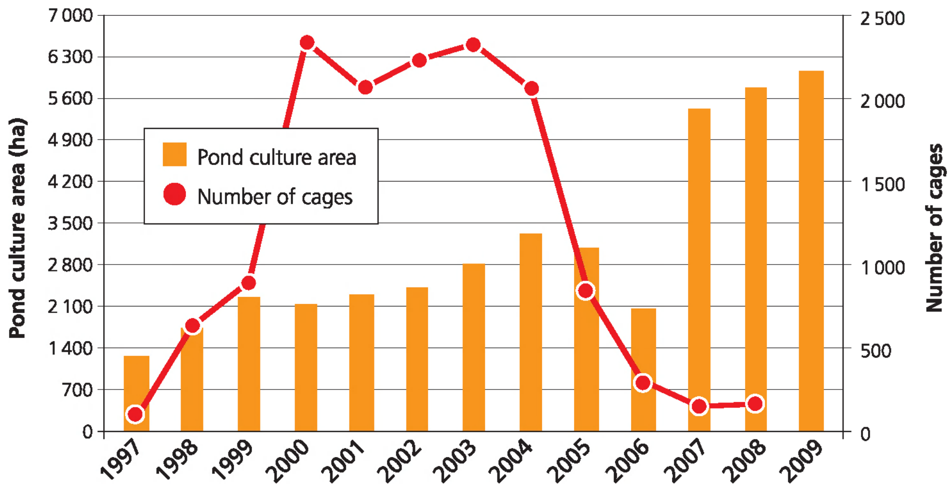
Ghana has typically farmed tilapia extensively in household ponds since the 1950s and to some extent under semi-intensive conditions using supplementary feeds. With market prices exceeding US$3/kg, farmers in Ghana targeted the intensification of tilapia culture, with the first cage farm being established in the late 1990s and the second in 2005 on Lake Volta. Locally made cages are stocked in a two-stage system, initially with fish weighing 5–8 g at 100 000 fry/cage. When they reach 40–50 g (2 months), they are transferred to other cages at half the stocking density and reared to a selling size of 250 g (2–3 months). Since 2005, cage-culture technologies have been developed for smallholder farmers. Typically, these cages (50 m^3) are stocked with 3 000–9 000 fingerlings of 10–30 g and fed on pelleted diets for 5–7 months.

2.2.3 Striped catfish (*Pangasianodon hypophthalmus*)

Viet Nam is the epicentre of Asian and global catfish culture, the practice of which was transformed in 2000 with the all-year-round availability of seed and a shift in cultured species and production system. Two species have dominated catfish culture in Viet Nam since the 1960s, "basa" (*Pangasius bocourti*) reared in cages and pens, and striped catfish or "tra" (*Pangasianodon hypophthalmus*) reared in ponds using traditional farming methods. Beginning in the mid-1990s, however, cage and pen culture practices declined, and then collapsed after 2004 (Figure 9), primarily owing to the cost of cages, poor growth performance, and increasing mortalities and disease outbreaks compared with pond culture (Nguyen *et al.*, 2004; Nguyen and Dang, 2009). The culture of striped catfish in small farms (<5 ha) using small (0.4 ha), deep (3.5–4.5 m) ponds predominated (Phan *et al.*, 2009), the total area of which had increased to 5 800 ha by 2008 (Figure 9). Since 2000, the farming practice has been characterized by a switch from farm-made pellets to complete commercial extruded diets (Nguyen and Dang, 2009).

FIGURE 9

Changes in production systems used for farming striped catfish in Viet Nam



Source: Nguyen (2013).

2.2.4 *Giant river prawns (Macrobrachium rosenbergii)*

In the last three decades, the farming of giant river prawns (*Macrobrachium rosenbergii)* has attracted considerable attention because of export potential. About 14 percent of the global production originates from Bangladesh. In this country, farming giant river prawns is a widespread small-scale activity where farmers integrate rice culture with rearing mainly wild-caught prawn postlarvae (PL) in small (0.2 ha) paddy fields. Inputs are limited and feeding is often characterized by the capacity of resource-poor farmers to procure feeds (mainly snail meat), with prawn yields of 350 kg/ha. In the 1990s, however, the high international prices and availability of hatchery-reared PL encouraged many small to medium-sized farmers to change their culture practice to focus only on farming in larger ponds (0.2–0.4 ha) using supplementary feeds, with yields of about 500 kg/ha. Rice fields were converted by raising the water dykes or bunds to deepen ponds and installing a deep channel to hold water during the dry season, a practice known as *gher* farming. The high returns have also attracted investment, and larger semi-intensive farms have been established since the mid-1990s using industrial feeds, with yields of 700 kg/ha. In all farming systems, mortalities were high and in the last few years farmers have introduced a nursery phase in ponds whereby PL are reared in hapas for 4–6 weeks before being introduced into ponds.

2.2.5 *Black tiger shrimp (Penaeus monodon)*

Asia is the most important shrimp-producing region of the world in terms of farmed black tiger shrimp output, with Viet Nam (43 percent), Indonesia (16 percent), India (12 percent), China (7 percent), Bangladesh and the Philippines (6 percent each) sharing most of the global production (Table 2).

The great bulk (90 percent) of shrimp farming in India is based on the extensive farming system. In recent years and particularly since the 1990s, there has been a trend towards increased intensification. Extensive and modified extensive farms are shifting towards semi-intensive farming of shrimps. For better management, pond units are much smaller (0.1–1.0 ha) but deeper (1.5–2.0 m). Stocking density ranges from 100 000 to 200 000 PL/ha per crop, with crop yields of 3–5 tonnes/ha using complete artificial feeds, increased aeration and intensive monitoring.

2.2.6 Whiteleg shrimp (*Litopenaeus vannamei*)

Following the downturn in black tiger shrimp production in the late 1990s owing to disease outbreaks, whiteleg shrimp offered an acceptable substitute, and by 2010 it was the dominant shrimp species, with a global production of 2.7 million tonnes. Although farmed illegally in Viet Nam since 2000, the Government of Viet Nam allowed the culture of whiteleg shrimp in the Mekong Delta in 2006. Hence whiteleg shrimp culture is relatively new in Viet Nam. In the last decade, farms have mainly practised intensive culture using commercial feeds and stocking densities of 100–200 hatchery-reared PL per square metre, but avoiding the use of fertilizers. The majority of farms are less than 1 ha in size, typically, less than 0.3 ha.

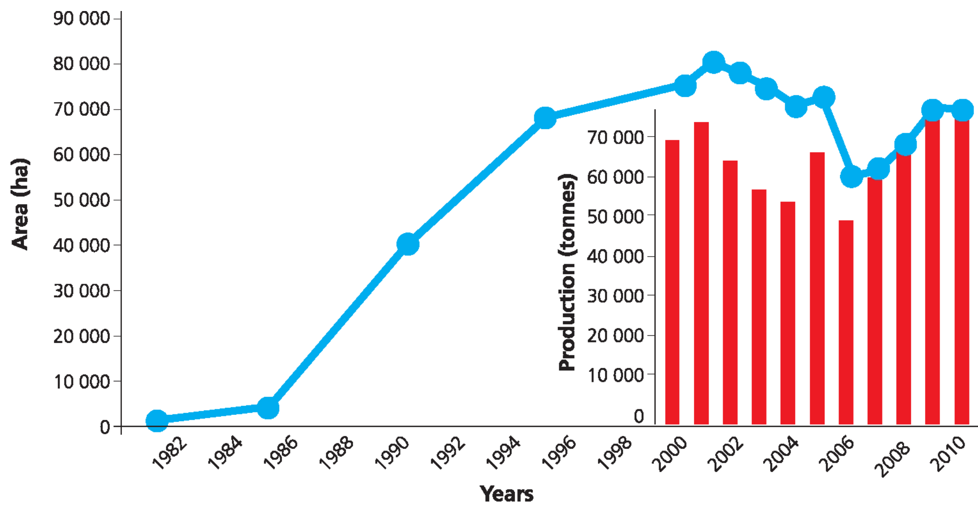
3. UTILIZATION OF AQUAFEEDS

3.1 Implications of diminishing resources for aquafeeds and feed management

Feedback from farmers in all case studies considered in this synthesis points to a varying degree of intensification to increase production volume and efficiency, this increase being principally achieved through using larger fingerlings, deeper ponds and varying levels and quality of supplementary or complete feeds. At a national level, however, improved production efficiencies and increased production are fast becoming a necessity to ensure national food security. In an environment of diminishing natural resources and rising costs, governments will have to develop policies specifically focusing on sustainable productivity, as countries already show resource-limited production.

Expansion of aquaculture in India, especially in key states such as Andhra Pradesh, may be limited by natural resources. The production of major carps in Andhra Pradesh follows and is capped by the area of ponds under cultivation (Figure 10). Under such conditions increases in production can only be achieved through improved productivity.

FIGURE 10
Estimated changes in area used to culture Indian major carps in Andhra Pradesh from 1981–2010 in relation to production

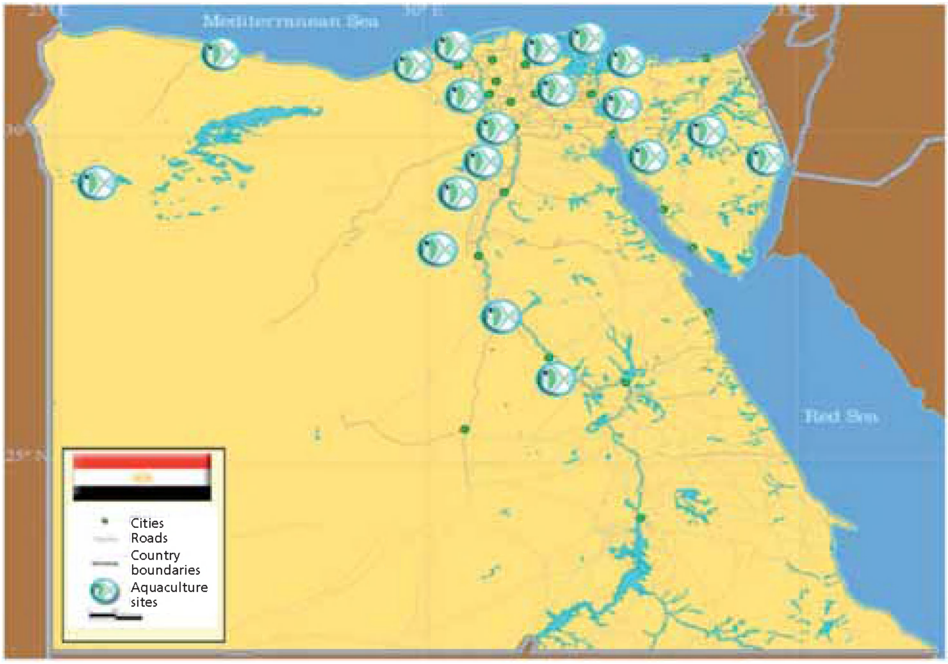


Source: Adapted from Ramakrishna, Shipton and Hasan (2013).

The area dedicated to the culture of Indian major carps plateaued at 80 000 ha in 2000 (Figure 10). Opportunities for expansion into new species, however, were confined to this area. During the expansion of catfish culture, 10 000 ha of ponds originally used for Indian major carps were converted for mono or mixed culture of striped catfish, which were introduced to Andhra Pradesh in the mid-1990s from Bangladesh *via* West Bengal State, India. Thus the culture area for Indian major carps was reduced to an estimated 70 000 ha. Currently, the total area in the state devoted to striped catfish is estimated to be 20 000 ha and is increasing at the expense of Indian major carps (Ramakrishna, Shipton and Hasan, 2013). In such circumstances, if additional land is not made available, farmers are likely to make an economic decision on the species to be farmed based on returns; traditional species are likely to be compromised or have their production intensified to secure greater returns. Such an approach will also require financial incentives from government. To meet this challenge, the Indian National Fisheries Development Board (NFDB) was established in 2006 under the administrative control of the Department of Animal Husbandry to empower all Indian states and union territories to promote aquaculture and provide financial support, mainly through subsidies for other feed inputs and on-farm feed production.

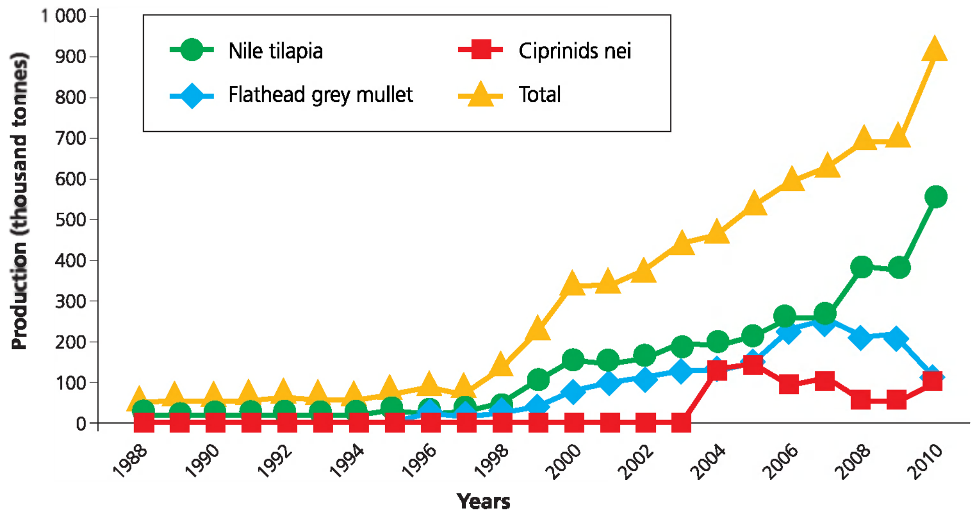
The availability of land and water is also a significant challenge in Egyptian aquaculture, with available areas showing saturation. Most aquaculture activities are located in the northern Nile Delta region, with fish farms clustered in the areas surrounding the four delta lakes (Maruit, Edko, Boruls and Manzala) and along the Nile River (Figure 11). Expansion in most of these areas is constrained by the lack of sites for land-based aquaculture and conflicts over water use. Despite water limitations and most of the land suitable for pond aquaculture being already in use, the target of the government to produce 1.5 million tonnes/year by 2017 is expected to be reached by converting traditional farms to intensive pond-culture systems. Within this paradigm, the competition for space and resources may also be reflected in the choice of species cultured. In recent years, there has been a shift from cyprinids to tilapias, as farm practices switch from polyculture to monoculture. In the last reporting year, this trend was also seen for mullets. In the last ten years tilapia production increased dramatically from 157 000 to 557 000 tonnes (Figure 12). In addition to natural resource constraints, these shifts in culture practices are also influenced by rising feed prices and lower market fish prices (Rana, Siriwardena and Hasan, 2009).

FIGURE 11
Geographic distribution of aquaculture production sites in Egypt



Source: Adapted from FAO (2003–2013).

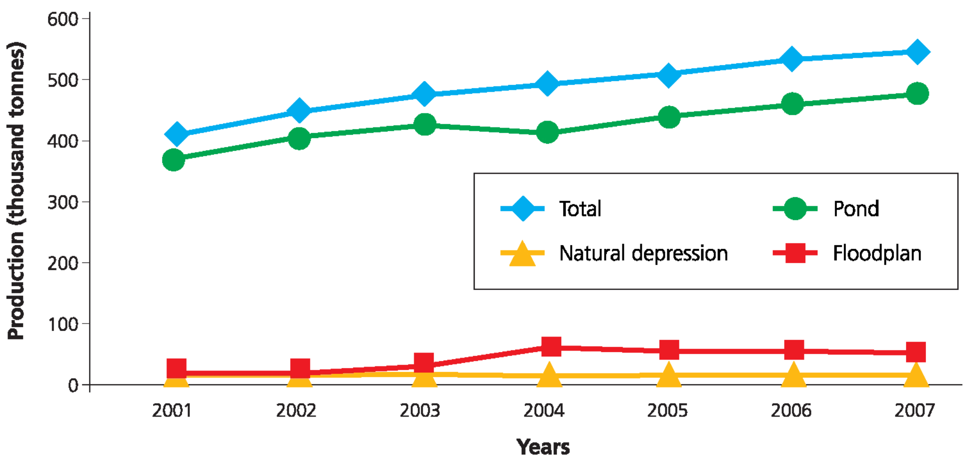
FIGURE 12
Changes in species cultured as sites in Egypt became limiting (1988–2010)



Source: Adapted from FAO (2012b).

Notable strains on farming systems and land resources are also evident in Bangladesh. Ponds are the predominant method of production, followed by floodplains and natural depressions (Figure 13). However, production from ponds has only increased by 5 percent annually in this millennium, and it actually decreased by 1–4 percent per year between 2004 and 2008 for production from floodplains and natural depressions (Figure 13). Fragmentation of landholdings for cultural reasons has significantly increased the number of small farms. Prawn farms average 0.31 ha compared with 0.60 ha for rice-only farms. With the increase in population, the average size of rice farms declined from 1.43 ha in 1961 to 0.87 ha in 1994, and is now just 0.60 ha (Rahman and Parkinson, 2007). Prawn farms were also larger more than a decade ago, averaging 0.35 ha. The reduction in pond size will inevitably result in a lower pro-rata net income for resource-poor farmers, and this calls into question the sustainability of such activities. Increased productivity through better feeds and feed and pond management practices is therefore imperative.

FIGURE 13
Temporal changes in production from different resource types used for aquaculture in Bangladesh



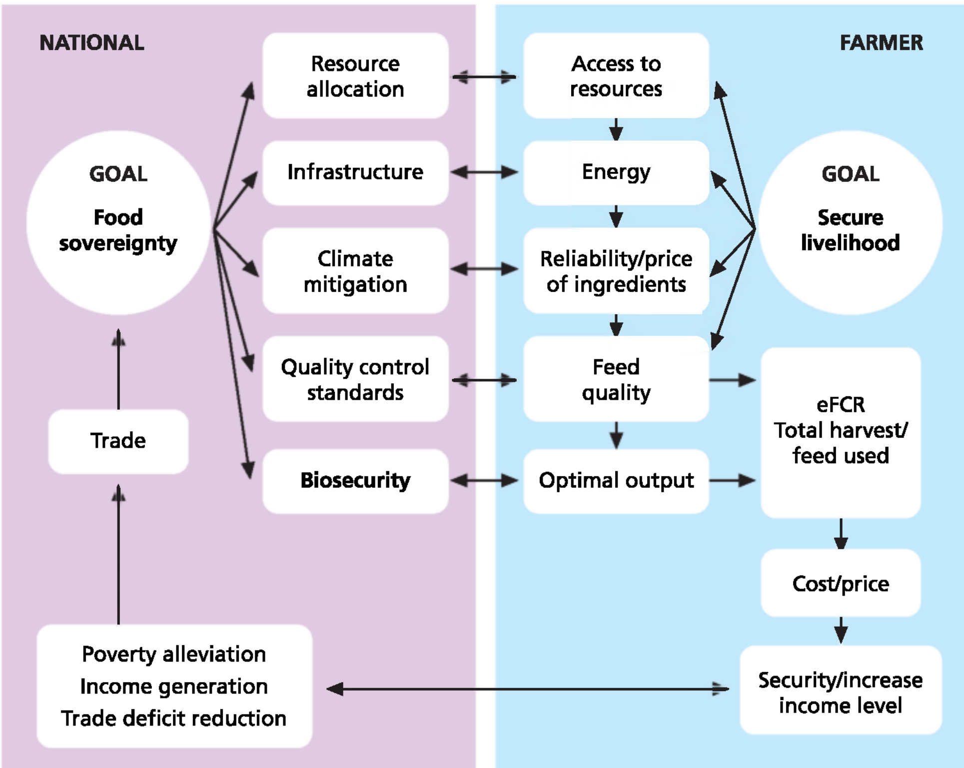
Source: Adapted from Sarder (2013).

3.2 Improving production volumes and efficiencies

3.2.1 Relationships between national and farmer aspirations

Government and individual farmers will have synergetic roles in contributing to increased aquaculture output, with government taking the lead role to address capacity and constraints to improve efficiency through prioritized research and development with measurable impacts. The key issues and roles of government that will affect farmers, especially as they relate to feed inputs, are highlighted in Figure 14. In order to address the national goal of food security, governments will have to put in place measures to secure and increase natural resources, improve farmer access for aquaculture and improve infrastructure to minimize the transaction costs of farmers while ensuring fair prices for energy that will be increasingly required to raise productivity. Securing aquafeed ingredients, either through increases in domestic production or by increased imports, will be key to future development of aquaculture, while quality control of manufactured feeds will be crucial to ensuring optimal use of feed ingredients. To maximize outputs, governments and farmers alike will have to put in place improved pragmatic management practices to reduce mortality.

FIGURE 14
Interrelationships between national roles and farmer aspirations to address aquaculture production constraints



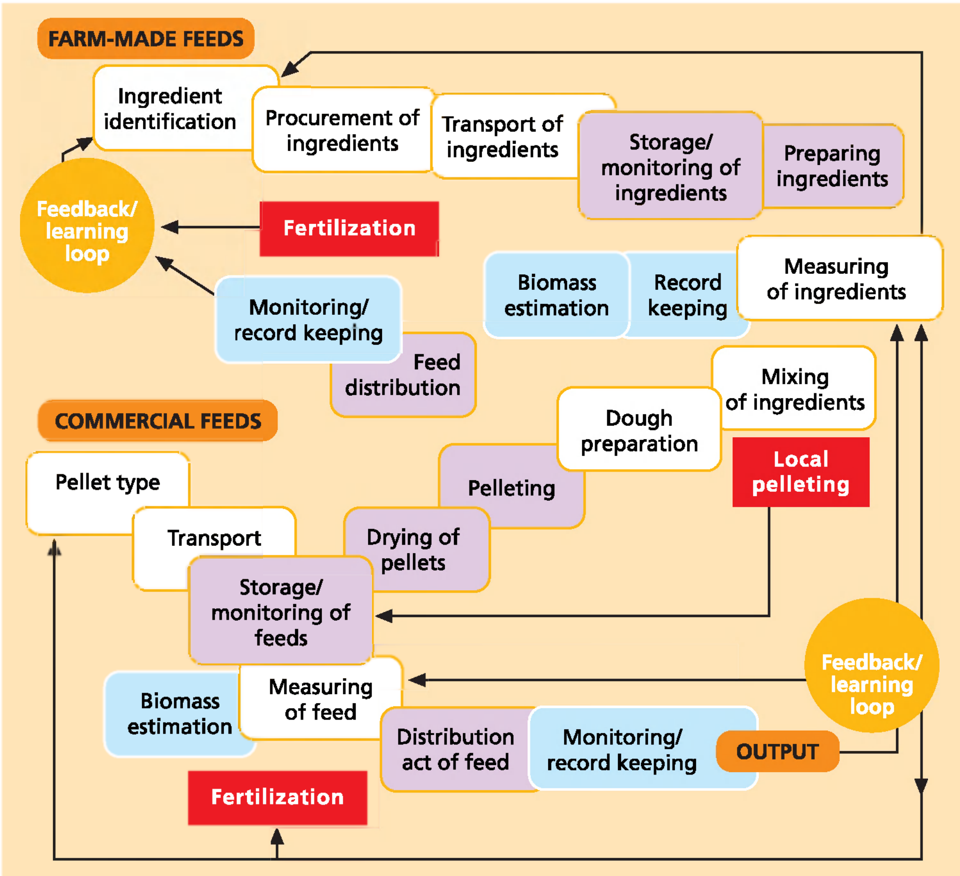
Source: Compiled by authors.

3.2.2 Use and management of on-farm feeds in selected countries

Farmers in the survey countries (Bangladesh, China, Egypt, Ghana, India, the Philippines, Thailand and Viet Nam) deploy a spectrum of practices for securing aquafeeds. Aquafeeds may be prepared with procured or home-grown ingredients on the farm or bought as complete manufactured feeds. Farmers deploy a range of options to secure aquafeeds. Farmers that make their own farm-made feeds often buy ingredients from local suppliers. These ingredients are transported to the farm site where they are milled, if required, or taken to local millers who prepare the ingredients for inclusion in diets. Depending on resources, farmers may distribute these ingredients as a powdered diet, but this practice is fast dwindling as farmers mix ingredients with water to produce dough balls; these are fed directly to fish either on trays or dispersed over ponds (e.g. major carps in Bangladesh) or pelleted in a simple pelletizer, the pellets then being air dried, stored and fed as required (Figure 15).

Where resources or credit facilities are available, farmers prefer to use commercially manufactured sinking or floating pelleted aquafeeds. In countries such as Egypt, 40 percent of the farmers surveyed used extruded feeds, often using demand feed dispensers.

FIGURE 15
Composite of specific components of on-farm feed production and management chain



Source: Compiled by authors.

3.2.3 Significance of feed cost

The use of concentrated feed in the form of floating or sinking pellets has been the key contributory factor to increased production, together with aeration and improved water management. In the last two decades, however, the price of ingredients has multiplied and significantly affected aquafeed prices. These impacts and consequent challenges for the sustainability of aquaculture have recently been reviewed by Rana, Siriwardena and Hasan (2009).

In a context of increasing feed and production costs, feed utilization efficiency is of paramount importance. The contribution of feed as a proportion of production cost is typically greater than 50 percent, irrespective of scale or intensity of production (Table 6). In China, where tilapias are cultured as the major crop in polyculture or intensive monoculture, feed accounts for 70–80 percent of production costs. Similarly, in Viet Nam feed contributes more than 80 percent of production costs for striped catfish production. Overall, the proportional cost of feed was lower when farm-made feeds (FMFs) were used. In India, where FMFs were used for Indian major carps, feed costs were below 60 percent. Similarly, for giant river prawns in Bangladesh, the use of on-farm feeds maintained feed costs below 35 percent. Irrespective of intensity of stocking or species, the use of commercial feed increases feed contribution to production costs. Although black tiger shrimp were farmed extensively in India, the use of commercial feeds increased feed costs to about ~60 percent of production costs (Table 6). In all scenarios, feed is the single most important production cost item; therefore, any management interventions to reduce feed input costs will have a significant bearing on the sustainability of aquaculture operations.

TABLE 6

Cost of feed as percentage of production cost for selected countries and pond-cultured species

Country	Species mix	Production system	Feed as % of production cost	Yield (tonnes/ha)	Source
Finfish					
China	Tilapia	Ponds – tilapia main crop polyculture + commercial feeds	68–84	7–9	Liu *et al.* (2013)
		Ponds – monoculture + commercial feed		8–12	
Philippines	Tilapia	Ponds – monoculture + commercial feed	50–60	7–15	Romana-Eguia, Laron and Catacutan (2013)
		Ponds – monoculture Farm-made +commercial feed		1–3	
Viet Nam	Striped catfish	Monoculture + commercial feed	83	325	Nguyen (2013)
		Monoculture + farm-made feed	77	398	
India	Indian major carps	Typical Indian major carps- mash	54	7	Ramakrishna, Shipton and Hasan (2013)
		Zero point culture – Indian major carps	48	5–6	
		Zero point culture – Indian major carps-mash-pellet	49	–	
		Zero point culture –Indian major carps-mash	41	–	
Shrimps and prawns					
Viet Nam	Whiteleg shrimp	Monoculture + commercial feed	66–69	9–15	Hung and Quy (2013)
Bangladesh	Giant river prawns	Extensive + snail meat	15	0.35	Ahmed (2013)
		Improved extensive + farm-made aquafeed	25	0.48	
		Semi-intensive + commercial feed	33	0.72	
India	Black tiger shrimp	Extensive + farm-made feed	52	0.38	Ramaswamy, Mohan and Metian (2013)
		Modified extensive Commercial feed + farm-made feed	59	1.3	
		Semi-intensive Commercial feed	62	2.8	

3.2.4 Risk options for farmers

Nations will have to prioritize how their resources are used. In the case of aquaculture, governments have two options to increase output: increase land and water area under cultivation; and/or increase unit productivity. An evaluation of the case studies suggests that farmers are faced with increasing uncertainty of feed price rises and limiting natural resources; consequently, farmers are intensifying production as one means of mitigation. However, the benefit-cost ratio (BCR) of aquaculture operations can be similar irrespective of feeding regime (Table 7) or intensification (Table 8). In India, the BCR ranged from 1.2 to 1.3 despite the use of improved feeds. In the case of Bangladesh, this ratio was greater, at 1.7–1.8, due to the higher price of prawns irrespective of intensification. Similarly, for semi-intensive culture of whiteleg shrimp in Viet Nam, the BCR was 1.6–1.7 (Hung and Quy, 2013). These data suggest that neither intensification, feed quality nor feed management by themselves necessarily increase returns on investment, yet where possible, farmers have intensified. The principal likely driver therefore for the increase in absolute net income is increase in farm size. For example, in Bangladesh, although the BCR was similar for extensive and semi-intensive culture, increasing farm size with intensification from 0.2 to 0.5 ha more than doubled annual net income from US$1 000/ha to US$2 100/ha (Ahmed, 2013). Data also suggest that increasing farm size and feed input may not necessarily result in increased unit returns.

TABLE 7

Benefit-cost ratio for culture of Indian major carps in India under various feed management conditions

Parameters	Zero point Indian major carp culture			
	Typical mash	Mash	Mash + pellet	Pankaj – mash
Annual net income (US$)	1 129	495	2 020	3 061
Annual net income (US$/ha)	1 505	914	3 730	5 247
Benefit-cost ratio	1.2	1.1	1.3	1.3

Source: Adapted from Ramakrishna, Shipton and Hasan (2013).

TABLE 8

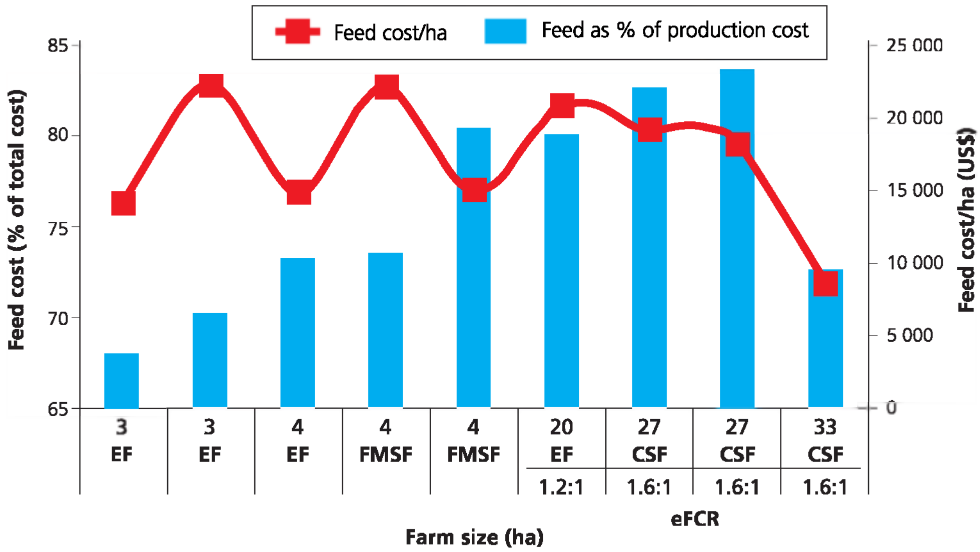
Benefit-cost ratio for giant river prawn culture in Bangladesh under varying intensification conditions

Parameters	Extensive	Improved-extensive	Semi-intensive
Annual income (US$/ha)	1 092	1 445	2 162
Benefit-cost ratio	1.7	1.7	1.8

Source: Adapted from Ahmed (2013).

In China, economic data suggest that larger intensive monoculture farms may not necessarily be as efficient as smaller polyculture units, and that larger farms could comprise feed management by virtue of their size (Figure 16). As farm size increased from 3 to 33 ha, the proportion of feed to total production cost increased, with one exception (33.3 ha), from 68 to 84 percent, showing no meaningful economies of scale. The per-hectare feed costs were similar, ranging from US$14 000 to 22 000/ha, with one exception. Increasing farm size was also not translated into improved feed conversion efficiencies of 1.6:1 (Figure 16).

FIGURE 16
Relationship between farm size, feed cost and feed utilization in China

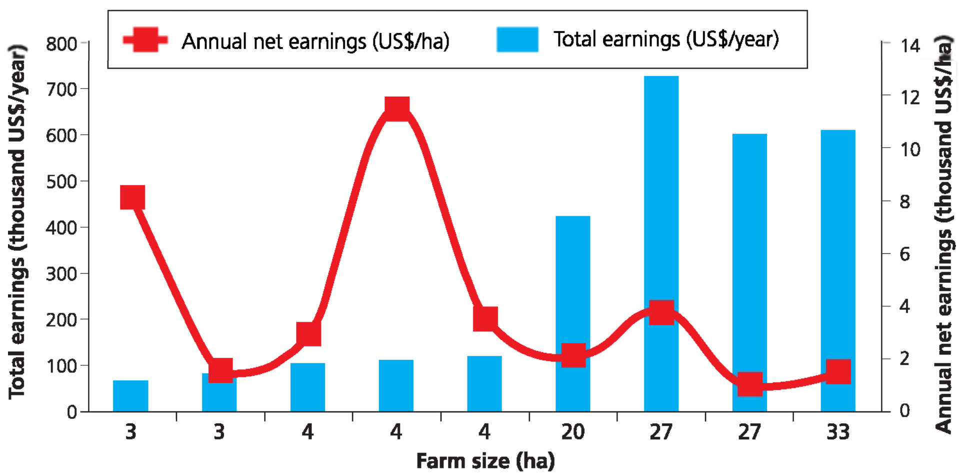


Source: Adapted from Liu *et al*. (2013).

Notes: EF = extruded feed; FMSF = farm-made sinking feed; CSF = commercially pelleted sinking feed; eFCR = economic feed conversion ratio. The feed conversion ratio is the ratio between the dry weight of feed fed and the weight of yield gain. It is a measure of the efficiency of conversion of feed to fish (e.g. FCR = 2.8:1 means that 2.8 kg of feed is needed to produce 1 kg of fish live weight). Two additional terms are used by the farmer, the biological FCR (bFCR) and the economic FCR (eFCR). The bFCR is the net amount of feed used to produce 1 kg of fish, while the eFCR takes into account all the feed used, meaning that the effects of feed losses and mortalities, for example, are included (adapted from FAO, 2010).

The larger, more intensive farms in China also did not necessarily translate into increased unit income (Figure 17). Although farms smaller than 4 ha showed a large range, their annual average earnings were US$8 400/ha compared with only US$2 000/ha for farm sizes between 20 and 33 ha, and larger farms showed no benefits, instead spending 2–4 percent of production costs on drugs and feed additives. Overall, the data suggest that increased income was attained by having a larger number of ponds and farm size rather than through improved production efficiencies.

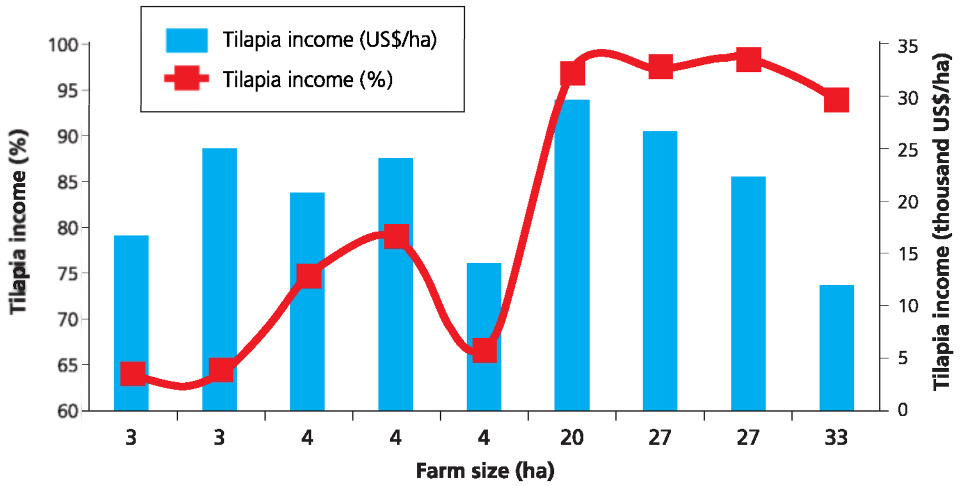
FIGURE 17
Relationship between Chinese farm size and total and unit area income



Source: Adapted from Liu *et al*. (2013).

The proportion of income from tilapia by farms of varying size is given in Figure 18. The contribution of tilapia income to farm income varied with type of production system and farm size. Farms of 4 ha and smaller adopted polyculture, a method in which tilapia was the main species, contributing 63–68 percent of total income. In the larger monoculture tilapia farms (> 20 ha), tilapia accounted for 94–97 percent of farm income. When the total farm revenue is considered, however, unit income decreased as farm size increased, while in smaller farms revenue from tilapia was similar (Figure 18). Overall, the Chinese experience points to larger monoculture farms being more inefficient, and increase in income is achieved by increasing farm size; this questions the resilience of the farming systems as currently managed.

FIGURE 18
Effect of increasing farm size on income from Nile tilapia in China



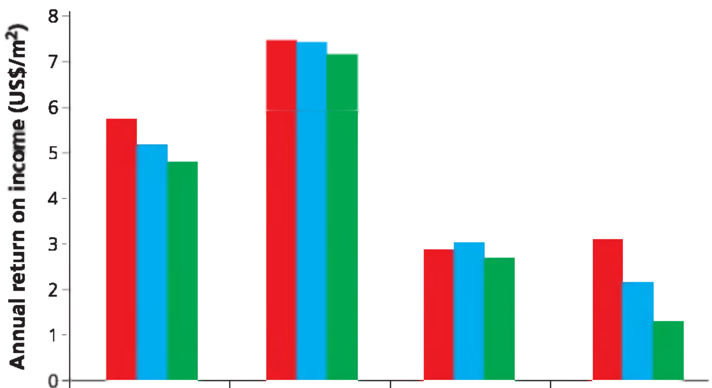
Source: Adapted from Liu *et al*. (2013).

3.2.5 Resilience of farming system to uncertainty of natural resources and feeds

Resource-poor farmers have limited capacity and resources to procure commercial feeds or to buffer themselves against escalating prices. Their ability to increase their net income from their aquaculture operations and to raise productivity is curtailed by virtue of their small farm size and limited capacity to secure finance. In countries such as Bangladesh, farms that are typically less than 0.3 ha are becoming smaller through subdivision when the land is transferred from parents to their children. Under these conditions, diversifying food production is a necessary livelihood strategy for sustained income. In this scenario, farmers have adapted, using local resourcefulness and knowledge, to stabilize and secure production (e.g. use of snail meat in Bangladesh). In addition, to increase net income from their small operations, farmers have switched to higher-valued species. In Bangladesh, for example, rice farmers have focused on rearing giant river prawns with fish and rice to successfully raise income and spread risk, the extent of increased production being feed-dependant. Nevertheless, 80 percent of farmers still farm using extensive (50 percent) or improved extensive (30 percent) methods with snail meat and farm-made feeds to earn between US$190/year (US$1 000/ha per year) and US$420/year (US$1 500/ha per year), respectively (Ahmed, 2013). The case study from Bangladesh also suggests that larger, more intensively farmed operations using commercial feeds are at best similar or poorer than extensively farmed operations and that increases in absolute income were achieved simply by virtue of their larger acreage.

In the case of giant river prawns, data suggest that extensive farming systems with fish and rice may be more resilient to external shocks such as feed price hikes, disease outbreaks and increases in fuel costs. The annual unit net income of such farms was on average, US\$5.7/m², 19 percent higher than the unit income from semi-intensive farms, while that from prawns and fish was similar (Figure 19). The switch by semi-intensive farmers from rice to prawns drastically reduced their income from rice by 58 percent and reduced the overall unit income by about US\$1/m² (Figure 19).

FIGURE 19
Income of giant river prawn farmers practising varying levels of intensive farming in Bangladesh



	Total net income	Prawn - total gross income	Fish - total gross income	Rice - total gross income
Extensive (190 m²)	5.7	7.5	2.9	3.1
Improved extensive (280 m²)	5.2	7.4	3.0	2.2
Semi-intensive (450 m²)	4.8	7.2	2.7	1.3

Annual return on income (US\$/m²)

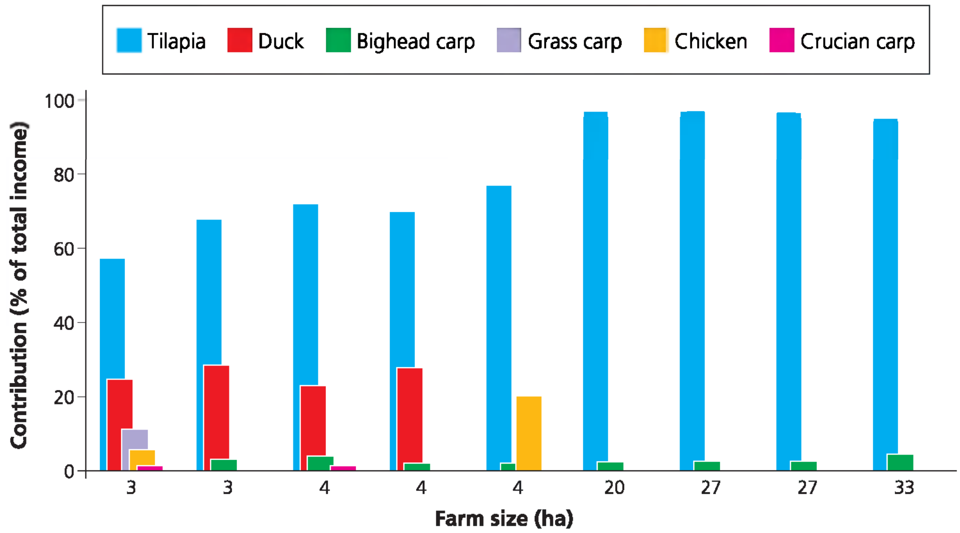
Source: Adapted from Ahmed (2013).

Note: Pond size (in square meters) is given in parentheses.

A similar trend is seen in China. Smaller fish farms diversify their farming activities through horizontal integration with poultry. These practices display a greater resilience compared with monoculture through spreading risk and improving cash flow. About 25–30 percent of income in these farms is derived from either ducks or chickens (Figure 20). Similar to Bangladesh, a few anomalies are seen; the unit return from the larger monoculture farms was similar to or lower than that of small, horizontally integrated farms, with no clear evidence for efficiency gains from scale. However, overall, greater income returns were achieved owing to larger farm size (see Figure 17).

In India, there is also a trend to intensify farming practices to improve the productivity and production of black tiger shrimp (Ramaswamy, Mohan and Metian, 2013). As elsewhere, the merits of such an approach will be determined by the degree of return on investment, in terms of both time and money. Black tiger shrimp farming in India is practised at three levels, with varying degrees of increasing inputs: extensive, improved extensive and semi-intensive (Table 9). Key features of intensification in black tiger shrimp farming in India include increase in stocking density from 4 to 8–20 PL/m², use of commercial feeds, water exchange and aeration (Table 9). Although these inputs increased production, the net return from such interventions in semi-intensive shrimp culture resulted in less than half the net unit return compared with improved extensive management.

FIGURE 20
Relationship between farm size and diversification of farming activities in China



Source: Adapted from Liu *et al*. (2013).

TABLE 9
Inputs, yield and returns with intensification of black tiger shrimp farming in India

	Extensive	Improved extensive	Semi-intensive
Pond size (ha)	0.5–2.0	0.5–1.5	0.3–1.0
Water exchange (%/day)	–	0–10	5.0–20.0
Stocking density (PL/m²)	<4	4–8	8–20
Feed	SF/FMF	SF	MPF
Aeration	none	partial aeration	continuous aeration
eFCR	1.27	1.31	1.38
Annual yield (tonnes/ha)	0.2–0.5	0.8–1.7	1.8–3.3
Net income (INR/kg shrimp)	59 (US$1.3)	50 (US$1.1)	24 (US$0.5)

Notes: SF = supplementary feed; FMF = farm-made feed; MPF = manufactured pelleted feed; eFCR= economic feed conversion ratio; US$1.0 = Indian rupees (INR) 46.4 using 2010 exchange rate.
Source: Adapted from Ramaswamy, Mohan and Metian (2013).

Overall, all these case studies suggest that there appears to be no automatic benefit of scale with regard to productivity, the higher incomes from intensive farms being mainly derived by virtue of their larger farm sizes.

4. OPTIONS TO IMPROVE PRODUCTIVITY

4.1 Approaches for improvements

The main purpose of intensification is to increase production volume and efficiency while reducing costs. Such increases are achieved through a spectrum of physical interventions and feed management strategies. Fish ponds continue to be a choice of production method. This synthesis acknowledges that farm output is the summation of all interrelated interventions but elaborates on the performance of feed and feed management practices as measured by production volumes and efficiencies.

Although the case studies illustrate that higher productivity is not automatically achieved with increasing inputs, various feed and feed management options are proposed in these case studies and these are tabulated in Table 10.

TABLE 10
Focus areas advocated for improving aquafeed performance and feed management and reducing feed costs

Diet performance	Feed management
• Promote nutritionally balanced feeds	• Maintain appropriate timing of feeding
• Reduce fishmeal content	• Alternate higher and lower protein diets
• Increase digestibility	• Use mixed feeding schedules
• Choose appropriate pellet type	• Delay onset of external feeding
	• Optimise feed administration

Progress on diet performance and feed management is discussed in detail in the individual case studies presented on the CD–ROM accompanying this publication (Ahmed, 2013; Awity, 2013; Bhujel, 2013; El-Sayed, 2013; Hung and Quy, 2013; Liu *et al.*, 2013; Nguyen, 2013; Ramaswamy, Mohan and Metian, 2013; Romana-Eguia, Laron and Catacutan, 2013; Sarder, 2013) and in Ramakrishna, Shipton and Hasan (2013). For this synthesis, case study data are evaluated to understand which interventions are increasingly deployed and having an impact on increased farm outputs.

4.2 Interpretation and evaluation of productivity

Given that aquafeeds account for up to 80 percent of production costs, their use, together with other interrelated synergistic farm management practices and interventions, has to translate into increased production while reducing production costs. The principal indicator used in aquaculture to evaluate feed performance is the economic food conversion ratio (eFCR), and this is used here to compare the outcomes of feed and feed management practices in selected countries using varying levels of feed inputs. Indeed, some salmon companies in Scotland, the United Kingdom of Great Britain and Northern Ireland, use eFCR as an incentive indicator for employee bonus (K.J. Rana, personal communication, 2011).

When feed inputs are increased, four key synergistic physical management interventions apparent in the case studies must also be recognized for their role in increasing overall output and extracting the best performance from diets:

- aeration of ponds;
- increased stocking density;
- increased water exchange;
- deeper ponds.

Increased aeration of ponds using an array of aeration types is the most common management intervention. In China, Egypt, India and the Philippines, aerators are used in ponds. However, such an intervention, together with increased stocking density can only be justified if reliable and reasonably priced energy supply and infrastructure can be secured to optimize feed utilization.

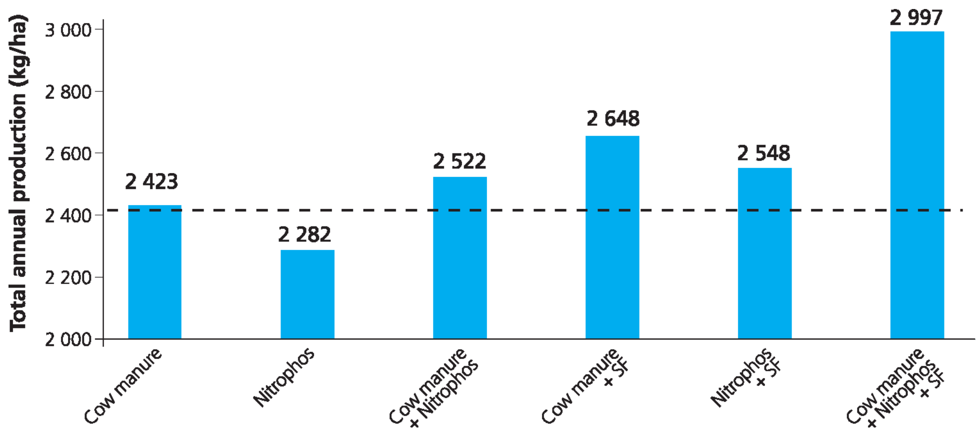
Although production from ponds is often cited as weight per unit area (usually hectares), this assumes that ponds are about the same depth, typically between 0.8–1.0 m. In recent years, farmers in, for example, China and notably in Viet Nam, have increased their tilapia and catfish pond depths to 1.5–2 m and 4–6 m, respectively, as a means of increasing output (Liu *et al.*, 2013; Nguyen, 2013). Accordingly, production from these ponds is typically 8–12 tonnes/ha and 360 tonnes/ha, respectively. Using the averages and adjusting production to a typical pond depth (1 m), such production for tilapia (Liu *et al.*, 2013) and carps

(Ramakrishna, Shipton and Hasan, 2013) is only 4–6 tonnes/ha, which can be easily attained from well-managed fertilized ponds. Careful evaluation of striped catfish farming in Viet Nam also suggests that productivity may not be as high as first envisaged, given the farming practice. Striped catfish ponds in Viet Nam are on average 4.4 m deep and 0.32 ha in size. Given this depth, the very high daily water exchange, typically 30–100 percent/day, and that water volumes in these ponds are typically 4–5 times that of standard ponds, it may be more prudent to interpret production in cubic metres rather than in two dimensions (square metres). For the average striped catfish pond farm yielding 360 tonnes/ha, this translates to only about 8 kg/m^3. This is significantly lower than 100–150 kg/m^3 for the African catfish reared in simple concrete tanks in Nigeria (K.J. Rana, personal communication, 2011) and for cage-farmed tilapia in Egypt (25–30 kg/m^3; El-Sayed, 2013) and the Philippines (4–40 kg/m^3, Romana-Eguia, Laron and Catacutan, 2013).

4.3 Performance of feeds used in aquaculture

This discussion focuses on the eFCR as a measure of feed performance in the selected case studies with reference to international benchmarks and later to the scope for improvement. An evaluation of diet performance based on eFCR as reflected by growth and production in these systems, however, is difficult owing to the confounding effect of unpredictable levels of natural feed in these rearing systems, which can make a significant contribution to overall production (Figure 21). Under comparable polyculture, natural food derived from organic and inorganic fertilizers alone resulted in annual carp production levels of 2.2–2.4 tonnes/ha. When 50 percent of nitrogen (N) for fish in ponds was provided in the form of supplementary feeds, the gross fish production increased by only a further 0.5 tonne/ha (Figure 21). Thus, the value and perceived efficacy of artificial feeds, especially supplementary feeds, will need to be more carefully evaluated. Nevertheless, irrespective of the contribution of natural feeds, given the high proportional production cost of feed incurred by farmers, eFCR is a valid and widely used index to evaluate the merits and justification of artificial feeds. In integrating such data for diet performance, however, due cognizance must be taken of the fact that eFCR is the outcome of the whole farming management system and not diets *per se*.

FIGURE 21
Impact of natural feed derived from a combination of organic and inorganic fertilizers and supplementary feeds on carps reared under similar pond polyculture conditions



Source: Adapted from Abbas *et al*. (2010).

Note: SF = supplementary feed.

The reported eFCRs for tilapias, Indian major carps, catfishes, shrimps and prawns reared on farm-made and commercial feeds from various production systems and intensity of production are given in Tables 11–13. While high water turnover tends to reduce the contribution of natural feeds in cages sited in rivers and lakes (unless highly eutrophic, e.g. Laguna de Bay, the Philippines), natural feeds can and do make a notable contribution in ponds where water exchange is limited. Under cage-farming conditions, natural feeds are generally limited. For cage-farmed tilapia using commercial, mainly extruded feeds, reported eFCR ranged from 1.2:1 to 1.5:1 (Table 11). Data on eFCR for farm-made feeds, which are often presented to fish in powdered form, were scanty but, where available, were notably higher. For striped catfish in Viet Nam and major carps in India, this ranged between 2.9:1 and 2.3:1 to 4.1:1, respectively (Table 12).

TABLE 11
Feed performance (eFCR) for Nile tilapia farmed in countries using various systems

	China	Thailand		Philippines		Egypt		Ghana	
System	**Pond**	**Pond**	**Cage**	**Cage**	**Pond**	**Cage**	**Pond**	**Cage**	**Pond**
Commercial feed	1.69:1[1]		<1.5:1[1]	1.50–1.71:1[1,2]	–	1.00–1.21:1 floating*	1.5–2.5:1[1] sinking	1.2–1.4:1[1] Coppens	1.8– 2.3:1[3]
Farm-made feed	NA	<1[4]	–		XX	Not used		NA	
Fertilizers	XX[5]	XX	–	Not used	XXX	–	X	Not used	xxx

Notes: [1]Intensive. [2]Semi-intensive (farm-made feeds). [3]Extensive (+ limited supplementary feeds). [4]Low FCR is probably due to availability of natural food in the pond. [5]X = not commonly used; XX = commonly used; XXX= frequently used.
*Extruded floating feed.
Source: Liu *et al.* (2013); Bhujel (2013); Romana-Eguia, Laron and Catacutan (2013); El-Sayed (2013); Awity (2013).

TABLE 12
Feed performance (eFCR) for striped catfish and Indian major carps farmed in countries using various culture systems

	Viet Nam	Bangladesh	India
Species	**Striped catfish**	**Indian major carps**	**Indian major carps**
System	Ponds: intensive	Ponds: semi-intensive	Ponds: semi-intensive
Commercial feed	1.6:1	NA	1.8:1–3.4:1
Farm-made feed	2.9:1	1.3:1–2:1	2.3:1–4.1:1
Fertilizers	Not used	XX	XX

Note: NA = data not available; XX = commonly used.
Source: Nguyen (2013); Sarder (2013); Ramakrishna, Shipton and Hasan (2013).

Such relatively high eFCRs (2.1:1–4:1) were also evident for giant river prawns in Bangladesh fed both commercial and farm-made feeds. The performance of marine shrimps reared in fertilized semi-intensive ponds in Viet Nam and India and fed commercial diets, however, was low at 1.0:1–1.4:1 (Table 13).

TABLE 13

Feed performance (eFCR) for shrimps and prawns farmed in countries using various culture systems

	Bangladesh	India	Viet Nam
Species	**Giant river prawns**	**Black tiger shrimp**	**Whiteleg shrimp**
System	Ponds: semi-intensive	Ponds: semi-intensive	Ponds: intensive
Commercial feed	2.30:1	1.27:1–1.38:1	1.00:1–1.20:1
Farm-made feed	2:1–4:1	NA	NA
Fertilizer	XX	XX	XX

Note: NA = data not available; XX = commonly used.
Source: Ahmed (2013); Ramaswamy, Mohan and Metian (2013); Hung and Quy (2013).

4.4 Presentation of nutrients

Although the data are far from complete, the reported eFCRs shown in Table 14 provide an indication of the broad trend. Farm-made feeds were poorer (1.9:1–4.1:1) when compared with manufactured feeds (1:1–2:1). For pelleted feeds either manufactured by local mills or commercial feed companies, diets appeared to yield similar results. Moreover, there were no clear performance differences between sinking and extruded diets or species, and performance was similar between countries (Table 11). Performance of feeds from cage-reared fish (eFCR 1:–1.5:1) was slightly better than that from pond-reared fish (eFCR 1.2:1–2:1) except for pond-reared whiteleg shrimp where eFCR varied between 1.0 and 1.2 (Table 14).

TABLE 14

Economic feed conversion ratios (eFCRs) for feed types used for farming finfish and shrimps in ponds and cages

Feed type	eFCR	Species	Rearing system	Country	Source
Farm-made feed					
Mash	2.3:1–4.1:1	Major carps	Pond	India	Ramakrishna, Shipton and Hasan (2013)
Mash + pellet	1.9:1	Major carps	Pond	India	Ramakrishna, Shipton and Hasan (2013)
Moist pellets	2.9:1	Striped catfish	Pond	Viet Nam	Nguyen (2013)
Manufactured pellets					
Sinking pellets	1.5:1	Nile tilapia	Cage	Egypt	El-Sayed (2013)
Sinking pellets	1.6:1–2.0:1	Nile tilapia	Pond	China	Liu *et al.* (2013)
Sinking pellets	1.3:1–2.1:1	Major carps	Pond	Bangladesh	Sarder (2013)
Extruded pellets	2.0:1	Nile tilapia	Pond	Ghana	Awity (2013)
Extruded pellets	1.6:1	Striped catfish	Pond	Viet Nam	Nguyen (2013)
Extruded pellets	1.5:1–1.7:1	Nile tilapia	Pond	Philippines	Romana-Eguia, Laron and Catacutan (2013)
Extruded pellets	1.2:1–1.4:1	Nile tilapia	Cage	Ghana	Awity (2013)
Extruded pellets	1.0:1–1.2:1	Whiteleg shrimp	Pond	Viet Nam	Hung and Quy (2013)
Extruded feeds	1.2:1–1.5:1	Nile tilapia	Cage	China	Liu *et al.* (2013)
Extruded feeds	1:1	Nile tilapia	Cage	Egypt	El-Sayed (2013)

It should be noted that the outcomes of diet performance were similar, irrespective of differences in feed administration methods and frequency, whether hand fed or automatically dispensed. Overall, presentation of the nutrient ingredients to fish seems most crucial. Better utilization is achieved through presenting nutrients in a concentrated form, typically as pellets.

4.5 Reduction of protein and fishmeal in diets

Farmers and feed manufacturers alike are attempting to reduce feed cost and secure ingredients to produce cost-effective diets. Several avenues have been explored. In particular, significant effort has been devoted to research into reducing fishmeal for inclusion in diets. This section evaluates data from farm surveys to assess which interventions may have the greatest impact.

A considerable amount of effort continues to be devoted to fishmeal replacements on the grounds of cost and availability (Rana, Siriwardena and Hasan, 2009; Tacon, Hasan and Metian, 2011), and there is a view that protein levels, including fishmeal, in diets are overprescribed. Specifically, the contention is that fish diets contain too much protein, and that protein reduction, which may increase grow-out time, may result in better economic gain (De Silva, 2010). However, as shown in Table 15, the crude protein levels in aquafeeds from across Asia and Africa (see case studies), with a few exceptions (e.g. shrimp, 35–40 percent) are relatively low, typically between 15–30 percent, with fishmeal only constituting up to 5–10 percent of diets (Table 15). In the last 13 years for which data are available (1995–2008), fishmeal inclusion in major fish and shrimp diets declined considerably (FAO, 2012a). Tacon, Hasan and Metian (2011) point to a reduction of fishmeal use at the global level, reporting the decline in fishmeal inclusion levels from 10 to 3 percent, from 10 to 5 precent and from 28 to 20 percent from 1995 to 2008 for fed carps, tilapias and marine shrimps, respectively.

Striped catfish feeds in Viet Nam, for example, which are estimated to be almost 2 million tonnes, only contain 18–20 percent crude protein, and any further reduction is unlikely to affect costs and will increase feed requirements and other variable costs with no likely gain in farm-gate price. Based on the case study data, a daily delay in harvesting due to an extended growth period will require, each day, an additional 6, 0.3 and 0.16 tonnes of feed per hectare for catfish, whiteleg shrimp and Nile tilapia, respectively (Table 16). Moreover, as the key plant protein sources are internationally traded commodities (e.g. soybean meal, wheat and corn), the bulk sourcing of these ingredients is on a par with fishmeal (Rana, Siriwardena and Hasan, 2009). From the perspective of farmers, the merits of advocated protein reduction will therefore have to be considered from a financial rather than a biological perspective. This is especially so as it will, in addition, incur other higher variable costs such as drugs, pumping, labour, which for striped catfish farming adds up to 8 percent of production costs (Nguyen, 2013).

TABLE 15
Crude protein levels in commercial diets reported in case studies for on-growing of various fish and shrimp species

	Species	Crude protein (%)	Fishmeal (%)	References
Ghana	Nile tilapia	30	NA	Awity (2013)
Egypt	Nile tilapia	25	6	El-Sayed (2013)
Thailand	Nile tilapia	16–30	NA	Bhujel (2013)
Viet Nam	Black tiger shrimp	36–42	NA	Hung and Quy (2013)
	Whiteleg shrimp	32–35	NA	
Philippines	Nile tilapia	22–32	NA	Romana-Eguia, Laron and Catacutan (2013)
Viet Nam	Striped catfish	18–20	3–20	Nguyen (2013)
India	Major carps	8–30	3.5	Ramakrishna, Shipton and Hasan (2013)
Bangladesh	Major carps	25–30	5–10	Sarder (2013)
China	Nile tilapia	28–30	NA	Liu *et al.* (2013)

NA = Data not available.
Source: Case study data.

TABLE 16
Implication of delayed harvesting on additional feed requirements

Case study examples	Standing stock at normal harvest (tonnes/ha)	Extra feed (2%/ha)	
		Tonnes/day	Tonnes/week
Striped catfish	300	6	42
Whiteleg shrimp	15	0.3	2.1
Nile tilapia/Indian major carps	8	0.16	1.12

Source: Case study data.

4.6 Least-cost prioritization options to address feed efficiency - where should the focus be?

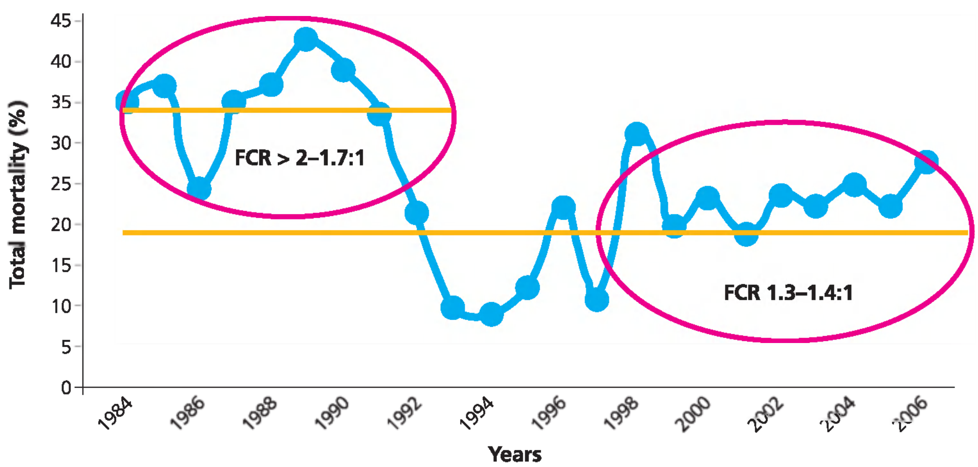
First, it is necessary to revisit the indicator is used for evaluating the farm diet performance (i.e. eFCR), which is a ratio of actual total weight gain and actual total weight feed used (or perhaps more relevantly, the total quantity of feed procured). Hence, without changing feed quality, any improvement in increased harvested tonnage and/or reduced feed usage will improve eFCR. Therefore, it is also necessary to take due cognizance of those factors that could most significantly influence these two variables. Based on the case studies, three main factors are considered here:

- mortality;
- feed presentation;
- storage.

4.6.1 Mortality and eFCR

As indicated in Tables 11–14, the eFCRs in many instances are relatively low and similar to the economic feed conversion efficiencies of the salmonid industry (Kaushik, 2013) and, in many instances, better than those of the seabass and seabream industry in Europe. In Turkey, for example, the FCR is about 1.6:1–2.0:1 for seabream and 1.8:1–2.2:1 for seabass (Okumus, 2005). Nevertheless, lessons may be evident from the historic evolution of diet performance in Europe. Prior to the 1990s, salmon farming in Scotland, the United Kingdom of Great Britain and Northern Ireland, was characterized by relatively high mortalities, with eFCRs in the range of 2:1 and the use of moist diets (Kaushik, 2013). Such performance is similar to that attained

FIGURE 22
Trends in reported Scottish salmon industry mortality pattern *versus* the industry-wide eFCR

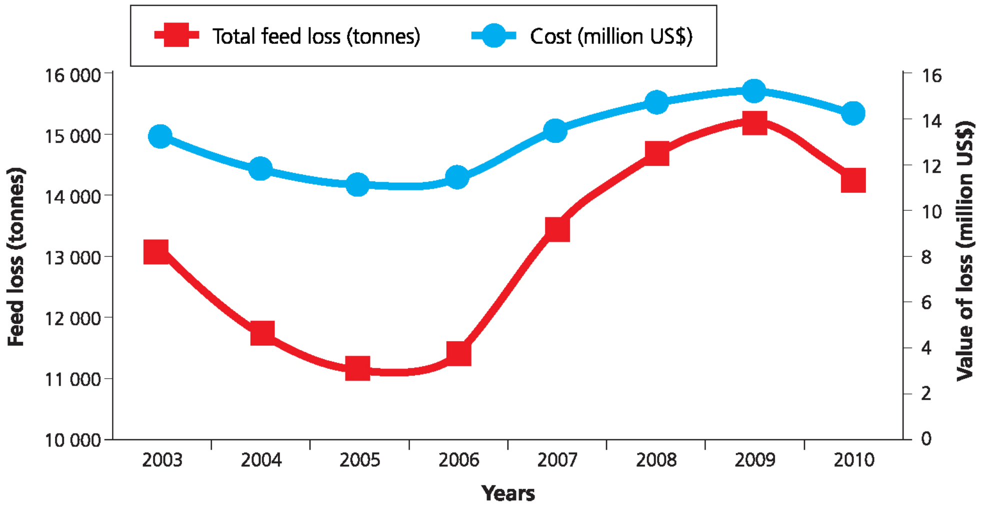


Source: Adapted from www.seeradonline.gov.uk and F. Johnston, FEAP, personal communication (2011).

by farmers using farm-made feeds (Tables 12–14). At the pragmatic farm level, the advent of pelleted feeds in the salmon industry and the improvement in industry-level survival by about 10–15 percent has improved feed performance from 2:1 to 1.3:1–1.4:1 (Figure 22). This was achieved by better accountability for ingredient utilization and improved feed usage through reduced mortality, reflecting higher harvested tonnage.

Taking into account that salmon farms hold two- and three-year-class fish, the feed loss for the industry, which in 2009 produced 144 000 tonnes, can be significant. In 2009, this loss was estimated at 15 000 tonnes valued at US$15 million (Figure 23).

FIGURE 23
Total annual feed loss by, and cost to, the Scottish salmon industry resulting from mortality based on stocked and harvested age classes reported to the Scottish Executive Environment and Rural Affairs Department



Source: Adapted from www.seeradonline.gov.uk

Note: Feed cost = US$1 000/tonne.

The above scenario represents a sector using a single production system, intensive cages. Where national production is significantly higher (e.g. Asia), and where production systems are diverse and operate at varying levels of intensification, total mortality may be significantly higher owing to a number of additional factors. Hence, a consideration of the contributing factors to total mortality may be useful and effective in improving eFCR and hence feed utilization efficiency.

The total mortality during the rearing phase represents all unaccountable fish based on initial stocking density. Losses may be due to a number of factors such as predation, theft, disease, handling and transport losses and escapes (Box 1). Given that the eFCR is a ratio of net weight gain and total feed used (Box 1), it would be prudent for farmers to target their efforts to identify significant contributors to total mortality to improve eFCR, irrespective of the type and quality of on-farm feed used. The Asian and African case studies suggest total mortalities may be significantly higher than in Europe, ranging between 30 and 50 percent during the grow-out phase (Table 17). An appreciation of the contributing factors to total mortality may therefore be useful in improving feed utilization efficiency.

Box 1
Mortality, net weight and eFCR

Total mortality (weight) = Total biomass loss from predation over production cycle + theft + disease + handling + grading + escapes

Total net weight at harvest = harvest weight – stocking biomass (if large fingerlings/yearlings used)

$$\textbf{eFCR} = \frac{\text{Total net weight gain at harvest (kg)}}{\text{Total feed used or procured}}$$

TABLE 17
Mortalities reported during the grow-out phase on farms in various countries

Country	Species	Mortality (%)	Stocking size (g)	Source
Egypt	Nile tilapia	25–35	NA	El Naggar, Ibrahim and Abou Zead (2008)
China	Nile tilapia	Up to 50–60	Up to 50	Liu *et al.* (2013)
Thailand (ponds)	Nile tilapia	40–50	NA	Bhujel (2013)
Thailand (cages)	Nile tilapia	35–40	30–50	Bhujel (2013)
Viet Nam (if harvested at 1.2 kg)	Striped catfish	38–40	50	Nguyen (2013)
Bangladesh	Giant river prawns	30	NA	Ahmed (2013)
Bangladesh	Indian major carps	35	NA	Sarder (2013)
Philippines	Nile tilapia	40	50	Romana-Eguia, Laron and Catacutan (2013)

NA = data not available.

The reasons for such mortalities or why such losses occur during the grow-out phase are unclear from the case studies in this document but they are crucial to understanding and developing strategies for improving on-farm feed utilization efficiencies. In these case studies for finfish, high mortality immediately post-stocking may be relatively rare given that larger fingerlings are stocked. In China, Thailand and Viet Nam, for example, 50 g fingerlings are used (Table 17). In instances where small fry or fingerlings (e.g. 3 cm) are used, predation could be higher. With larger fish, losses from theft and diseases are likely to be greater. In China, farmers have reported up to 30 percent losses due to bacterial diseases, possibly initiated by inadequate water quality management (Liu *et al.*, 2013). Such mortalities are likely to be increasingly prevalent as stocking densities are increased and total biomass increases beyond the carrying capacity of the rearing system. In such cases, relatively larger fish will be lost, reducing the harvestable yield and increasing feed loss and the eFCR of diets used.

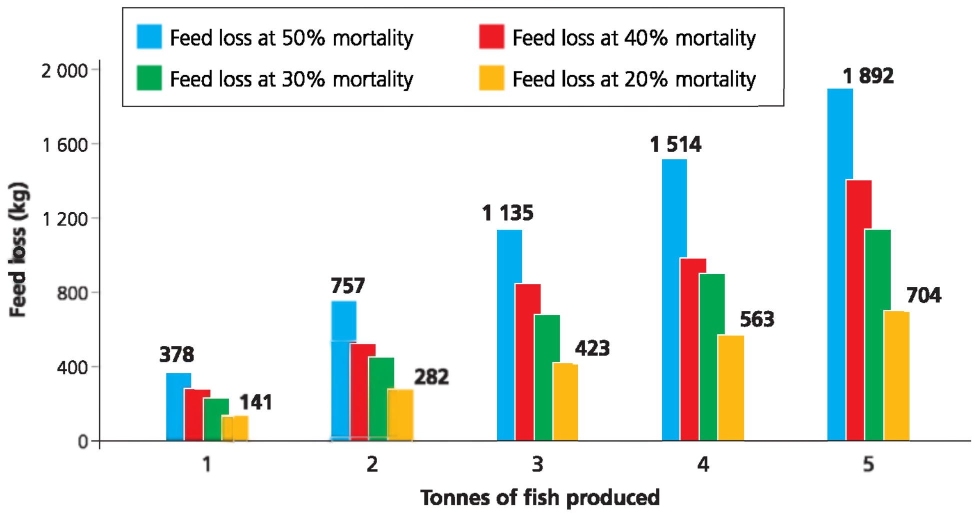
The details on such impacts are limited in the literature and are unavailable in the case studies. However, modelling such losses can shed some insight into their significance. The impact of total mortality on potential farm feed wastage using a typical growth rate (1.9 percent/day) and simulated survival pattern under different production levels (Table 18) is illustrated for tilapia in Figure 24. If the production of one tonne of fish incurs a total loss of 20 percent, then, over a seven month production cycle, 0.14 tonnes of feed would be wasted. Similarly, 5 tonnes of tilapia production would incur 0.7 tonnes of feed loss. At 50 percent mortality, such waste escalates to 0.4 and 1.9 tonnes, respectively. In Bangladesh (Sarder, 2013), the Philippines (Romana-Eguia, Laron and Catacutan, 2013), Egypt (El-Sayed, 2013) and Ghana (Awity, 2013), where feeds prices are reported as US$435, US$500, US$650 and US$1 000/tonne, respectively, farmers producing one tonne of fish and incurring 20 percent total mortality would lose

US$61, US$70, US$91 and US$140/tonne of fish harvested, respectively. At 50 percent mortality, these losses would reach US$170–390/tonne of fish harvested (Table 19).

TABLE 18
Simulated survival pattern for four final mortalities

Month	Final mortality (%) at end of 7 month grow-out phase			
	20	30	40	50
	Simulated survival pattern (%)			
1	100	100	100	100
2	95	90	80	80
3	90	85	75	70
4	90	85	75	65
5	85	80	70	60
6	85	75	65	55
7	80	70	60	50

FIGURE 24
Predicted feed loss under various final total mortality scenarios and production levels of tilapia



Source: This review.

Note: Survival pattern used in model for mortality scenarios given in Table 17.

The later and greater the mortalities occur in the production cycle (i.e. the greater the biomass), the higher the financial losses are. The significance of mortality and its financial impact on economic viability also varies between countries depending on the price of feeds. Irrespective of diet quality, the financial loss in Ghana is 2.3 times greater than in Thailand for the same amount of fish produced (Table19). Therefore, irrespective of diet type and quality, the first priority of farmers to improve eFCR must be to assess and critically reduce mortality to increase tonnage harvested and reduce financial loss.

TABLE 19

Monetary loss for each tonne of tilapia produced under various mortality scenarios

Country	Feed cost (US$/tonne)[1]	Feed loss (US$/tonne of fish produced)			
Total mortality at harvest (%)		20	30	40	50
Thailand	435	61	100	122	170
Philippines	500	70	115	140	195
Egypt	650	91	150	182	254
Ghana	1 000	140	230	280	390
Feed loss (tonnes/tonne fish of harvested		0.14	0.23	0.28	0.39

[1]Feed price based on case study data, feed loss from Figure 24.

4.6.2 Feed presentation

The highest cost component in feed production is the ingredients. Therefore, the key consideration in improving eFCR should be maximization of feed ingredient utilization by the fish. The presentation of ingredients to fish is briefly explored here, based on case study information from the countries.

Feed is presented to fish in ground and powdered form (Sarder, 2013), as dough balls (Sarder, 2013; Ramakrishna, Shipton and Hasan, 2013) and in two pelleted forms, sinking and extruded (Nguyen, 2013). Overall, where feed presentation is powdered or a dough, the eFCR is notably higher than if the ingredients are presented in a pelleted form (Table 12). For this case study, it should be noted that both pelleted and mash diets use similar inclusion levels of key ingredients such as soybean meal and rice bran. The inefficiency of single or multiple ingredient presentation to fish as powdered or mashed diet can be illustrated for Indian major carps in India using the bag–mash feeding method in which mixed ingredients are placed. The eFCRs for mash-fed systems are 2.3:1–4.1:1, whereas those of pelleted feeds are acknowledged as one third that of mashed feeds (Ramakrishna, Shipton and Hasan, 2013). However, data on comparative unit costs of feeds were unavailable. Farmers broadcast or place such feeds in bags in ponds, and the capacity of fish to acquire and utilize these dispersed feed ingredients is low. Thus, it is prudent for farmers to develop simple on-farm pelleting and drying of feeds using the same ingredients to ensure better acquisition of ingredients with reduced effort and wastage. Therefore, the second priority is to encourage farmers to switch from using single-ingredient or moist diets to compressing the same single or mixed ingredients into dry pellets.

Pellet stability

The case studies highlight two key areas for consideration for pelleted feeds: cohesion of major ingredients in pellets; and stability of pellets in water. Both have an impact on wastage and utilization. Poorly compressed and bound pellets can result in unacceptable breakage resulting in "fines" or dust that is unlikely to be consumed by fish and becomes an expensive route to fertilize ponds. Pelleted diets produced by smaller feed factories in China were regarded as of inferior quality (Figure 25). According to Liu *et al.* (2013), ingredients used for diets were not adequately ground and hence pellet integrity was poor, resulting in a high percentage of powdered diet being wasted. Poor pelleting is not just a concern for farm-made feeds. In Malawi, compressed pellets manufactured by feed mills can also be of suboptimal quality (Figure 26). In some instances this can exceed 15 percent (K.J. Rana, personal communication, 2011), contributing to financial loss and poorer eFCR. This hidden cost can be significant for larger farms, and it varies between countries owing to price differences (Table 20). The cost implication of varying amounts of fines and dust per tonne of fish feed and for a tonne of fish produced using feed with 5 percent fines and dust at various eFCR is presented in Table 21 for various countries. Depending on the eFCR achieved, farmers in Bangladesh will incur losses of between US$19 and US$31 for each tonne of fish produced, whereas in Ghana, where feed price is considerably higher, these losses equate to US$40–58.

TABLE 20

Monetary loss for each tonne of fish and shellfish produced under varying mortality scenarios

Country	Feed price (US$/tonne)[1]	Monetary cost of "fines" (US$) at 80% feed wastage		
Percentage fines		2.5	5	10
Major carps, Bangladesh	390	8	16	31
Nile tilapia, Egypt	425	9	17	34
Major carps, India	450	9	18	36
Nile tilapia, Philippines	600	12	24	48
Nile tilapia, China	560	11	22	45
Black tiger shrimp, India	640	13	26	51
Nile tilapia, Ghana	720	14	29	58

[1]Based on estimates from case studies.

FIGURE 25

Locally pelleted feed in China

[Note the high level of disintegrated pellets and dust]

Source: Liu *et al*. (2013).

FIGURE 26
Pelleted feed produced in Malawi
[Note the high level of dust and crumbled pellets]

COURTESY OF FAO/K.J. RANA.

TABLE 21
Financial loss incurred by farmers per tonne of fish and shrimp produced at various eFCR using diets containing 5 percent fines and dust

Country	Financial loss (US$) per tonne fish produced at 5% dust and fines in diets at various eFCRs				
	1.2	1.4	1.6	1.8	2
Bangladesh	19	22	25	28	31
Egypt	20	24	27	31	34
India (fish)	22	25	29	32	36
Philippines	27	31	36	40	45
China	29	34	38	43	48
India (shrimp)	31	36	41	46	51
Ghana	35	40	46	52	58

Related to compression is the binding of ingredients in pellets to optimize their water stability such that fish consume the whole pellets, thus benefiting from a complete diet. The third priority should be to focus on methods to reduce dusts and fines in feeds and optimize the binding properties of pellets to improve pellet hardness and water stability.

4.6.3 Feeding strategy options

In most cases, farmers feed their fish a ration of 2–3 percent of body weight per day, 1–2 times a day. Smaller farmers disperse their feeds by hand (e.g. Ghana, the Philippines and Thailand) or in bags (India), whereas larger farms deploy automated (e.g. China) or demand feeders (e.g. Egypt); however, there appear to be limited gains in reduction in FCR through use of the latter. The priority of farmers is to reduce feed costs, and they have responded to this challenge by adopting various cost-saving strategies in the administration of feeds. These include the use of:

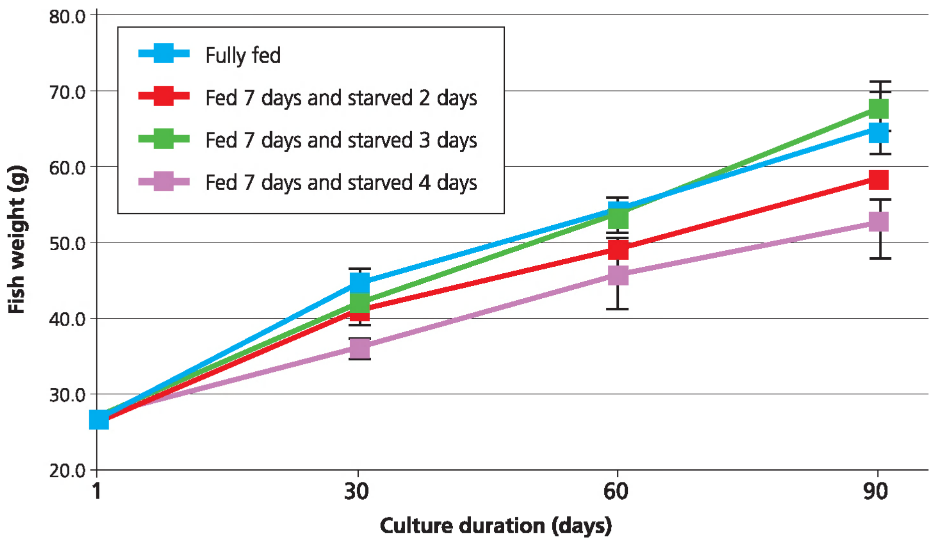
- fertilizers;
- alternate day feeding;
- alternative feeds with low and high-quality diets;
- feeding to satiation.

The most notable and promising approaches seem to be restricted feeding regimes and alternate use of high and low-protein diets.

Use of fertilizers
Fertilizers, both organic and inorganic, are extensively used to provide natural food. Poultry and cattle manure is predominantly used at annual rates of up to 13 tonnes/ha (India). In view of projected demands for fish globally and changes in land use patterns, the required tonnage of organic manures to provide the nutrient source for natural foods and fish is unlikely to be available and therefore, reliance on such fertilizers will be increasingly unpredictable. Moreover, some studies have indicated that the cost of macronutrients in dry chicken manure (on the basis of available amount of nutrients per 100 kg of manure and fertilizer) is seven times greater than inorganic urea for N and four times more than triple super phosphate for P (Knud-Hansen, 1998). In addition, the action of inorganic fertilizers is faster than organic manures; they require less labour and have a lower demand on dissolved oxygen. The value of fertilizers in providing micronutrients via natural food, however, may be a useful contribution to reducing on-farm feed costs, and the matter requires further research. A more promising farmer-driven approach is alternate day and diet feeding.

Restricted feeding and alternate feeding regimes with low and high-quality diets
Restricting feeding frequency to once a day was reported to reduce eFCR for striped catfish by 17 percent (Nguyen, 2013) for fish more than 500 g, and further reductions can be achieved by extending this feeding regime over the entire cycle, although this may extend the grow-out period by three weeks (Nguyen, 2013); however, the extra cost for three weeks of rearing is unclear. The growth of fish fed for 7 days and then starved for up to 3 days was not significantly different from that of fish fed daily (fully fed; Figure 27), and reduced eFCR by 18 percent (Nguyen, 2013).

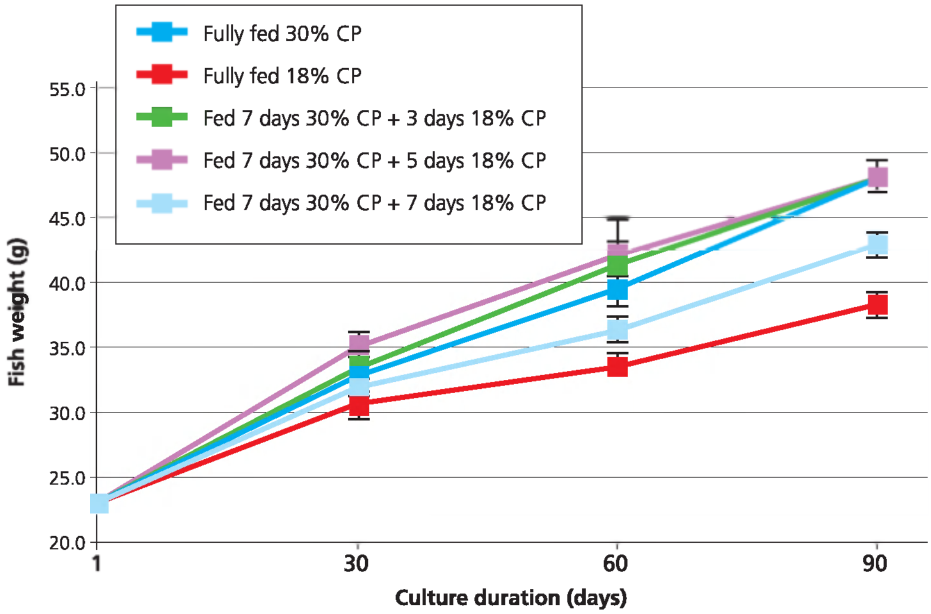
FIGURE 27
Growth of striped catfish fed different restricted feeding regimes



Source: Nguyen (2013).

In the Philippines, alternate feeding has shown promising results, and farmers who have adopted the schemes have noted a positive impact on reducing production costs (Romana-Eguia, Laron and Catacutan, 2013). Alternate feeding with high and low-protein commercial pellets also appears to be effective in reducing eFCRs. The growth rates of striped catfish fed 30 percent protein pellets for 7 days and then fed on 18 percent protein pellets for the next 3 or 5 days were not significantly different when compared with those fed only 30 percent protein diets all of the time (Figure 28), although it should be noted that these and other studies were conducted on fingerlings.

FIGURE 28
Growth of striped catfish fingerlings fed different alternate feeding regimes of high- and low-protein commercial diets



Source: Nguyen (2013).

Note: CP = crude protein.

Mixed feeding schedules using high and low-protein diets were demonstrated to be useful for many other cultured species, such as common carp (*Cyprinus carpio*) (Srikanth *et al*., 1989); catla (*Catla catla*), rohu (*Labeo rohita*) and common carp (Nandeesha, De Silva and Krishna Murthy, 1993; Nandeesha, Gagadhara and Manissery, 2002); Nile tilapia (Santiago and Laron, 2002; Patel and Yakupitiyage, 2003); striped snakehead (*Channa striata*) (Hashim, 1994); and tilapia in on-farm trials (Bolivar, Jimenez and Brown, 2006). These studies report better FCRs and suggest significant savings on feed costs. The fourth priority should therefore be for farmers to reduce the extent to which higher protein diets are used.

4.6.4 Feed transport, storage and handling

The final value of feeds to farmers is a summation of all the stages in the production and value chain for fish diets. The transport and storage conditions of diet ingredients and post-manufacture handling and storage conditions of feeds are as important as the nutritional quality of the diet. Inadequate attention to pre- and post-manufacture phases can significantly reduce the economic benefits of any commercial or on-farm feed to the farmer. High humidly (up to 90 percent), high ambient temperatures (up to 50 °C), and improper storage and handling are key factors affecting the end-use quality of feeds and are therefore of particular, although not exclusive, importance in non-temperate countries. Such conditions may result in fungal contamination of both feed ingredients and feeds, reduce nutritional value of ingredients, especially micronutrients, and increase the amount of dust and fines in bagged feed and losses due to pests.

Transport

Imported commercial diets (i.e. Ghana and Nigeria) are particularly vulnerable to spoilage as they have to be shipped by sea freight adding up to 25–45 days to delivery times (from Northern Europe to West Africa) to farms with uncertainty concerning the date of manufacture and transit storage conditions. Bagged diets are often packed in closed metal containers without any climate control, adding to potential diet deterioration caused by high temperatures and humidity build-up. Moreover, in Ghana, feeds are transported in metallic containers on vehicles from the ports to central warehouses in Accra (Awity, 2013) and subjected to higher ambient temperatures and humidity.

Transport of feeds or feed ingredients to farms in open trucks or on motorbikes and bicycles also increases transport times, often compounded by poor road conditions, causing bags to bounce, increasing friction between pellets and hence fines in bags.

Storage conditions and handling

Three key considerations are relevant to optimize feed usage: the control of pests such as rodents, temperature, and humidity; these are of concern in most developing countries. In the central warehouses of large importers in Ghana feeds were stored on pallets above ground level and crevices around buildings were plugged to keep out rodents. Small farmers, however, are unable to invest in dedicated storage facilities; feed storage is poor and simple good practices are not followed by farmers. In Ghana, farmers stacked feed directly on the floor during storage. At farms of this type that were visited, gnawed bags with feed spillage and escaping mice were evident. The store rooms at most of the farms visited were not designed to prevent the entry of rodents. One farmer stored feed in the open covered with a tarpaulin at night to keep off the rain (Awity, 2013).

Although private feed mills in Egypt have excellent handling, storage and transportation facilities, complying with the Code of Practice for Good Animal Feeding (FAO, 1998), this is not universal. In Egypt, handling of tilapia feed and storage facilities are regarded as the most serious problem facing the Egyptian aquafeed industry (El-Sayed, 2013). Feed stores at many feed mills have inadequate basic storage and handling standards. Ingredients are piled outdoors on the ground and exposed to direct sunlight, heat, moisture, and other weather conditions (Figure 29).

FIGURE 29
An example of poor feed ingredient storage in the open in Egypt

Source: El-Sayed (2013).

Pellets with high stability have good handling characteristics. If feed ingredients for formulated and on-farm feeds are not finely and uniformly ground and the binders used are inadequate their pellet strength and hardness may not be ideal; this increasing the incidence of pellet collapse and feed dust and fines (Figure 26). This can be especially high, resulting from compression and abrasion between pellets following the rough handling of bagged feeds and by people walking on bags. While not feasible for small operations, the use of forklifts and pallets, or hand-trucks and mini-pallets, to handle multiple bags minimizes handling. Larger fish farms with high volumes of fish inventories requiring significant qualities of feeds have the capacity to build dedicated storage facilities, as seen on striped catfish farms in Viet Nam (Figure 30).

FIGURE 30

Examples of feed storage on striped catfish farms in Viet Nam

(Note that the feed bags off floor on pallets and away from walls.)

COURTESY OF FAO/T.P. NGUYEN.

In China, smaller farmer with limited resources also store feed under poor conditions (Figure 31 left). Larger operators procure feed regularly, and this is transported to fish farms by the feed producers. There, it is usually stored on-farm in well-ventilated brick-tile buildings (Figure 31 middle) or in concrete buildings (Figure 31 right). Whilst these feed stores are watertight, the bags are stacked against walls, reducing air circulation and causing damp spots (Figure 31 middle and right). Storing ingredients and feeds on the floor is also common among small farmers in Viet Nam. The majority (>85 percent) of whiteleg shrimp small farmers in Central Viet Nam keep their feed in their houses (Figure 32) where humidity and temperatures are high.

FIGURE 31

Examples of tilapia feed stores in Guangdong and Hainan provinces, China (left: shanty store in Guangdong Province; middle: brick-tile house in Guangdong Province; and right: concrete building in Hainan Province

COURTESY OF FAO/JIASHOU LIU (LEFT); AND LIU ET AL. (2013) (MIDDLE AND RIGHT).

Examples of poor storage practices also include farmers who were observed to store purchased sacked feed along pond dykes in open weather conditions. This is common in Thailand, where farmers keep feed in covered plastic buckets (Figure 33), where temperatures can be very high, causing loss of micronutrients (Bhujel, 2013).

Many smaller farmers with limited financial resources procure feed ingredients in small quantities from local markets and make on-farm feeds on a daily or weekly basis, thus minimizing on-site storage and reducing the risk of ingredient and feed spoilage.

FIGURE 32
A typical in-house feed store in whiteleg shrimp farm, central Viet Nam

Source: Hung and Quy (2013).

FIGURE 33
Feed stored in plastic bucket at pond side in hot and humid conditions, Thailand

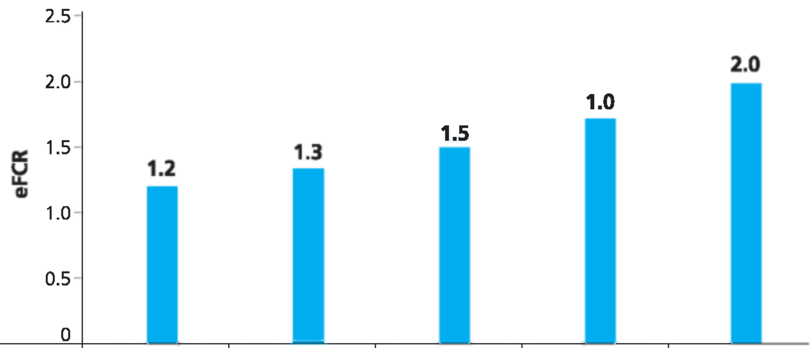
Source: Bhujel (2013).

5. CONCLUSIONS – FOCUS FOR IMPROVING FEED EFFICIENCIES.

In this assessment, the eFCR has been used as a primary indicator for on-farm feed utilization efficiency. Where available, data in case studies where commercial feeds are used suggest that eFCR is comparable with developed-country benchmarks for species such as Atlantic salmon in Europe (cf. Table 14 versus Figure 22).

As indicated in Table 10, several options are advocated to improve feed efficiencies. However, farmers will have to prioritize options to focus on those providing the best gains. In this synthesis, it has been shown that total fish mortality has a significant bearing on feed wastage. At just 20 percent total mortality, about 140 kg of feed is wasted (Figure 24) for every tonne of tilapia produced. The impact of such losses on eFCRs is illustrated in Figure 34. In an ideal scenario of no mortality, and using better management practices (BMPs), one can assume an eFCR of 1.2:1 (or the requirement of 1.2 tonnes of feed to produce one tonne of fish). Using the same feed quantity and a mortality rate of 20 percent will increase the eFCR to 1.5:1, and similarly at 40 percent mortality the eFCR jumps to 2:1, irrespective of diet quality. This highlights the paramount importance of mortality reduction strategies as a primary measure to improve feed utilization efficiencies. In addition, for tilapia, 20 percent mortality also incurs a financial loss of feed to the value of US$60–140/tonne of fish produced (Table 19).

FIGURE 34
Hypothetical changes in eFCR with increasing mortality



Biomas at harvest (kg)	**1 000**	**900**	**800**	**700**	**600**
Mortality (%)	**0**	**10**	**20**	**30**	**40**

Source: This review.

Note: 1 000 kg fish at 0% mortality at ideal eFCR of 1.2:1 (1 200 kg feed); if same feed volume used with 10% mortality, eFCR increases to 1.3:1 and to 2.0:1 at 40% mortality.

Concentrating feed ingredients into compressed pellets has been equally important in reducing improving) eFCR from 3:1 – 4:1 to 2:1 – 3:1. Pellet quality is also crucial in maximizing the value of diets. Poor pelleting results in dusts and fines and, at just 5 percent, will cost farmers US$19–38/tonne fish produced at an eFCR of 1.2:1. In countries where feed prices are higher and where eFCRs are poorer, these losses will be greater (Table 21).

Considering the factors of mortality, dust in feed, and pellet stability alone, farmers may lose between US$79 and US$178/tonne of fish produced, which highlights where farmers should focus their efforts.

Alternate feeding strategies with high- and low-protein commercial pellets have also proved to be effective in reducing eFCR, with a possible role for fertilizers in fulfilling micronutrient needs of fish. The data in the case studies provide no clear evidence for choosing the more expensive extruded feed over sinking pellets, and it would seem likely that any differences are probably due to the water stability of sinking pellets rather than to any difference in nutritional quality.

REFERENCES

Abbas, S., Ahmed, I., Salim, M. & Rehman, K. 2010. Comparative effects of fertilization and supplementary feed on growth performance of three fish species. *International Journal of Agriculture and Biology*, 12 (2): 153-168.

Ahmed, A. 2013. On-farm feed management practices for giant freshwater prawn (*Macrobrachium rosenbergii*) farming in southwest Bangladesh. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 269–301. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Awity, L.K. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Ghana. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 191–211. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Bhujel, R.C. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Thailand. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 159–189. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Bolivar, R.B., Jimenez, E.B.T. & Brown, C.L. 2006. Alternate-day feeding strategy for Nile tilapia grow-out in the Philippines: marginal cost-revenue analysis. *North American Journal of Aquaculture*, 68: 192–197.

De Silva, S.S. 2010. Feed management in small-scale aquaculture in the Asia-Pacific. A review prepared for FAO. 23 pp. (*unpublished*).

El Naggar, G.O., Ibrahim, N.A. & Abou Zead, M.Y. 2008. Influence of fertilizers' types and stocking density on water quality and growth performance on Nile tilapia-African catfish in polyculture system. *In* H. Elghobashy, K. Fitzsimmons & A.S. Diab, eds. Proceedings of 8th International Symposium on Tilapia in Aquaculture, pp. 157–170. Cairo, Egypt.

El-Sayed, A-F.M. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in Egypt. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 101–129. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

FAO. 1998. Animal feeding and food safety. *Food and Nutrition Paper*. No. 69. Rome, FAO. 45 pp.

FAO. 2010. *Report of the FAO Expert Workshop on on-farm feeding and feed management in aquaculture.* Manila, the Philippines, 13–15 September 2010. FAO Fisheries and Aquaculture Report No. 949. Rome, FAO. 37 pp.

FAO. 2003-2013. National Aquaculture Sector Overview. Egypt. National Aquaculture Sector Overview Fact Sheets. Text by A.M. Salem & M.A. Saleh. *In FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 16 November 2010. [accessed 21 January 2013]. (available at www.fao.org/fishery/countrysector/naso_egypt/en).

FAO. 2012a. *The State of World Fisheries and Aquaculture 2012*. Rome, FAO. 209 pp.

FAO. 2012b. *Fishstat Plus, Vers. 2.32*. Rome, FAO. (available at www.fao.org/fishery/statistics/software/fishstat/en).

Hasan, M.R., ed. 2007. *Economics of aquaculture feeding practices in selected Asian countries.* FAO Fisheries Technical Paper No. 505. Rome, FAO. 205 pp.

Hasan, M.R., Hecht, T., De Silva, S.S. & Tacon, A.G.J., eds. 2007. *Study and analysis of feeds and fertilizers for sustainable aquaculture development.* FAO Fisheries Technical Paper No. 497. Rome, FAO. 510 pp.

Hashim, R. 1994. The effect of mixed feeding schedules of varying dietary protein content on the growth performance of *Channa striata* fry. *Asian Fisheries Science*, 7: 149–155.

Hung, L.T. & Quy, O.M. 2013. On-farm feeding and feed management in whiteleg shrimp (*Litopenaeus vannamei*) farming in Viet Nam. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 337–357. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Kaushik, S.J. 2013. Feed management and on-farm feeding practices of temperate fish with special reference to salmonids. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 519–551. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Knud-Hansen, C.F. 1998. *Pond fertilization: ecological approach and practical applications*. Aquaculture Collaborative Research Support Program, Corvallis, Oregon State University, 125 pp.

Liu, J., Li, Z., Li. X. & Wang, Y. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in southern China. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 71–99. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Nandeesha, M.C., De Silva, S.S. & Krishna Murthy, D. 1993. Evaluation of mixed feeding schedule in two Indian major carps, catla (*Catla catla*) and rohu (*Labeo rohita*). *In* S.J. Kaushik & P. Luquet, eds. *Fish nutrition in practice. 4th International Symposium of Fish Nutrition and Feeding, Biarritz, France, June 1991*, pp. 753–765. Paris, INRA. 972 pp.

Nandeesha, M.C., Gangadhara, B. & Manissery, J.K. 2002. Further studies on the use of mixed feeding schedules with plant-and animal-based diets for common carp, *Cyprinus carpio* (Linnaeus). *Aquaculture Research*, 33: 1157–1162.

Nguyen, T.P. 2013. On-farm feed management practices for striped catfish (*Pangasianodon hypophthalmus*) in Mekong River Delta, Viet Nam. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 241–267. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Nguyen, N.P., Pham, M.D, Vu, N.S. Tran, V.B. & Au, T.A.N. 2004. *A review of the application of bio-technologies for quality improvement and production cost reduction of giant freshwater prawn (*Macrobracium rosenbergii*), catfishes (*Pangasius bocourti *and* Pangasius hypophthalmus*) and Tilapia (*Oreochromis niloticus*) farming in An Giang province.* Report submitted to the Department of Science and Technology of An Giang province, 24 pp. (in Vietnamese).

Nguyen, T.P. & Dang, T.H.O. 2009. Striped catfish (*Pangasianodon hypophthalmus*) aquaculture in Viet Nam: an unprecedented development within a decade. *In* S.S. De Silva & F.B. Davy, eds. *Success Stories in Asian Aquaculture*, pp. 133–149. Springer, NACA and IDRC, Dordrecht, Bangkok and Ottawa. 214 pp.

Okumus, I. 2005. *The marine aquaculture and management in Turkey*. Rize, Faculty of Fisheries, Rize University. 13 pp.

Patel, A.B. & Yakupitiyage, A. 2003. Mixed feeding schedules in semi-intensive pond culture of Nile tilapia, *Oreochromis niloticus*, L.: is it necessary to have two diets of differing protein content. *Aquaculture Research*, 34: 1343–1352.

Phan, L.T., Bui, T.M., Nguyen, T.T.T., Gooley, G.J., Ingram, B.A., Nguyen, H.V., Nguyen, P.T. & De Silva, S.S., 2009. Current status of farming practices of striped catfish, *Pangasianodon hypophthalmus* in the Mekong Delta, Vietnam. *Aquaculture*, 296: 227–236.

Rahman, S. & Parkinson, R.J. 2007. Productivity and soil fertility relationships in rice production systems, Bangladesh. *Agricultural Systems*, 92: 318–333.

Ramakrishna, R., Shipton, T. & Hasan, M.R. 2013. *Feeding and feed management of Indian major carps in Andhra Pradesh, India*. FAO Fisheries and Aquaculture Technical Paper No. 578. Rome, FAO. 90 pp.

Ramaswamy, U.N., Mohan, A.B. & Metian, M. 2013. On-farm feed management practices for black tiger shrimp (*Penaeus monodon*) in India. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 303–336. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Rana, K.J., Siriwardena, S. & Hasan, M.R. 2009. *Impact of rising feed ingredient prices on aquafeed and aquaculture production*. FAO Fisheries and Aquaculture Technical Paper No. 541. Rome, FAO. 63 pp.

Romana-Eguia, M.R.R., Laron, M.A. & Catacutan, M.R. 2013. On-farm feed management practices for Nile tilapia (*Oreochromis niloticus*) in the Philippines. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 131–158. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Santiago, C.B. & Laron, M.A. 2002. Growth and fry production of Nile tilapia, *Oreochromis niloticus* (L.), on different feeding schedules. *Aquaculture Research*, 33: 129–136.

Sarder, M.R.I. 2013. On-farm feed management practices for three Indian major carp species (rohu *Labeo rohita*, mrigal *Cirrhinus cirrhosus* and catla *Catla catla*) in Bangladesh: a case study. *In* M.R. Hasan & M.B. New, eds. *On-farm feeding and feed management in aquaculture*, pp. 213–239. FAO Fisheries and Aquaculture Technical Paper No. 583. Rome, FAO. 585 pp.

Srikanth, G.K., Nandeesha, M.C., Kesavanath, P., Varghese, T.J., Shetty, H.P.C. &, Basavaraja, N. 1989. On the applicability of a mixed feeding schedule for common carp, *Cyprinus carpio* var. *communis*. *In* E.A. Huisman, N. Zonneveld & A.H.M. Bouwmans, eds. *Aquacultural research in Asia: management techniques and nutrition. Proceedings of the Asian Seminar on Aquaculture, Malang, Indonesia, 14–18 November 1988.* pp. 254–260. Wageningen, Pudoc. 271 pp.

Tacon, A.G.J., Hasan, M.R. & Metian, M. 2011. Demand and supply of feed ingredients for farmed fish and crustaceans: trends and prospects. *FAO Fisheries and Aquaculture Technical Paper.* No. 564. Rome, FAO. 87 pp.

This technical paper provides a comprehensive review of on-farm feeding and feed management practices in aquaculture. It comprises of a) ten case studies on feeding and feed management practices carried out in seven selected countries of Asia and Africa for eight species that belong to four major farmed species of freshwater finfish and shellfish; b) an analysis of the findings of the above ten case studies and a separately published case study for Indian major carps carried out in India; c) ten invited specialist reviews on feed management practices from regional and global perspectives; and d) an overview of the current status of feed management practices.

The broad thematic areas that were addressed in these case studies and invited reviews are i) current feed types (including fertilizers) and their use in semi-intensive and intensive farming systems; ii) on-farm feed production and management; iii) feeding and feed management strategies, feed procurement, transportation and storage; iv) environmental, economic, regulatory and legal frameworks of feeding and feed management practices; and iv) identification of research needs.

Based on the information presented in the eleven case studies, ten specialist reviews and from other relevant publications, an overview paper presents concluding remarks and recommendations on some of the major issues and constraints in optimizing feed production, use and management.