COSMOS, Vol. 12, No. 1 (2017) 1–14

DOI: 10.1142/S0219607716500026

CLIMATE CHANGE AND FISH AVAILABILITY

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Received
Revised
Accepted
Published

Human consumption of fish has been trending upwards in the past decades and this is projected to continue. The main sources of fish are from wild fisheries (marine and freshwater) and aquaculture. Climate change is anticipated to affect the availability of fish through its effect on these two sources as well as on supply chain processes such as storage, transport, processing and retail. Climate change is known to result in warmer and more acid oceans. Ocean acidification due to higher CO_2 concentration levels at sea modifies the distribution of phytoplankton and zooplankton to affect wild, capture fisheries. Higher temperature causes warm-water coral reefs to respond with species replacement and bleaching, leading to coral cover loss and habitat loss. Global changes in climatic systems may also cause fish invasion, extinction and turnover. While this may be catastrophic for small scale fish farming in poor tropical communities, there are also potential effects on animal protein supply shifts at local and global scales with food security consequences. This paper discusses the potential impacts of climate change on fisheries and aquaculture in the Asian Pacific region, with special emphasis on Southeast Asia. The key question to be addressed is "What are the impacts of global climate change on global fish harvests and what does it mean to the availability of fish?"

Keywords: Sea-food security; climate change; ocean acidification; aquaculture.

1. Introduction

Fish has been an important part of human diet in many parts of the world throughout history and has in the modern era further become an important source of protein for many marginalized communities. At least 4.5 billion people consume fish which contributes to at least 15% of their average per capita intake of animal protein.[1] There is growing demand for fish as a nutritious and functional food because of growing populations in most fish-eating countries and also dietary shifts which recognize fish as a healthy source of protein.

Fish consumption per capita has increased from an average of 9.9 kg/person in the 1960s to 19.2 kg/person in 2012[2] and 20.0 kg/person in 2014.[3] This can only be maintained or increased if aquaculture makes an increasing contribution to the volume and stability of global fish supplies. Despite the surge in annual per capita fish consumption in developing regions (from 5.2 kg in 1961 to 20.0 kg in 2014)[3] and low-income food-deficit countries (LIFDCs) (from 3.5 kg in 1961 to 7.6 kg in 2013,[3] developed countries still have higher levels of consumption (26.8 kg/per capita in 2013),[3] although the gap is narrowing (NFDS 2016).[4] A sizeable and growing share of fish consumed in developed countries consists of imports, owing to steady demand and declining domestic fishery production. In developing countries, fish consumption tends to be based on locally and seasonally available products, with supply driving the fish chain.[2]

Fish (finfish, crustacea, molluscs) are last of the major food items to be captured from the wild. Globally, "wild" fish harvest peaked at about 93.4 M tons in 2011[3] and has remained at around that level since. The reality too is that most wild fish stocks are either stagnant or declining, with many fisheries in a threatened state. Wild fisheries have traditionally provided "captured" fish for human consumption but in the 21st millennium, "cultured" fish through fish farming (aquaculture) has been rising rapidly, to about 73.8 M tons in 2014, or about 44% of the global fish production, and has mainly been responsible for the increase in total fish production (captured and cultured) in the world since 2011. Both wild fisheries and aquaculture, however, are subject to environmental changes such as climate change arising from anthropogenic factors, as well as non-anthropogenic factors. Marine fisheries, by far the most important to supply fish for human use, in particular face substantial challenges to their sustainability from climate change due to altered ocean temperatures, ocean acidity and sea level rises. Land-based fisheries are also likely to be exposed to changes in rainfall regimes and land temperature change.[5] However, the effects on fish production overall that may be directly attributable to climate change are also admittedly difficult to separate from inter-annual to decadal climate variability.[6]

In this paper we aim to identify the potential impacts of climate change on fisheries and aquaculture in Asian countries with special attention to Indonesia, Malaysia, Vietnam and Thailand. We do so by downscaling the generalized effects of climate change into specific phenomena and reviewing estimates of their effects on fish production at several future dates to give an indication of effects.

2. Current State of Fisheries and Fish Availability

To understand the potential effect of climate change on world fish availability, it is first necessary to determine what the current state of fisheries is, as this is the major source of caught fish. Assessments by FAO showed that in 2005, marine fisheries were already in a perilous state even before factoring in the potential impact of climate change and other factors — 52% of global fisheries were already fully exploited and therefore producing catches that were at or close to their maximum sustainable limits, with no room for further expansion; 17% were overexploited, and 7% depleted, with the remaining at different levels of exploitation.

China still leads the world annual marine capture production by 14 M tons as of 2014. While Indonesia stands at the second place, producing at least 6 M t/annum. It is interesting to note the dynamics of fisheries production in the Year 2014 in Southeast Asia where Myanmar rose to the top ten marine capture produce by producing 2.4 M tons, while Vietnam had 2.7 M tons, Philippines 2.1 M tons, Thailand 1.6 M tons and Malaysia 1.5 M tons.[3] Korea, Norway and Japan have been producing above 1 million tons annually (Fig. 1).

As of 2014, at least 60% of the global aquaculture production is contributed by China alone (45.5 out of 74 M tons), followed by Indonesia 5% (4.5 M tons) and Vietnam 4.5% (3.4 M tons). The total first-sale value of world aquaculture is estimated at US$160.2 billion where finfish dominates the economic value by 62% followed by molluscs 12% and crustaceans 22%.[3]

Apart from marine fisheries, inland waters also provide capture fish; China leads the world with a capture production of 2.3 M tons followed by Myanmar with 1.4 M tons. For Southeast Asia Cambodia and Indonesia have been in the top ten major producers of inland water capture, with 0.5 M tons and Indonesia 0.4 M tons respectively.[3]

In the last 3 or 4 decades, capture fisheries production has come under intense exploitation. In 2000, capture fisheries contributed 73% of world's total fisheries production; in 2014 it contributed only 56%.[3] Almost all fish produced from aquaculture are destined for human consumption, although by-products may be used for non-food purposes. World aquaculture production of fish accounted for 44% of total production (including for non-food

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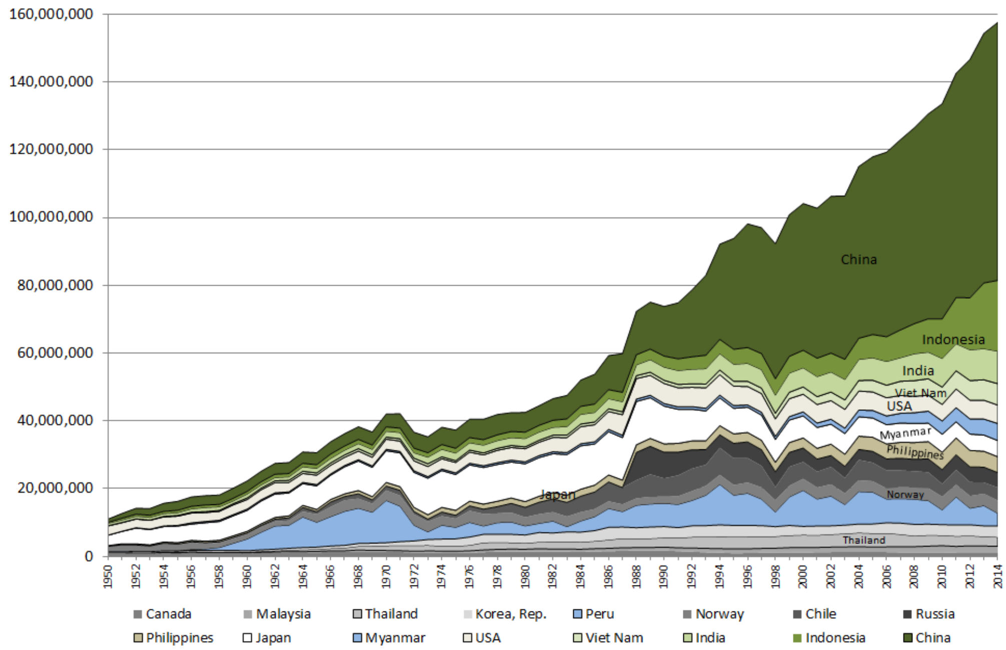

Fig. 1. Global trends in fisheries production.

Source: Adapted from FAO Fisheries Statistics – [http://www.fao.org/fishery/statistics/en].

uses) in 2014, up from 42.1% in 2012 and 31.1% in 2004. All continents have shown a general trend of an increasing share of aquaculture production in total fish production, although in Oceania this share has declined in the last three years. Thirty-five countries produced more farmed than wild-caught fish in 2014 and include five major producers, namely, China, India, Vietnam, Bangladesh, and Egypt. The other 30 countries in this group have relatively well-developed aquaculture sectors, e.g. Greece, the Czech Republic and Hungary in Europe, and the Lao People's Democratic Republic and Nepal in Asia.

In addition to fish production, aquaculture produces considerable quantities of aquatic plants. World aquaculture production of fish and plants combined reached 101.1 million tons in live weight in 2014, for an estimated total farmgate value of US $165.8 billion, with farmed aquatic plants contributing 27.3 million tons (US$5.6 billion).

In general, global food fish aquaculture production expanded at an average annual rate of 6.2% in the period 2000–2014 (9.5% in 1990–2000) from 32.4 million to 73.8 million tons in 2014.[3] Aquaculture production growth in Africa is 11.7% and Latin America and the Caribbean reach 10%. Responding to domestic and global demand, top fish producers such as China, Indonesia, the Philippines and Southeast Asian nations have been expanding their aquaculture sectors in the recent decades, notably since the 1990s. However, these sectors are by no means immune to the impact of climate change as it may have impacts on fresh water supply and coastal degradation as well.

In Southeast Asia, the fishing industry is dominated by four countries, namely Indonesia, Vietnam, Malaysia and Thailand, although fish is also an important part of the diet and fishing a livelihood in other countries like the Philippines, Myanmar and Cambodia.

3. Framing the Effects of Climate Change on Fish Availability

Experts generally agree that fish producers and consumers of fish will be affected by climate change and the magnitude and scale of the challenges will vary from place to place.[7] Production of fish from catch and aquaculture depends on several factors namely water temperature, quality of feed and water and the quality of the ecosystem where the fish grow. The quality of wild fish further depends on the quality of feed such as phytoplankton, which underpins the marine food web and "regulate key biogeochemical processes".[8]

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Small Scale Fishers (SSFs) have populated the fishing and aquaculture sectors and many of them are in the poor countries.[9] Most of these poor fisher folk live in vulnerable coastal ecosystems which depend on coral reef ecosystems. Such ecosystems provide food and other resources to more than 500 million people and has an annual value of US$5 billion or more.[10,11]

3.1. *Framework for discourse on climate change and fish availability*

There is a plethora of reported studies on climate change and on how climate change is likely to affect fisheries. In order to contextualize the discourse on climate change effects on fisheries and aquaculture, it is considered necessary to frame this complex topic. A conceptual framework is used in this paper as shown in Fig. 2.

Fish availability is considered to consist of fish for human consumption and for processing for other uses (e.g. as fishmeal) –right hand side of Fig. 2. Fish is available through production systems which comprise wild capture fish and cultured fish, both either marine or freshwater. Additionally, there is emerging now a small production sector of fish grown under controlled, contained environments.

Climate change as a phenomenon is considered to consist of disaggregated sub-phenomena or factors such as temperature, precipitation, ocean acidification and sea level rise. These factors individually or separately have the potential to affect fish systems (wild fisheries in marine and freshwater systems; or aquaculture systems) and result in changes in fish availability. Physical changes in marine and coastal environments include ocean acidification and increases in temperature and sea level rise. The climate change factors singly or together affect fish production systems but operate under the influence of a set of non-climate factors.

3.2. *Disaggregated CC factors*

A general overview on observed and projected changes in the world's oceans is provided in the 5th IPCC Assessment Report 2014, Chapter 5, Chapter 6 and Chapter 30.[5,11,12] These chapters in the Assessment Report were written by large groups of experts, numbering often to almost 30 scientists. Some of the key findings of high confidence among experts are summarised below:

- Global average sea surface temperatures have increased since both the beginning of the 20th century and the 1950s. The average sea surface temperature (SST) of the Indian, Atlantic, and Pacific Oceans has increased by 0.65°C, 0.41°C, and 0.31°C, respectively, over the period 1950–2009 (very likely, p-value $\leq$ 0.05). Sub-regions within the Ocean also show robust evidence of change, with the influence of long-term patterns of variability.
- The Ocean has absorbed 93% of the extra energy from the enhanced greenhouse effect and approximately 30% of anthropogenic carbon dioxide (CO_2) from the atmosphere. The uptake of the anthropogenic CO_2 by the ocean has decreased ocean pH (approximately 0.1 unit over 100 years). Such an increase in CO_2 in oceans has led to the

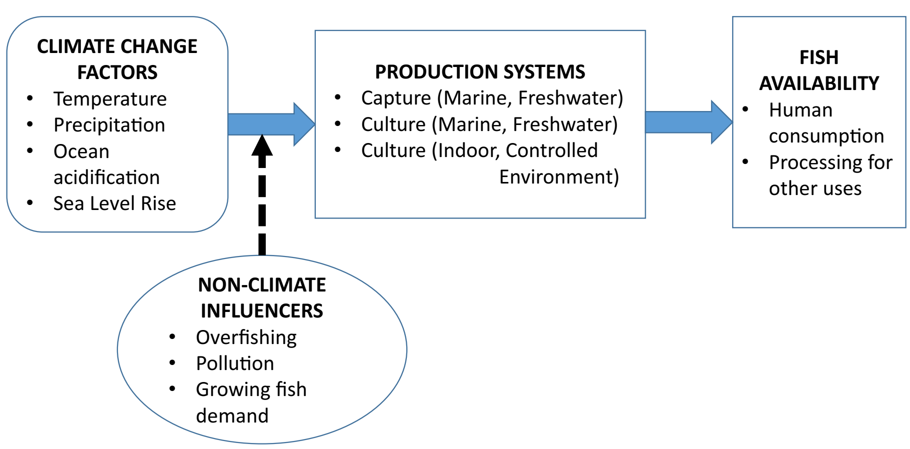

Fig. 2. Conceptual framework for assessing climate change effects on fish availability.

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change in ocean carbonate chemistry in all ocean sub-regions, particularly at high latitudes.

- Experts have high confidence that the increase in temperatures and increased acidity and carbonate ion concentrations present risks to the productivity of fisheries and aquaculture as a result of the direct and indirect impact of these on physiological processes (e.g. skeleton formation, reproduction, physical growth) and ecosystem processes (e.g. primary productivity, reef building and erosion).
- Projected temperatures of the surface layers of the Ocean will be 1 to 3°C higher by 2100 under Representative Concentration Pathway 8.5 (RCP8.5).[a] The projected changes in ocean temperature pose serious risks and vulnerabilities to ocean ecosystems and dependent human communities (robust evidence, high agreement; high confidence).
- In Asia seawaters, regional average sea surface temperatures (SST) have increased since the 1950s. Changes can be observed in the Indian Ocean (+0.65°C), Atlantic Ocean (+0.41°C) and the Pacific Oceans (+0.31°C). Over the last twenty years (from the baseline 1961–1990 period), the Southeast Asian sea (SAS) regions have experienced an increase in both land and sea temperature at 0.34°C and 0.38°C respectively (Table 1 and Fig. 3).
- It is predicted that the coastal system in Southeast Asia will be also affected by higher sea levels. IPCC recently projected global mean sea level rise to reach 0.28 m to 0.98 m by 2100. The risk is highlighted as 'unavoidable risk' because even when greenhouse gas emissions can be reduced to some degree, the risk of sea level rise may persist and therefore adaptation is the only plausible solution. The SAS SST is likely to experience warming by +0.98°C in 2030; 1.28°C in 2050; 1.64°C in 2050 and 2.03°C in 2100 [based on RCP 6.0, with One-Mean model projection].
- The Southeast Asian Seas or the so-called "Coral Triangle" is one of the world's most biologically diverse marine areas. It includes parts of Malaysia, Indonesia, the Philippines, Timor Leste, the Solomon Islands, and Papua New Guinea. The sea surface temperatures (SST) increased significantly from 1985 to 2006, although with considerable spatial variation. The region has experienced an increase in warming trends at significant level (+0.80°C, p-value $\leq$ 0.05; measured since 1950–2006).[11]
- Sea level is rising by up to 10 mm/year in much of this region. Like other tropical areas in the world, coral reefs within SAS have experienced periods of elevated temperature, which have driven several mass coral bleaching and mortality events since the early 1980s.[11]
- Under the climate change scenario Representative Concentration Pathways (RCP 6.0) it is projected that the Southeast Asian seawater is likely to experience an increase of 1.20°C in 2050, 1.86°C

Table 1. Observed and anticipated temperature change in Southeast Asia (S.E.A.).

	Observed S.E.A. sea temp	Observed S.E.A. land temp	Change in S.E.A. sea temp	Change in S.E.A. land temp
Baseline	26.82	24.31	—	—
Avg 1981–2005	27.02	24.53	0.20	0.22
2020	27.52	25.12	0.70	0.81
2030	27.68	25.30	0.86	0.99
2050	28.02	25.70	1.20	1.39
2080	28.68	26.48	1.86	2.17
2100	28.96	26.83	2.14	2.52

*Based only on RCP 6.0 with One Mean Projected Change [GCM: CIMP5 IPCC AR5 Atlas Subset]

[a]RCP is Representative Concentration Pathways. The Fifth Assessment Report (AR5) in 2013-14 based its findings on a new set of scenarios that replace the Special Report on Emissions Scenarios (SRES) standards employed in past reports. The new scenarios consist of four pathways: RCP8.5, RCP6, RCP4.5 and RCP2.6. The RCP number are named after a possible range of radiative forcing values in the year 2100 relative to pre-industrial values https://www.skepticalscience.com/rcp.php.

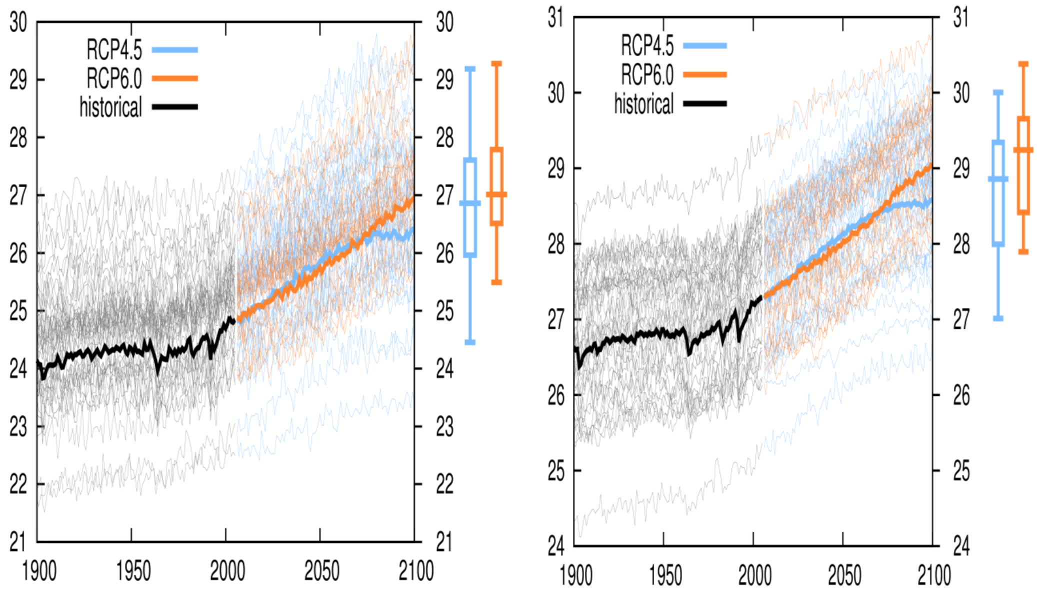

Fig. 3. Temperature Southeast Asia Land (left) and Sea (right) Jan-Dec projections [Based on AR5 CMIP5, IPCC 2014].

in 2080 and 2.14°C in 2100 (According to GCM One Mean Model, Table 1). Overall change in SEA land temperature is also projected to be higher where it may reach increases of 1.2°C in 2050, 2.14°C in 2080 and 2.52°C in 2100 (Table 1). Even under lowest emission scenario (RCP 4.5, see Fig. 3), it is likely that both land and see temperature will exceed 1.5°C beyond 2050. An increase in temperature of more than 1°C–3°C can either cause local extinctions of particular fish species or can cause the cold-blooded creatures to shift their habitat from the tropics to higher latitude regions.

3.3. "*Stimulus-response*" *relationships*

Part of our assessment of climate change on fish availability requires the determination of the link between specific climate change sub-phenomena (such as ocean temperature), the "stimulus", and fish populations or yield, the "response", what we are terming as "stimulus-response" relationships.

Ocean acidification Rising anthropogenic carbon dioxide reduces ocean pH and lowers seawater calcium carbonate which leads to delays in shell-forming marine organisms from plankton to corals.[13] Ocean acidification may cause negative effects on calciferous animals, including slowed rates of coral growth which in general causes a decline in fish production. Ocean acidification will also have negative impact on the culture of calcifying organisms including mollusc species[11] of which 14.2 MT were produced by aquaculture in 2010, equivalent to 23.6% of global aquaculture production.[2]

Ocean temperature The increase in ocean temperature causes warming of the upper ocean layers which may shift plankton and fished species pole-ward. Warming will also affect changes in timing of phytoplankton blooms and zooplankton composition. The consequences of this are changes in yield and production of fished species, including the impact of potential mismatch between prey (plankton) and predator (fished species) and declines in production. Sea level rise may cause loss of coastal habitats and saline intrusion into freshwater habitats which in turn leads to reduced production of coastal marine and freshwater systems and related fisheries.[14]

Change in marine fish stock can be also associated with higher water temperatures and changes in ocean currents. Warming oceans can alter physiology and sex ratios of fished species, timing of spawning, migrations, and/or peak abundance as well as increased invasive species, diseases and algal blooms. These combine to cause potential lower levels of productivity across marine and freshwater systems and reduced production of certain species in marine and fresh water systems. Changes in ocean currents can have an impact on fish recruitment (the ability of fish to reach certain size or reproductive stage) which would lead to changes in availability of fish and consequently, production in marine and fresh water.[14] In fact, ocean acidification will also have a serious impact on the structure of future phytoplankton communities which may alter future fish catch potential.[4,7]

Sea level rise Coastal infrastructure and fishing operations are likely to be impacted by sea level rise and increased frequency of storms. This is likely to add more pressure on adaptation as it may cause fishing to become less profitable due to increased coastal infrastructure recovery and overall increase in coastal vulnerability. Such changes are also likely to bring about negative effects on coastal livelihood, limiting options for the poor fisher folk and cause reduced profitability of larger scale coastal business and increased costs of insurance.

Rapid changes in physical and chemical conditions within ocean sub-regions have already affected the distribution and abundance of marine organisms and ecosystems. Responses of species and ecosystems to climate change have been observed from every ocean sub-region (high confidence). Marine organisms are moving to higher latitudes, consistent with warming trends (high confidence), with fish and zooplankton migrating at the fastest rates, particularly in high-latitude spring bloom systems (HLSBS) regions.

Precipitation Inland fishing operations and livelihoods will suffer from the greater uncertainty in rainfall and the general tendency to have more droughts or floods. Such changes will increase the risks for coastal livelihoods and the vulnerability of poor households and communities that are dependent on the fishing sector. It is also clear that inland water ecosystems will be affected by changes in lake water levels which may lead to overall reduced lake and river productivity.[15]

4. Assessed Scenarios of Fish Availability with Climate Change

Direct effects of climate change include changes in the abundance and distribution of fish species and an increase in the frequency and severity of extreme events, such as floods and storms, which affects fishing operations and infrastructure. Secondary effects of climate change in the sector include changes in quantity and quality of aquatic habitat, ecosystem productivity and the distribution and abundance of aquatic competitors and predators.[14]

When the rates of shift of fish catch potential occurs at the range from around 30-130 km per decade towards the pole and 3.5 m per decade to deeper waters as experts have suggested,[16–18] it can obviously be a catastrophe for SSFs in the poor tropical communities. This should also be seen as potential global animal protein supply shift. Some of the impacts of climate change on fisheries are hard to quantify including those on aquaculture. Some qualitative responses have been noted such as the likelihood of sea level rise, coastal erosion and coastal flooding.

Coastal fisheries are also affected by climate change through the change in coastal ecosystems such as the reduction of coral reef cover that affects the food supply of fish. Given the fact that climate change will also affect the migration of small fish (especially the ones that are used for fishmeal), the future of aquaculture will also be affected by change in fish stocks in sea water. It has been observed that warming and acidity in seawaters has contributed to the shift in fish migration to cooler waters at about 50 km per decade poleward and about 2.5 to 5 m deeper per decade.

In this paper, we provide assessments of the impact of climate change on fish availability from two perspectives – by region and by timeframe.

4.1. *By region*

There is growing literature on climate change impact on global fisheries and aquaculture. Experts have predicted that marine biodiversity in tropical regions (such as Indonesian and Malaysian waters) may reach their thermal maxima.[18,19] Recent studies from 67 marine national exclusive economic zones (EEZ), suggest that high fisheries dependency regions such as South and Southeast Asia will experience decline in fish catch potential.[20]

The shifts in fish catch potential will occur as individual fish species are projected to shift their ranges northwards in response to rising sea surface temperatures.[21] The combined effects of changes in distribution, abundance and physiology may reduce the body size of marine fishes, particularly in the tropics and intermediate latitudes.[22]

Table 2 provides a general summary of the potential yield impact (%) in fish catch in top exporting regions and countries. It is interesting to note that global models in fisheries have just been recently developed – for instance the C-PBM

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Table 2. Published estimates of climate change effects on fish catch.

Region/country	Scale	Estimated yield impacts %	Scenario	Source
Worldwide	Global	+3.4%	2050	Barange *et al.*, 2014.
	Global	+6 (big fish) +3.6 (small fish – fish meal)	2050 [C-PBM]	Merino *et al.*, 2012.
	Global	+1%	2050 [BCEM]	Cheung *et al.*, 2009, 2011.
	High latitude	+30 to +70		
	Low latitude	Up to −40		
	Global	−14 to −24%	2050 [max body weight, high emission scenario	Cheung *et al.*, 2013
Antarctica		30 to 70 (baseline 2000)	A1B (≈RCP6.0)+2°C	IPCC AR5 WG II Chapter 6
China	National	−3 (fish meal)	2050[C-PBM]	Merino *et al.*, 2012.
Southeast Asia Ocean	Tropics- Low latitude	−40 to −60	2050	IPCC AR5 WG II Chapter 6
Indonesia (EEZ)	Indian Ocean Java Sea Banda Sea Celebes Sea	−50 to −20 < −50 −5 to −1 −20 to −6	2050 SRES A1B	Cheung *et al.*, 2010, 2013 IPCC AR5 WG II Chapter 6
Malaysia (EEZ)	South of South China Sea	−5 to −1	2050 SRES A1B	IPCC AR5 WG II Chapter 6
Vietnam (ZEE)	Philippines Sea East of South China Sea	−20 up to +19 −50 up to −1	2050 SRES A1B	IPCC AR5 WG II Chapter 6
Thailand	Gulf of Thailand	−20 up to −1	2050 SRES A1B	IPCC AR5 WG II Chapter 6

(Coupled Physical-biological Model) by Merino *et al.*,[23] the Bio-climate Envelope Model by Cheung *et al.*[16,24] and the Shelf-Sea Physical-Biological Model (SSPBM) by Barange *et al.*[20] These models provide strong information for the IPCC 5th Assessment Report in 2014. [See also Fig. 4 for the geographic/visual information on potential change in global fish catch.

Some global projection of fish catch potential suggests that climate change may bring a net

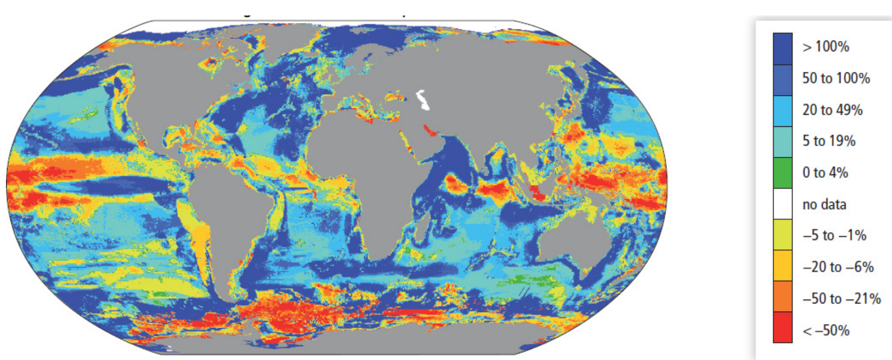

Fig. 4. Change in maximum catch potential.

Source: IPCC AR5 WGII Chapter 6 – Ocean Systems (Portner *et al.* 2014)

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positive in fish catch ranging from 1–6% yield change by 2050. Unfortunately, despite this positive projection, such an increase is still far below the population change that is predicted to increase by >30% in 2050, from present day. Furthermore, not all regions will be able to benefit from climate change. Only high latitude areas might benefit from such changes as they are likely to enjoy 30 to 70% increase in fish catch potential. Such areas include Norway, Finland, and Canada waters – Fig. 4.

In the tropics and most of the low latitude areas, it is likely that fish population could shrink by up to 40%. In some areas in Indonesia, it is likely that the fish catch potential could shrink by as much as 60%. In most of Indonesia's major seas (e.g. Java Sea, Indian Ocean and Celebes Sea), it is predicted that the loss could be as much as 50%. Thailand's sea water is projected to experience up to 20% loss (Fig. 4). Malaysia's fish catch in its EEZ could experience a decline of as much as 5%. Vietnam is the only country that may benefit from climate change given its position. The North and North Central South and South Central are predicted to host an increase of fish of as much as 49% (Table 2).

Thailand is likely to experience a long term decline in both inland fisheries as well as marine fisheries. Under climate change scenarios coupled with the long term decline of the Mekong River system fishery, Thailand fisheries have been facing multiple challenges. A recent report suggests that SSFs in Chiang Rai could not properly fish due to lower water levels in Mekong River.[25] In the context of marine fish catch potential, Thailand depends on the Gulf of Thailand as well as the Northeast part of the Andaman Sea. In regards to the Gulf of Thailand, under elevated CO2 emission, it was projected that the loss could reach 20% by 2015.[12] The Government of Thailand recently reported that despite less anthropogenic pressures in the Andaman coast, it still recently experienced 20% fish losses.[26]

There will be a big gap between domestic demands for fish (proxied by projected population) and potential fish catch in Indonesia by 2050. Malaysia is very likely to benefit far less from its future fish catch. Even though Indonesia and Malaysia have been benefiting from rapid aquaculture development, there is no guarantee that this will be always the case. New measures of adapting to climate change as well as dealing with mis-management of both coastal and marine fisheries ecosystems must be introduced. With climate change affecting temperature, both Indonesia and Malaysia's coastal-based fisheries are facing problems such as coral reef degradation and disseverance of mangrove ecosystem. Thailand's marine fisheries are likely to be only slightly affected by climate change. It should improve its inland fisheries and find ways to adapt to climatic change. Vietnam fish catch potential may increase based on the global modelling exercise. Vietnam can still benefit more from inland fisheries while benefitting from future fish catch potential by 2050.

For other world regions, Norway will enjoy higher fish catch potential. Its marine culture (salmon industry) is very well developed. While it may be affected by fishmeal supply, this is subject to further research. A new potential outlook for fisheries comes from the West African waters (Ghana) where their fish stocks could more than double by 2050.[20]

Observed inter-annual variation of Ocean Heat Content (OHC) showed an increasing trend in Indonesian seawater especially in West Sumatra.[27] Most global studies have predicted Indonesian waters are likely to experience big loss in fish catch potential. Lack of attention from scientific communities and also from public policy suggests that the country needs to start acknowledging potential loss in fish sector in 2050.

4.2. *By timeframe (IPCC CC scenarios)*

The IPCC Report[12] provides climate change impact scenarios for several future timeframes, notably 2030, 2050 and 2080/2100. These will be used in this paper to allow assessment of potential changes in fish availability.

Anticipated changes by 2030

The direct impact of climate change in the fisheries sector remains uncertain. Existing studies provide no clear projection for 2030 for marine or inland fisheries. Southeast Asia's deltas will continue to face problems such as overfishing, water abstraction, drainage of wetlands, pollution and dam construction. Despite the fact that climate change has already impacted coastal ecosystems as seen in coral reef degradation, fisheries' problems are likely to be dominated by existing non-climate drivers ranging from overfishing, habitat modification, pollution, population change and global change in fish based protein diets, rather than be affected by climate change factors.

Anticipated changes by 2050

Increases in ocean temperature, ocean acidification.[b] and changes in solar irradiation[c] in the coming decades may likely create volatility in fish production in 2050. By 2050, ocean fish catch potential in the Southeast Asian sea waters (and low latitude regions including Indian Ocean, Java Sea, south of South China Sea) may be reduced by 40 to 60% due to fish migration[12] as a response to both warmer temperatures and ocean acidification. Fish feed used for aquaculture, which constitutes a third of the world's fish catch, will also be affected, resulting in increasing costs of aquaculture.[19] Indonesia's EEZ (Exclusive Economic Zone) regions will likely experience the biggest loss in maximum catch potential.[18] Indonesian seawaters are predicted to host less fish catch than the EEZ regions in the Indian Ocean. It is predicted that a reduction ranging from 20% to 50% is likely to occur by 2050 while in the Java Sea, it is like to be reduced by up to 50% (Fig. 4). The Celebes Sea (or Sulawesi) is likely to reduce its fish catch by 6% to 20%. One of the few places that may experience less impact is the Banda Sea region.

As for Malaysia, it is predicted that the south regions of the South China Sea may experience a decline of 1–5%. In the gulf of Thailand, the reduction can be as much as 20%. The projected yield changes in 67 marine national EEZs represent about 60% of global fish catches and/or fish production. By 2050, it is likely that there is an increased productivity at high latitudes and decreased productivity at low/mid latitudes, with considerable regional variations. With few exceptions, increases and decreases in fish production potential by 2050 are estimated to be less than 10% with mean +3.4% from present yields.[20]

Among the regions showing a high dependency on fisheries, West Africa is one where climate change is predicted to increase productive potential. One of the predictions suggests that some West African nations may more than double the present fish population in their sea waters. Unfortunately, West African fisher folk may not be able to benefit from future comparative advantage arising from the decrease in South and Southeast Asia as their farmers may not have the appropriate fish catch technology to benefit from the potential increase.

Anticipated changes by 2080/2100

Towards 2080/2100, the anticipated increase in the frequency and severity of extreme events, such as floods and storms, will affect fishing operations and infrastructure in coastal regions (and in oceans). Warming in the tropics by 2100, combined with non-climate stressors such as unsustainable coastal and marine management practices, is likely to cause local extinctions of particular fish species at the edges of their ranges and have serious negative impacts on fisheries. Coastal fisheries in tropical developing countries are likely to be vulnerable to climate change due to the decline of coral reef cover that may lead to declines in fish species associated with coral reefs.[d] More than 60% of coral reefs are considered to be under immediate threat of damage from a range of local factors, of which overfishing is the most serious and the percentage under threat rises to approximately 75% when the effect of rising ocean temperatures is added to these local impacts.[28]

4.3. *Supply chain*

Wild captured fish and cultured fish from aquaculture are moved from "source to table" through supply chains with common features (Fig. 5). The starting point of these supply chains is either an ocean or freshwater fishery from which fish are caught using a set of technologies, or a farm. Supply chains are essential in current food security to move fish from where it is produced through various steps, to make fish available to the consumer. Most literature has focussed on climate change effects on fish production systems, as reviewed in previous sections of this paper.

There is scant literature on the effect of climate change on the preparation of fish feed for aquaculture, or of climate change on the supply chain steps

[b]Ocean acidification is the decrease in the pH (acidity) of the Earth's oceans caused by the uptake of carbon dioxide (CO_2) from the atmosphere. An estimated 30% of the CO_2 released by humans into the atmosphere dissolves into oceans. See https://www.ipcc.ch/publications_ and _data/ar4/wg1/en/ch10s10-4-2.html.

[c]The total amount of solar radiation energy received on a given surface area during a given time, often measured by an energy unit per square meter (e.g. megajoule per square meter).

[d]Porter JR *et al.*, 2014, op cit.

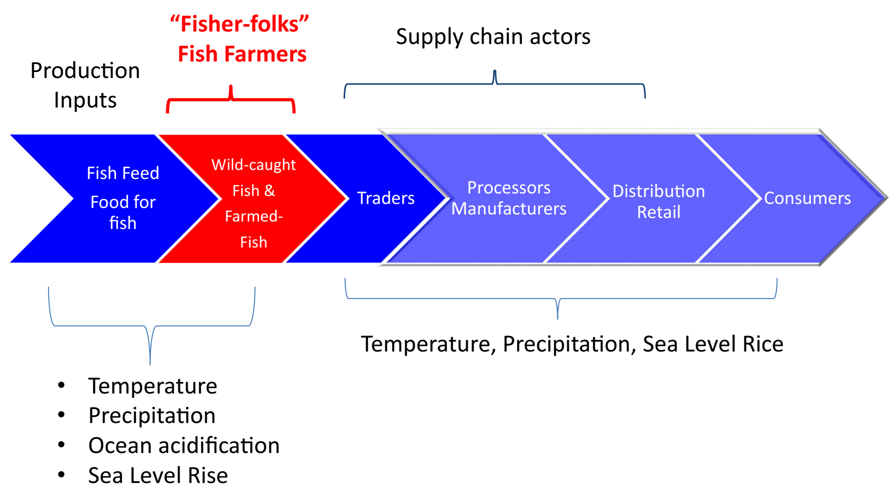

Fig. 5. Fish Supply Chain.

associated with processing, storage, or transport.[29] It can be postulated though that increased precipitation and sea level rises are likely to affect the logistics and operations of transporting fish within and between countries. Increased temperature may also likely affect fish loss as many small fishers currently do not have effective cold chain management technology. Climate change effects on the non-production aspects of the fish supply chain is an area requiring much research.

5. Concluding Remarks

Even without climate change, it is generally acknowledged that there is a "crisis in fisheries" due to declining fish stocks in the world's major fisheries.[2] The causes of this crisis are many and include weak Governance (e.g. Code of Conduct for Responsible Fisheries), technological advances and increased demand for fish as a healthy source of protein. To meet these growing demands for fish, it will be necessary to increase production through aquaculture. Merino *et al.*[23] forecast that in addition to a predicted small increase in marine fisheries production, between 71 and 117 million tons (MT) of fish will need to be produced by aquaculture to maintain current average per capita consumption of fish. Local dynamics such as social, economic factors coupled with environmental degradation often affect progress of aquaculture development.

Captured fish from inland waters is still increasing but the same from marine waters is plateauing to declining.[3] In general, scientific literature suggests that fish catch (and fish culture/production systems can be improved via two key strategies, namely, biological tolerance and genetic adaptation. Unlike crops, increasing stress tolerance of fish and livestock to single and/or multiple stresses are more difficult to be re-engineered at genetic level. In marine fisheries, fish migration is also part of a biological response to any changes in the physical, chemical and biological properties of the seawaters.

Marine fish know no boundaries. Solving ocean acidification and warming requires ambitious targets and trans-boundary cooperation. Effective and efficient management of marine resources and aquaculture often face challenges such as resource competition and conflict[30] which hinders effective policy implementation and practice. The solution could be to identify common language and principles that can facilitate productive conceptual framing and application of equitable principles in practice.[30]

Adaptation to climate change in the fisheries sector requires comprehensive understanding of a range of options.[31] Unfortunately, such capacity often does not exist in countries that host vulnerable fishers, and these range from Southeast Asian to the Pacific small island states. There are challenges to promote relevant adaptation policy that can potentially lead to effective adaptation planning and implementation to augment existing capacity and building the resilience of fishing communities and the sector in general. In small island states such as Fiji and the Solomon Islands, recent predictions suggest that by 2050, local fish demand may exceed supply.[32,33] With climate driven migration of fish, the decline of supply could be faster than expected in many parts of the tropical marine countries.

Immediate and medium term adaptation solutions to fisheries and aquaculture are possible. First, systematic collection of evidence of potential climatic change impacts on local fisheries is needed. Experts have a high degree of consensus that traditional fisheries in the tropics will be the most vulnerable to climate change. However, the risks are unknown to many policy makers and fishers in the regions. Even local expert knowledge is limited for detecting both immediate and long term impacts of climate change on fisheries and aquaculture in general. Second, communicate more generally about the risk of climate change on potential loss of wild fish production. Most small/artisanal fishers are not aware of the risk of fish migration as wild catch will be moving far from the coasts, while livelihood assets such as most shipping vessels are still traditionally limited to coastal waters. Building coastal ecosystems resilience by involving the fishers and consumers is necessary. Third, it is additionally important to ensure immediate solution to existing problems such as marine pollution, overfishing and different forms of unsustainable practices. This includes putting more efforts to end unreported and unregulated fishing as suggested by SDG #14. Fourth, promoting adaptive fisheries governance at local level to improve farmers' adaptive capacity. This includes bolder commitment to increase the investment in adaptation through fish catch technology and reduction of loss and damage in fisheries sectors including post-harvesting technology in fisheries.

It is also important to capitalise on the recent climate change advocacy to address existing fisheries problems such overfishing, pollution and unsustainable coastal development that contribute to irreversible damage to marine habitats, ecological functions and biodiversity. Failures to address these can potentially lead to decline in 'blue economic growth' in the near future. Lastly, it is necessary to promote loss and damage assessment in the fisheries and aquaculture sectors as part of local and national adaptation strategies to deal with climate change. Fisheries officials and non-governmental organisations can find ways to address loss at different stages in the fish supply chain including post-harvest losses of fish which has been highlighted in the FAO's Code of Conduct for Responsible Fisheries, adopted by its member states since the International Conference on Responsible Fishing held in 1992 in Cancûn Mexico.

Ongoing technological development in the aquaculture industry suggests that projected global fish demands in 2050 could be met, thus challenging existing predictions of inevitable shortfalls in fish supply by the mid-21st century. Human factors such as changes in marine and fisheries governance (such as management effectiveness and trade practices) will remain the main influence on realized gains or losses in global fish production.

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