The Effects of Climate change on World Aquaculture:
A global perspective

DFID Department for International Development

Handisyde N.T., Ross L.G., Badjeck M-C & Allison E.H.,

Executive summary

1. Climate change and global aquaculture

Outline of global climate change and climate prediction

- It is now widely accepted that observed changes in the earth's climate are at least in part a result of human activities.
- Models for future climate prediction are continually growing in sophistication with the current generation of General Circulation Models linking both ocean and atmosphere components. The resolution of global climate models is relatively low and considering their theoretical nature they are better suited for predicting long term changes in variables such as temperature and precipitation over larger areas than more localized and variable phenomena such as cyclones.
- Temperature is predicted to increase more at higher latitudes compared with equatorial areas. Maximum and minimum temperatures at a given point will vary and there may be an increase or decrease in the range of temperatures seen at the diurnal, seasonal and inter-annual time scales.
- As a global average precipitation levels are predicted to increase although southern Africa, Australia and central America will most likely see a decrease. Changes in seasonal variation will also be important and may lengthen or shorten growing seasons in relation to water availability or increase the risk of flood damage at certain times of year.
- Mean sea level is predicted to increase between by 10 and 90cm during the 21st century with most predictions falling within the 30 to 50cm range although some uncertainty remains in relation to land based ice in Antarctica and Greenland.
- Changes in climate variability and extreme events are considered harder to predict although increases in the intensity of precipitation events, risk of drought and peak cyclone wind intensities are considered likely in some areas.
- Changes in ocean currents as well as having a substantial influence on the worlds climate may have significant direct effects on aquaculture through changes in temperature, primary productivity and hence food availability, and the distribution of disease, toxic algae blooms and predators.

An overview of global aquaculture

- The global aquaculture industry in continuing to grow, accounting for an increasing share of total fisheries production.
- Asia and particularly China accounts for the majority of the worlds aquaculture production.
- While aquaculture plays an important role in the livelihoods of people from a wide range of areas it is again Asia the greatest numbers can be seen. There are an

estimated 9.5 million aquaculturists in Asia and it is likely that many more people will be involved in supplying a range of goods and services to the sector.

- Although the average rate of growth in the aquaculture sector appears to have slowed in recent years compared with the rapid growth seen during the 80's and 90's, continued expansion is predicted for the coming decades as a result of an increasing demand for fish and the limited production capacity of capture fisheries.
- As a result of economic pressures and the increased development and spread of aquaculture technologies, it seems likely that a general trend towards more intensive culture practices will occur.

Impacts of climate change on aquaculture production systems

- Climate change impacts on aquaculture are considered in the current study as either direct e.g. changes in water availability, temperature or damage by extreme climatic events, or indirect such as in the case of increased fishmeal costs and its consequences for aquaculture feeds.
- Potential direct impacts on aquaculture are outlined here in table 1.

Table 1. Potential impacts of climate change on aquaculture systems and production

Drivers of change	Impacts on culture systems	Operational impacts
Sea surface temperature changes	• Increase in harmful algal blooms that release toxins in the water and produce fish kills • Decreased dissolved oxygen • Increased incidents of disease and parasites • Enhanced growing seasons • Change in the location and/or size of the suitable range for a given species • Lower natural winter mortality • Enhanced growth rates and feed conversions (metabolic rate) • Enhanced primary productivity (photosynthetic activity) to benefit production of filter-feeders • Altered local ecosystems - competitors and predators • Competition, parasitism and predation from exotic and invasive species	• Changes in infrastructure and operation costs • Increased infestation of fouling organisms, pests, nuisance species and/or predators • Expanded geographic distribution and range of aquatic species for culture • Changes in production levels
	• Damage to coral reefs that may have helped protect shore from wave action – may combine with sea level rise to further increase exposure	• increased chance of damage to infrastructure from waves or flooding of inland coastal areas due to storm surges
Change in other oceanographic variables (variations in wind velocity, currents and	• Decreased flushing rate that can affect food availability to shellfish • Alternations in water exchanges	• Accumulation of waste under pens • Increased operational costs

wave action)	and waste dispersal • Change in abundance and/or range of capture fishery species used in the production of fishmeal and fish oil	
Seal level rise	• Loss of areas available for aquaculture • Loss of areas such as mangroves that may provide protection from waves/surges and act as nursery areas that supply aquaculture seed • Sea level rise combined with storm surges may create more severe flooding. • Salt intrusion into ground water	• Damage to infrastructure • Changes in aquaculture zoning • Competition for space with ecosystems providing costal defence services (i.e. mangroves) • Increased insurance costs • Reduced freshwater availability
Increase in frequency and/or intensity of storms	• Large waves • Storm surges • Flooding from intense precipitation • Structural damage • Salinity changes • Introduction of disease or predators during flood episodes	• Loss of stock • Damage to facilities • Higher capital costs, need to design cages moorings, jetties etc. that can withstand events • Negative effect on pond walls and defences • Increased insurance costs
Higher inland water temperatures (Possible causes: changes in air temperature, intensity of solar radiation and wind speed	• Reduced water quality especially in terms of dissolved oxygen • Increased incidents of disease and parasites • Enhanced primary productivity may benefit production • Change in the location and/or size of the suitable range for a given species • Increased metabolic rate leading to increased feeding rate, improved food conversion ratio and growth provided water quality and dissolved oxygen levels are adequate otherwise feeding and growth performance may be reduced	• Changes in level of production • Changes in operating costs • Increase in capital costs e.g. aeration, deeper ponds • Change of culture species
Floods due to changes in precipitation (intensity, frequency, seasonality, variability)	• Salinity changes • Introduction of disease or predators • Structural damage • Escape of stock	• Loss of stock • Damage to facilities • Higher capital costs involved in engineering flood resistance • Higher insurance costs
Drought (as an extreme event (shock), as opposed to a gradual reduction in water availability)	• Salinity changes • Reduced water quality • Limited water volume	• Loss of stock • Loss of opportunity – limited production (probably hard to insure against)
Water stress (as a gradual reduction in water availability (trend) due to increasing evaporation rates and decreasing rainfall)	• Decrease water quality leading to increased diseases • Reduce pond levels • Altered and reduced freshwater supplies – greater risk of impact by drought if operating close to the limit in terms of water supply	• Costs of maintaining pond levels artificially • Conflict with other water user • Loss of stock • Reduced production capacity • Increased per unit production costs • Change of culture species

- The particular sensitivities of aquaculture related livelihoods to different aspects of climate change will be linked to the type, scale and intensity of aquaculture taking place as well as the environment in which it is being conducted. There has been a considerable amount of work focusing on the different aspects of aquaculture dependant livelihoods, but little that deals directly with the potential effects of climate change. The sustainable livelihoods approach can be useful in assessing how climate change may impact on the natural, physical, economic, human and social capitals necessary for aquaculture.

2. GIS based assessment of aquaculture related vulnerability to climate change

A Geographic Information System (GIS) based model is used to indicate areas where livelihoods are likely to be vulnerable to climate change impacts on aquaculture. The model used the concept that vulnerability (V) is a function of exposure to climate change (E), sensitivity to climate change (S) and adaptive capacity (AC).

$V = f(E, S, AC)$

The concept of climate trends, such as gradual changes in mean temperature and precipitation levels, compared with climate shocks, for example; floods and cyclones, is considered important when assessing potential impact pathways. The categories of fresh, brackish and salt water culture are used to give some indication as to the location and type of aquaculture likely to be taking place within a country. It is considered that the type and location of the aquaculture environment will influence its vulnerability to particular climate related impacts.

The indicators used in the vulnerability model along with its basic structure are shown in figure 1. All layers are reclassified on a scale of 1 – 5 and layer combination is by Multi Criteria Evaluation (MCE) using weighted linear combination. Different levels of significance/weightings can be assigned to layers being combined in the sub and main model. Decisions regarding weightings were maid by the authors after obtaining a consensus of expert opinion from a focus group and guided questionnaire.

Eight combinations of component layers are used to assess vulnerability in relation to a range of issues, culture environments and climate factors. Table 2 highlights countries which score at least 4 out of 5 for at least part of their area under the different combinations.

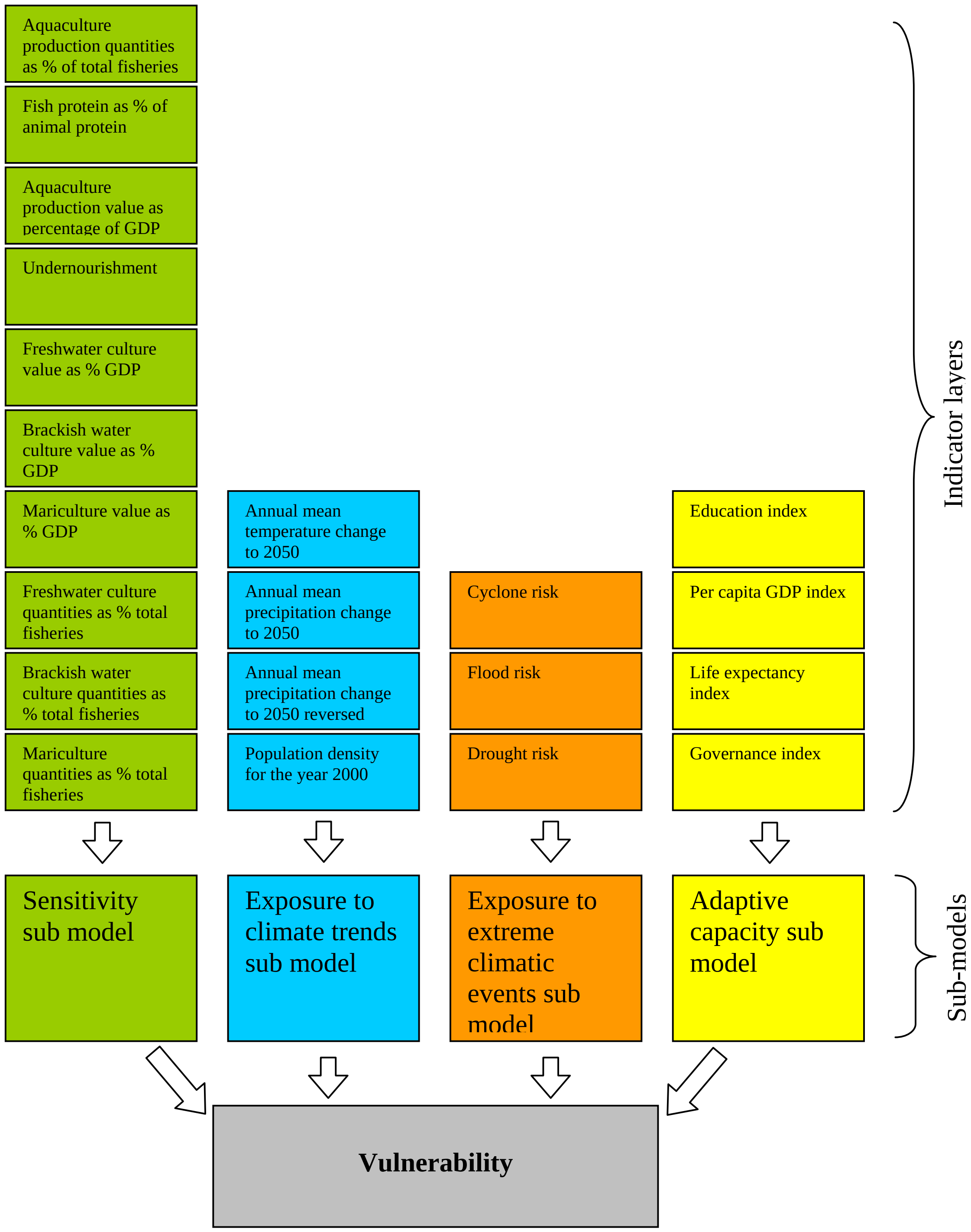

Figure 2.1: Schematic representation of the vulnerability assessment model.

Table 2. * = countries indicated as being vulnerable over at least part of their area.

	Vulnerability General	Vulnerability in terms of food security	Vulnerability based with the emphasis on areas where aquaculture is a significant contributor to GDP	Vulnerability with emphasis on adaptive capacity	Vulnerability of freshwater aquaculture to inland flooding	Vulnerability of freshwater aquaculture to drought	Vulnerability of brackish water culture to cyclone	Vulnerability of mariculture to cyclone
Bangladesh	*	*	*	*	*	*	*	
Cambodia	*	*	*	*	*	*		
China	*	*	*		*	*		*
India	*	*	*	*	*	*	*	
Indonesia	*	*	*	*	*	*		
Iran					*	*		
Jordan						*		
Korea, rep. of	*	*	*	*		*		*
Kyrgyzstan						*		
Laos	*	*	*	*	*	*		
Nepal	*	*		*	*	*		
Pakistan	*	*		*	*	*		
Philippines	*	*	*	*	*		*	*
Syria						*		
Tajikistan					*	*		
Thailand	*	*		*		*		
Uzbekistan	*	*		*	*	*		
Vietnam	*	*	*	*	*	*	*	*
Papua New Guinea		*				*		
Burundi				*	*			
Egypt			*					
Ivory Coast				*				
Lesotho						*		
Madagascar	*		*			*		*
Malawi	*	*			*	*		
Mali				*	*			
Morocco						*		
Mozambique	*	*			*	*		*
Niger				*	*			
Nigeria	*	*		*	*	*		
Rwanda					*			
Sierra Leone		*		*				
Sudan	*			*	*	*		
Swaziland						*		
Tanzania					*			

Uganda					*			
Zambia						*		
Zimbabwe						*		
Belize			*				*	
Brazil					*	*		
Colombia					*	*		
Costa Rica			*		*			
Ecuador			*		*			
Guatemala	*	*		*	*	*		
Jamaica					*			
Mexico						*		
Nicaragua	*	*	*	*				*
Belarus					*			
Czech Republic					*			
Hungary					*			
Romania					*			
Turkey						*		
Ukraine					*			

Asia featured highly in the vulnerability assessment with the large aquaculture producing countries such as; Bangladesh, Cambodia, China, India, The Philippines and Vietnam indicated as vulnerable under most of the layer combinations used.

Aquaculture production in Africa as a whole is low when compared to Asia. However many African countries are considered to have a very low adaptive capacity and are therefore considered vulnerable in some instances.

A number of Central and South American countries are considered vulnerable with Nicaragua and Guatemala being the areas of most concern.

3. Case study - Bangladesh

Introduction

Bangladesh is one of the world's most densely populated countries with nearly half of the 138 million population being considered bellow the poverty line. Bangladesh is recognised as being very vulnerable to climate change and sea level. Approximately 85%

or the countries poor live in rural areas, and it is estimated that around 61.5% of the countries employed people are connected to agriculture. With estimates of over 3 million fish farmers aquaculture is highly significant within Bangladesh both in terms of food security and economic income.

The physical geography, climate and weather of Bangladesh

Bangladesh is an extremely flat and low-lying deltaic country (Fig. 3.1) with a large proportion of its area comprising of the floodplain of three converging rivers; the Ganges, the Brahmaputra-Jamuna and the Meghna (GBM river system). Bangladesh experiences a cooler dry winter period and a summer monsoon season during which it is forced to drain a large quantity of cross boarder runoff and as a result an average of 20.5% of the country floods annually. Peoples livelihoods are typically well adapted to the average annual flooding, however during extreme flood events such as in 1998 up to 70% of the country can be inundated. Such events are typically associated with synchronisation of peak flow within the GBM river system and cause widespread damage.

Bangladesh is also vulnerable to cyclones and associated storm surges which can inundate the flat low lying coastal areas.

Current state of aquaculture in Bangladesh

Traditionally aquaculture in Bangladesh has taken the form of extensive pond culture of freshwater fish species such as carp species, and often relied on natural stocking of fish seed during flood periods. The current trend is towards more intensive methods and deliberate stocking of select species. A greater range of fish species are now cultured along with high value crustacean species such as *Penaeus monodon* and *Macrobrachium rosenbergii.*

Future potential for aquaculture in Bangladesh

Bangladesh's population is predicted to expand from its current level of 138 million to between 190 and 222 million by 2030. Aquaculture has an important potential role in providing food for this increasing population in a country where malnutrition is currently common.

There are a large number of nongovernmental organisations within Bangladesh that are helping to promote aquaculture. It is hoped that through micro credit schemes and provision of appropriate information and training that poorer people will be able to participate in small scale aquaculture, providing both additional food and income.

The culture of high value species such as shrimp is seen as having the potential of generate substantial export earnings and is been promoted.

Potential future climate change in Bangladesh

Sea level rise is a major concern due to the low elevation of much land in Bangladesh with inundation estimates of 2500 km^2 (2%), 8000 km^2 (5%) and 14000km^2 (10%) for 0.1, 0.3 and 1.0 metre rises respectively.

Increased salination of ground water may alter the range of species that can be cultured at a given location.

Loss of natural coastal defences may increase the risk from storm surges.

The Bengal delta has a high level of subsidence with an estimated effective sea level (the combination of actual sea level rise and the subsidence of land) or more than 10mm per year under current conditions.

Storm surges represent a serious threat to aquaculture in the countries coastal areas. A relationship between sea surface temperature and cyclone intensity has been suggested. Estimated maximum surge height under conditions similar to the 1991 cyclone is 7.6m with a predicted increase to 9.2m and 11.3m under 2°C and 4°C surface temperature increases respectively.

Temperature increases within the Bangladesh region are predicted to be greater during the winter period compared with the summer. Precipitation levels are predicted to be greater during the summer monsoon period with possible decreases during the winter months. These predictions suggest a potential increase in the risk of flooding during the monsoon season as well as a limited water supply during the winter period. The potential for greater variation as well as a greater likelihood of synchronised peak flow in the major rivers and consequent increases in flooding should also be considered.

Summary – vulnerability of aquaculture in Bangladesh and potential adaptation

Within Bangladesh sea level rise with its associated land loss and salination of ground water as well as risk from storm surges and inland flooding would appear to represent the greatest potential climate related risks to aquaculture. The potential for water shortages during winter as a result of decreased precipitation combined with an increasing population should also be considered.

The promotion of suitable culture methods and species within a given area in relation to both people's socio economic situation and changing environmental conditions will be important in helping gain the maximum benefit from aquaculture. Further research should be encouraged with the following areas seen as especially significant:

- Awareness of latest climate predictions for the Bangladesh area, especially those involving precipitation regimes, sea level rise and if possible tropical storms.
- Organisation and availability of historic data and research.
- Analysis of site suitability for aquaculture based on:
  - Predicted changes in climate and consequent environmental factors: Water availability, Salinity and temperature.
  - Risk from extreme events notably riverine and storm surge floods.
  - Social and economic evaluations and predictions.
  - Resource availability e.g. Seed, inputs and support networks.
- Continued improvement and development of aquaculture practices for a broad range of species in order to maximise production where possible.
- Production and distribution of quality seed.
- Cost benefit analysis for a wide range of species and culture methods in relation to climatic and environmental variables.

4. Conclusions

- The current study provides a strong starting point and a useful guide for further investigations both at more local level and with a focus on more specific issues.
- More focused case studies will be very important not only in guiding policy decisions for the areas concerned, but also for the increased understanding of the ways in which climate change impacts will take place along with possible adaptive measures to counter them. It may then be possible to apply the knowledge and working methods gained from one area to others with similar characteristics.
- Ability to adapt to climate change will be strongly linked to adaptive capacity making economic predictions an important part of vulnerability assessment.
- The promotion of suitable species and culture methods at a given location in order to maximise production and profits in the face of a changing climatic, socio economic and environmental variables will be important. The use of Geographic Information Systems (GIS) are seen as providing powerful tools in this area.
- The efficient organisation, distribution, and where possible free availability of data and literature will greatly assist future work and help determine what can be achieved with the limited time and resources available.