A STUDY ON DAM CONSTRUCTION, HYDROLOGICAL CHANGES, AND THE SHIFT IN DIETARY PROTEIN IN THE LOWER MEKONG RIVER BASIN

By

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ABSTRACT

A STUDY ON DAM CONSTRUCTION, HYDROLOGICAL CHANGES, AND THE SHIFT IN DIETARY PROTEIN IN THE LOWER MEKONG RIVER BASIN

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An important ramification that could be linked to the accelerated dam construction in the Lower Mekong Basin (LMB) is a dietary shift from fish as a source of protein to land-animal-based protein. The proposed chain of events that lead to this conclusion starts with a disruption in the river's hydrodynamics from dams (e.g., flood-pulse, annual discharge, seasonality, water level), combined with physical barrier (i.e., a dam structure) lead to lower fish catch rates and reproduction from migratory impediment. A shift to a westernized diet by the developing country population of the LMB countries, can be observed as well. A relationship between fish catch and flooded area is developed to downscale fish catch to a 10 km grid in the study area, which enables the quantification of yearly distributed catch per capita. It is found that wet years yield higher catch per capita than dry years. Further, a statistical analysis on fish and meat production and consumption show an overall increase in local production of meat. The 2% cropland expansion is found to be largely attributed to an increase in meat production as most of the crops are grown for animal feed. Finally, a meat virtual water trade (VWT) network of is constructed between 1988 and 2016. Virtual water outflow is four to eight orders of magnitude larger than inflow from 1998 to 2003, when outflow drops significantly, and the direction of flow completely reverses. In fact, in 2011 the LMB countries' virtual water inflow reached similar values to that of past outflow (1998-2003). The abrupt virtual water flow change opens the door for a water savings analysis, where local and international production of meat is discussed to reach greater regional water savings (RWS) (i.e., minimizing water footprint).

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1. INTRODUCTION

The Mekong River Basin (MRB hereafter) is the second most biodiverse river system in the world after the Amazon that hosts the region for the largest inland fishery production (Ziv, Baran, Nam, Rodríguez-Iturbe, & Levin, 2012a). The river originates in the Tibetan Plateau, and works its way down to and through Vietnam, passing Myanmar, Lao People's Democratic Republic (Lao PDR), Thailand, and Cambodia with a total length of ~4800 km (MRC & Mekong River Commission Lao PDR, 2005a, 2010b). In the past two decades the river withstood significant hydrological changes due to extensive manmade structural progress in the form of dams (Arias, Piman, Lauri, Cochrane, & Kummu, 2014; Baran, Guerin, & Nasielski, 2015; Baran & Myschowoda, 2009; Brownell, Reeves, Thomas, Smith, & Ryan, 2017; Dugan, Barlow, Agostinho, Baran, Cada, Chen, Cowx, Ferguson, Jutagate, Mallen-Cooper, et al., 2010; Kondolf, Rubin, & Minear, 2014; Kummu & Sarkkula, 2008; Lu & Siew, 2006; Wild, Reed, Loucks, Mallen-Cooper, & Jensen, 2019; Xue, Liu, & Ge, 2011). The industry's push for expanding water infrastructure is affecting all ecosystems dependent on the river's natural cycles (Baran & Myschowoda, 2009; Dugan, Barlow, Agostinho, Baran, Cada, Chen, Cowx, Ferguson, Jutagate, & Mallen-Cooper, 2010; Grumbine & Xu, 2011; Kummu & Sarkkula, 2008; Li et al., 2013; Piman, Cochrane, Arias, Green, & Dat, 2013a; Wild et al., 2019; Winemiller et al., 2016a). Moreover, the Mekong River's ~53,000 MW potential of the main stem and its additional 35,000 MW potential of its tributaries will result in the building of 16 dams at the main stem and over 100 dams which are at the tributaries by 2030 (ICEM & Management, 2010a; Pokhrel, Burbano, et al., 2018; Stone, 2011). The accelerated development of dam construction is bound to disrupt the river's natural hydrology as well as fish populations and specie biodiversity altogether. Projections predict a drop in migratory fish biomass by up to 51.3%, condemning 100 fish species and moving them to the list of critically endangered species (Ziv et al., 2012a). Meanwhile the MRB is the world's second richest freshwater capture fishery as well as the second most aquatically biodiverse ecosystem (MRC & Mekong River Commission Lao PDR, 2010b; Winemiller et al., 2016b). Managing the world's water resources properly is critical for the environment as populations rise and the world's economy grows. Balancing water use through food production is crucial because food production shares the highest portion of global freshwater consuming; ~80% of the world water resource is used for this sector alone (Rost et al., 2008).

Today, the livelihood of 80% of the 60 million inhabitants of the Lower Mekong Basin (LMB hereafter) is reliant on fishery and agriculture that depended heavily on the seasonal rainfall and flood pattern (Baran & Myschowoda, 2009; ICEM & Management, 2010b). More importantly, fish remains as the main source of protein for countries in the Lower Mekong River Basin (LMRB), namely Vietnam, Lao PDR, Thailand, and Cambodia. The river's distinctive flood pulse secures the reproduction of most migratory fish (ICEM & Management, 2010b). With a compromised availability of their main protein source, a forced dietary shift towards alternative sources of protein such as land animal-based protein, or high protein crop derivatives should be considered (Orr, Pittock, Chapagain, & Dumaresq, 2012a; Pittock, Dumaresq, & Orr, 2017). This in turn, triggers an array of measurable effects as the protein calories are replaced through locally grown or imported commodities. While hydrological variation is tracked using large-scale hydrological models, analyses regarding secondary effects such as a drop in fish catch per capita and its effects on alternative diets calls for an urgent need to better understand the dynamics between dam development, hydrologic variations, land use/land cover changes, and the potential effects of food production and fisheries.

1.1 Background

The Mekong River faces many great challenges like climate change, which is expected to rise basin-wide temperatures, change monsoon patterns, and ultimately result in unpredictable hydrological changes. For example, a -3% to 15% change in total annual flows has been suggested to be heavily driven by irrigation expansions and climate change (Hoang et al., 2019). The countries surrounding the basin are on the midst of fast-passed economic growth, creating a cycle of increased food and energy requirements, followed by deforestation, expansion of road networks, and dam construction (Pokhrel, Burbano, et al., 2018).

1.1.1 Flood Variations

Flood variation anomalies in the LMB have been observed through time (since before dam construction to present) showing an increasing trend towards new extreme wet and dry periods (Erban & Gorelick, 2016; Han, Long, Fang, Hou, & Hong, 2019; Hoang et al., 2019; Lauri et al., 2012a; Piman, Cochrane, Arias, Green, & Dat, 2013b; Piman, Lennaerts, & Southalack, 2013; Räsänen, Koponen, Lauri, & Kummu, 2012; Shrestha et al., 2013). Granted, these anomalies could, to some extent, be attributed to changes in large-scale atmospheric mechanisms such as: Niño-Southern Oscillation (ENSO), Western North Pacific Monsson (WNPM) and the Indian Summer Monsson (ISM) (J. M. Delgado, Apel, & Merz, 2010; J. M. Delgado, Merz, & Apel, 2012; Räsänen & Kummu, 2013; Ward, Beets, Bouwer, Aerts, & Renssen, 2010). However, research shows that the changes are also due to dam construction (J. M. Delgado et al., 2012; Lauri et al., 2012b; Sabo et al., 2017a). In fact, the direct impact of dam construction to the flood pulse dynamics of the LMB was modeled at varying flow regulation scenarios 10-50% peak flow reduction. The model results on the Tonle Sap Lake (TSL) show a reduction in peak flow of 7-37% and 7-34%, and a reduction of the reversed flow of 11-80% and 15-88% at LO (Lake Outlet) and PK (Prek Kdam) station respectively (Pokhrel, Shin, Lin, Yamazaki, & Qi, 2018a). The flood pulse reduction is a variable to consider when considering fish population drop, however, a much more heavily studied variable is the physical barrier created by dams is another important issue because it prevents spawning of migratory species which are of biological and economical importance (Dugan, Barlow, Agostinho, Baran, Cada, Chen, Cowx, Ferguson, Jutagate, Mallen-Cooper, et al., 2010). This study strives to advance the understanding of the former as its effect on fish catch remains vaguely understood.

1.1.2 Fish catch and flooded area relationship

It's known that drastic physical manipulations of the river flow contribute to a drop in fish populations, especially migratory fish, which account for 71% of the fisheries yield in the LMB (Barlow, Baran, Halls, & Kshatriya, 2008). For instance, an strong association between fish catch and water level for a small temporal resolution (1998-2001) in Tonle Sap Lake (Van Zalinge, n.d.-a). In Van Zalinge's report the importance of flood variation and its effect on fish catch and migration patterns is captured (N van Zalinge et al., 2003). Years later a large study by McIntyre and colleagues developed a relationship between discharge and fish catch in order to downscale fish catch to the major river basins of the world and study freshwater fishery (McIntyre, Reidy Liermann, & Revenga, 2016). A more complex approach was late taken by Sabo and colleagues, when they developed a multivariate relationship between fish catch and flood anomalies of the Mekong River in order to design river flows to improve food security futures in the LMB (Sabo et al., 2017b). Sabo's model points us in the right direction, by showing a greater correlation between flood and fish catch, over discharge and fish catch. This study develops a univariate model between flooded area and fish catch, taking advantage of the simpler requirement for one variable which allows for higher resolution downscaling, but also incorporating a variable with greater correlation than that of discharge.

1.1.3 Water footprint, VWT network, and Regional water savings

Locally grown land-based food production explains land use conversion. However, water consumption from food production (local and imported) can be quantified through water footprint, virtual water trade (VWT), and regional water savings (RWS) changes (Cai et al., 2019; A K Chapagain, Hoekstra, & Savenije, 2006; Ashok K. Chapagain & Hoekstra, 2008; da Silva et al., 2016; Dalin, Konar, Hanasaki, Rinaldo, & Rodriguez-Iturbe, 2012; Dalin, Qiu, Hanasaki, Mauzerall, & Rodriguez-Iturbe, 2015; Dang, Lin, & Konar, 2015; Duarte, Pinilla, & Serrano, 2019; Hanasaki, Inuzuka, Kanae, & Oki, 2010; Konar, Hussein, Hanasaki, Mauzerall, & Rodriguez-Iturbe, 2013; Oki, Entekhabi, & Harrold, 2004; Suweis et al., 2011; Tian et al., 2018; Zhang, Zhang, Tang, Chen, & Wang, 2016).

A significant loss of fish protein is projected and as population grows the demand for an alternative will leave a quantifiable water footprint (Dugan, Barlow, Agostinho, Baran, Cada, Chen, Cowx, Ferguson, Jutagate, Mallen-Cooper, et al., 2010; Li et al., 2013). In fact, a study by Orr et al., (2012) projects water footprint changes under two separate scenarios. The first scenario models the effects of 11 main stem dams, while the second scenario models the effects of 88 main stem and tributary dams combined. The water footprint outcomes are a 4-7% increase use under scenario 1 and a 6-17% increase use under scenario 2. The results on the study mentioned are conservative and operate under the assumption that the demand for food doesn’t change with population growth nor do they account for the increase in demand for crop production such as rice, which would require even more water (Orr et al., 2012a). VWT is not taken into account in the study by Orr and colleagues, which would potentially shed light on regional interactions with the rest of the world

(ROW). Additionally, regional water savings (RWS) (sum of virtual water trade) is not taken into consideration. Knowing how much water is flowing in and out of the region can explain water saving potential to alleviate water scarcity globally and/or locally.

The study by Dalin et al., (2015) projects China's future water consumption and trade (VWT) embedded in food demand and consumption combining a hydrological model and an economical model. Two scenarios are put forward for decadal projection stemming from the baseline scenario (BL), which provides a feasible picture of developments based on expected trends: Inner Mongolia (IM) scenario reduces IM's irrigated land area by 50% in 2020 and 2030, Inner Mongolia plus baseline (IM+B) scenario reduces both IM and Beijing area by 50% in 2020 and 2030. The model results find that virtual water transfers will increase by a volume of 206 km^3 from 239 km^3 to 445 km^3. As importations rise in the form of virtual water in China, water savings (WS) rise (Dalin et al., 2015). So long as the countries that produce a commodity produce it more efficiently than other nations, their production is preferred in terms of RWS. The last section of this study takes a similar approach for the Mekong region where RWS and the best scenario is presented in discussion form.

1.1.4 Land use/land cover change

Land use/land cover cropland expansion is are directly related to food production including crops and livestock (Abdullah, 2006; Aleksandrowicz, Green, Joy, Smith, & Haines, 2016; Bonfils & Lobell, 2007; Carpenter, Stanley, & Vander Zanden, 2011; Gephart et al., 2016; Jacobi et al., 2018; Monfreda, Ramankutty, & Foley, 2008; Smajgl et al., 2015; Stonestrom, Scanlon, & Zhang, 2009). In fact, the deforestation of the Amazon rainforest, is strongly attributed to an increased soybean production (Dalin et al., 2012). The previously mentioned study by Orr and colleagues also calculates land use change and footprint. The land footprint outcomes are a 13-27% increase use under scenario 1 and a 19-63% increase use under scenario 2 (Orr et al., 2012a). This study will present similar land use/land cover observable changes from the dietary shift on the LMB.

1.2 Research Motivation

Freshwater resources are under increasing pressure as the demand for water-intensive products rises. Because loss of fish catch is highly likely, a dietary shift towards other sources of animal products will inevitably occur as aquaculture couldn't possibly make up for the sized fish catch loss and retaining fish exportation would come at a high economical cost to the LMB countries (Pittock et al., 2017; Ziv et al., 2012a). This calls for a robust analysis in spatiotemporal fish catch variations. Additionally, managing the world's water resources properly is critical as populations rise and the world's economy grows. Balancing water use through food production is crucial because it's the highest freshwater consuming process taking up to 80% of the world water resources (Rost et al., 2008). Hence, a suggested effort to reduce fresh-water use globally is optimizing VWT (Dalin et al., 2012). VWT has been studied at different spatial and temporal scales (Liu et al., 2019). This study proposes a fractal basin-wide study focused on temporal variation (1988-2016) embedded in meat (e.g., beef, chicken, and pork) production and trade. While the LMB is often studied by itself, it's also necessary to take a step back to look at this basin's interaction with the rest of the world. Therefore, this study proposes a RWS analysis on meat stemming from the VWT network. Lastly, it's important to analyze commodities individually as RWS analyses on rice showed regional water losses (RWL) while wheat showed RWS (Konar et al., 2013). The last section of this study analyses meat commodities individually RWS. The study recognizes that countries in the LMB, specifically the coastal ones, are highly dependent on income from fishery exports. (Allison et al., 2009). However, economic impacts of food are outside of the scope of this study.

1.3 Research Questions and Objectives

The overall goal of this thesis is to explore the causes and effects of protein source dietary shift of the LMB countries. In the efforts of achieving this goal the study asks the following scientific questions:

- Is there a relationship between fish catch and hydrological variations induced by dam construction in the LMB?
- What is the impact that a dietary shift from fish to livestock products has on virtual water transfers between the LMB and the ROW?
- How can we optimize RWS by balancing livestock production between the LMB and the ROW?

These questions are answered through the reach of the following objectives:

- Development of a univariate relationship between fish catch and flood to downscale fish catch data using results from a hydrological model and study fish catch temporal variability.
- Construct a VWT network using virtual water contents (VWC) of meat (e.g., cattle, chicken, pork) commodities and trade data to study the impacts of adopting a higher meat-based diet.
- Compare the estimated effects of domestic (LMB) versus internationally sourced livestock commodities in terms of RWS to discuss optimal production locations for each commodity.

The outcomes of this research will provide insight to the accelerated addition of dams to the LMB. This study is relevant as it will determine whether or not hydrological changes will take a toll on fish reproduction abilities, which in turn could hinder fish catch. These effects could be another driving force to a dietary shift from fish protein to livestock. Additionally, the observed virtual water flows could present a significant enlargement of virtual water inflow and outflow in terms of livestock commodities. The study will show the outcome of RWS of each individual commodity (e.g., chicken, beef, pork). Meaning, policy makers will be encouraged to push for more efficient trade policies for the LMB.

1.4 Structure of Thesis

The thesis has five sections including the introduction. An introduction of the main topics and background is provided in section one. The study area, model, and data used are presented in section two. The third section outlines the methods used for every analysis and model presented in the results. The results and discussion, section four, of the thesis is structured as follows: First, the relationship between fish catch and flooded area is presented. Second, the study presents the process of fish downscale and distribution to 10 km grids. Third, the study presents the observed land use change of nearly two and a half decades. Fourth, a statistical analysis and discussion of fish and meat production and consumption is presented. Fifth, the VWT network is constructed. Last, the RWS results are presented with their respective discussion. Section five of the study, conclusions, presents the closing remarks and findings and the thesis ends.

2. STUDY AREA, DATA, AND MODEL

The thesis focuses on what is known as the LMB, which begins at the Golden Triangle where the national borders between Thailand, Laos, and Myanmar meet and ends down at the Mekong Delta at the bottom of Vietnam. The area is delineated in red in Figure 1. The data retrieved for the analyses mainly come from the FAO website, including fish catch, fish consumption, meat production, and meat consumption. Population that is retrieved from IMF, specifically, the October 9^{th}, 2018 iteration. The hydrological model employed is CaMa-Flood and its results from the study by Pokhrel and colleagues (2018) are also used in this study. The model results of use include discharge, water storage, flood depth, and flooded area. The following sub-sections expand on these topics to a greater detail.

2.1 Study Area Details

The LMB, located in Southeast Asia, has a total area of ~606,000 km^2, which is 76% of the entire Mekong Basin which has a total area of ~795,000 km^2 (Frenken & FAO, 2011). The countries sharing the basin include Laos, Thailand, Cambodia, and Vietnam. Their area contribution to the basin is summarized in Table 1.

Table 1: Summary of the LMB spatial distribution (Frenken & FAO, 2011)

Area (km^2)	Countries included	Area of country in basin (km^2)	Percentage of total area of basin %
606 000	Laos	202 000	33
	Thailand	184 000	30
	Cambodia	155 000	26
	Vietnam	65 000	11

The Mekong River's mean annual water discharge is approximately ~475 km^3/year or ~15,000 m^3/s making it the 10th largest river in the world in terms of annual flow at its mouth (MRC & Mekong River Commission Lao PDR, 2005b). It flows through ~2600 km of channels from the Golden Triangle to the China Sea at the Mekong Delta (Mekong River Commission (MRC), 2010; MRC & Mekong River Commission Lao PDR, 2005a). The LMB is characterized by flat-fertile lands that stretch over long distances and strong climatic gradients. Human development and a plethora of managed ecosystems co-evolve in the basin resulting in rapidly emerging global issues such as land cover change, river regulation, and habitat loss (Pokhrel, Burbano, et al., 2018).

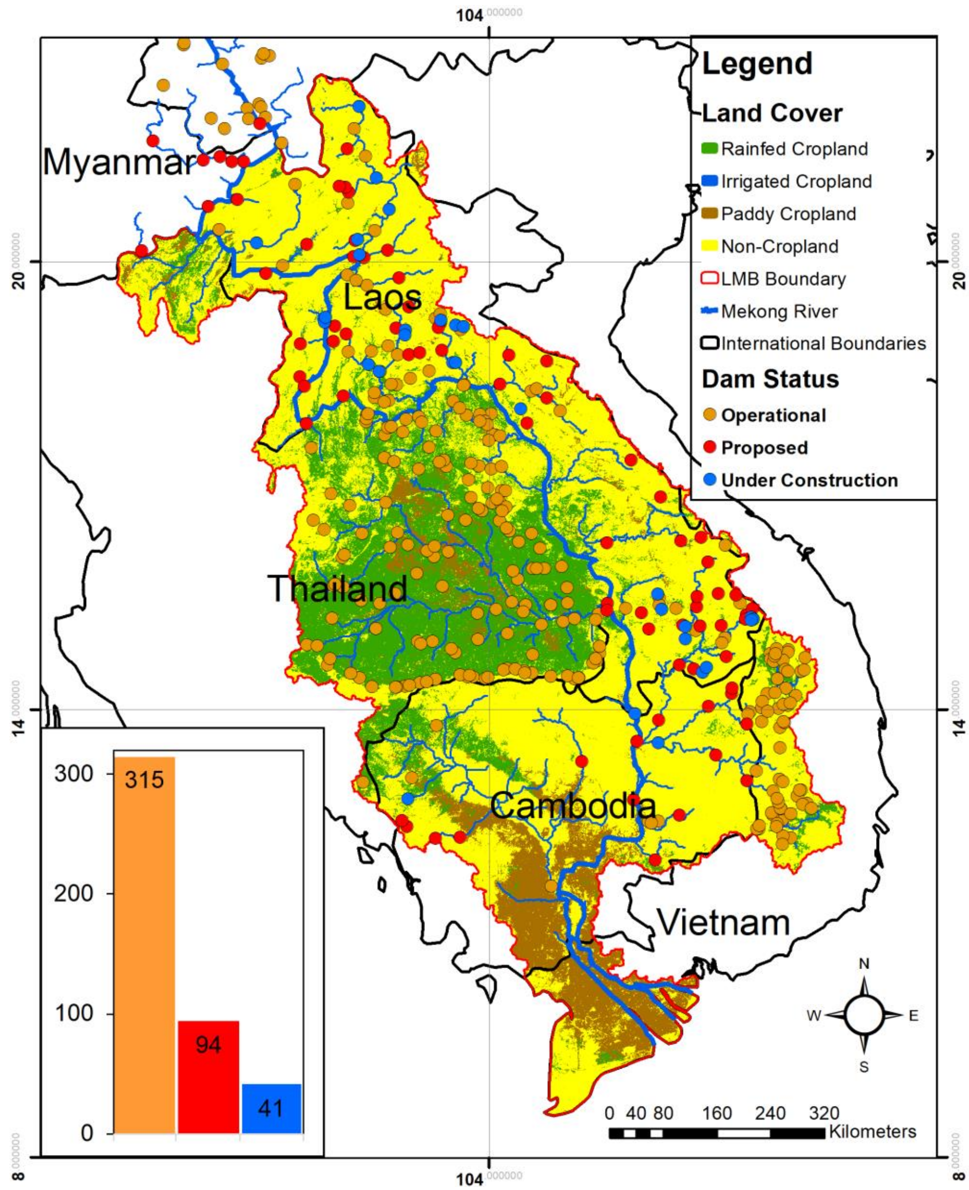

Figure 1. Dams in the Mekong River Basin. The red and black contour lines show the Upper and Lower Mekong Basin respectively breaking at the border between Laos, Myanmar and China. The background shows land use types and irrigated croplands obtained from (Salmon, Friedl, Frolking, Wisser, & Douglas, 2015). Dams are broken down into three categories (operational, proposed, and under construction) to highlight the number of dams that will become operational in the near future. The database for the dams was retrieved from the Research Program on Water, Land and Ecosystems (WLE), Greater Mekong.

Contrary to popular belief, the vast potential for hydropower that the Mekong River presents hasn't been largely exploited yet. Compared to other major river basins of the world the MRB remains relatively unaltered (Grumbine & Xu, 2011; Nilsson, Reidy, Dynesius, & Revenga, 2005). Despite having many dams constructed over the past few decades, the effects are minimal because most are located in the tributaries (Figure 1) and only capture a small portion of the river flow (Grumbine & Xu, 2011; Winemiller et al., 2016b). By extent, the hydrology of the Mekong remains largely governed by natural flow variation. The river system at hand still manifest distinctive wet and dry seasons as direct outcomes of the precipitation seasonal variability, which supports highly productive riverine ecological systems and agriculture. Food production in the LMB is heavily reliant on timely rainfall, seasonal flood pulse, fisheries and rivers. In fact, crops are grown on naturally fertilized soils from nutrient-rich sediments and flows timed with plentiful seasonal rainfall, while wetlands benefit from abundant freshwater and nutrients supplied by the seasonal flood (Fredén, 2011). These characteristics allow the LMB house an important ecosystem responsible for the largest inland fishery that feeds the locals and a significant fraction of rest of the world (Ziv et al., 2012a). To put it into perspective last decade's estimate of 2.2 million tonnes harvest of wild fish from the Mekong worth between $2.2-3.9 billion at first scale and $4.3-7.8 billion on retail markets (Hortle, 2009) expectedly went up and it continues to rise.

Unfortunately, the ideal of the unchanged ecosystem that is the MRB is beginning to show measurable changes. For starters, widespread alterations in land use along from the construction of several large dams in the main stem of the river and hundreds of other in the tributaries. For instance, by 2030 there are 16 dams in the mainstream and ~110 dams in the tributaries are planned (Grumbine & Xu, 2011; Keskinen, Kummu, Käkönen, & Varis, 2012; Lauri et al., 2012a; Stone, 2011; Winemiller et al., 2016b; Ziv, Baran, Nam, Rodríguez-Iturbe, & Levin, 2012b). Main land use categories along with operational proposed, and under construction dam projects are shown in Figure 1. Additionally, further stress is expected on the region's ecosystems in the coming decades due to climate change. Crop stagnation and dramatically altered aquatic ecosystems deeply disrupt rural livelihoods and are a direct result of more frequent floods and droughts (Adamson, 2006; Fredén, 2011; MRC & Mekong River Commission Lao PDR, 2010a). Another measurable change is the result of temperature rises in the headwaters of the Mekong River (Lauri et al., 2012a; Lutz, Immerzeel, Shrestha, & Bierkens, 2014), which in turn alters the seasonality of stream flows, affecting agricultural productivity and aquatic ecosystems. Additional downstream pressures come in the form of groundwater overexploitation, and sea level rise, which leads to salt water intrusion and aquifer contamination. Overall, the falling quality of the ecosystem from the proliferation in dam construction, climate change, and sea level rise will likely present the LMB with unwanted changes in the hydrologic, agricultural, and aquatic systems (Johnston & Kummu, 2012; Lauri et al., 2012a; MRC & Mekong River Commission Lao PDR, 2005b; Nesbitt, Johnston, & Solieng, 2004).

As aforementioned, this thesis focuses on the hydrological causes and effects of a dietary change from fish to land-based meat protein in the LMB. Studies focused on food security of the region at hand show that due to dam construction and associated fishery loss (Stone, 2016) maintaining current levels of food supply would require 19 to 63% expansion of agricultural land (Orr, Pittock, Chapagain, & Dumaresq, 2012b). Such an expansion would require substantial amounts of additional water, leading to unknown potential consequences in the LMB. Thus, this study explores the ramifications of affected aquatic systems, and analyses the increased water usage from agriculture and new dietary demands of the LMB nations.

2.2 Data

In its first analysis, fish downscale, the thesis uses: yearly fish catch historical data (1979-2010) from the calculated dataset from FAO FishStat (http://www.fao.org/fishery/statistics/en), model results data from CaMa-Flood (1979-2010) (Pokhrel, Shin, et al., 2018a), and historical population data (1986-2010) from the International Monetary Fund (IMF), specifically the October 9th, 2018 iteration (https://www.imf.org/en/Data). The CaMa-Flood results include discharge, storage, flood depth, and flooded area. The land use/land cover change historical variation inspection is mapped and calculated from European Space Agency-Climate Impact Initiative (ESA-CCI: https://www.esa-landcover-cci.org/, accessed on 27 January 2018). For the second analysis, meat and fish production and consumption, is carried out using: production FAOSTAT data (http://www.fao.org/faostat/en/#data/QL), supply FAOSTAT data (http://www.fao.org/faostat/en/#data/CL) for both meat and fish, and fish catch from the aforementioned FAO FishStat in the place of fish production. The VWT network construction required detailed trade matrix meat (e.g., cattle, chicken, pork) data from FAOSTAT (http://www.fao.org/faostat/en/#data/TM) and VWC values retrieved from Chapagain & Hoekstra (2003) results.

2.3 Hydrological and Flood Dynamics Model Settings

The hydrodynamic model CaMa-Flood (version-3.6) requires runoff and TWS components (e.g., soil moisture, snow, river storage, and groundwater) data as part of the input variables. These data are fed from an alternative model, HiGW-MAT, which ran for the same temporal scale (1979-2010) using the same parameters as in Pokhrel et. al. (2015). HiGW-MAT is a global model; thus, its results were extracted for the MRB (90-110°E, 5-35°N) at a 1° grid resolution. CaMa-Flood is driven using runoff and the TWS analysis is carried out using the storage components.

CaMa-Flood was run using similar approaches to that of previous studies (Yamazaki, Sato, Kanae, Hirabayashi, & Bates, 2014a; Zhao et al., 2017), if fact all of the simulation settings are identical to Yamazaki et. al., (2014). River-floodplain hydrodynamics at 1° over the MRB were simulated using runoff. Further simulations are conducted for various year combinations including wet and dry year specific simulations. For the purpose of this thesis, the relevant resulting simulations from the mentioned study were conducted at varying degrees of dampened flood peak (i.e., by 10, 20, 30, 40, and 50%). These scenarios were designed to capture peak flow reduction in magnitude that come with hydropower and flood-control dams. While these scenarios don't actually capture the flow regulation effects of future dams, they present plausible flow regulation effects from cumulative upstream dams.

The hydrological data are results from the global hydrodynamic model CaMa-Flood are a crucial component of this study. This model has been extensively validated globally and over the MRB (Chaudhari, Felfelani, Shin, & Pokhrel, 2018; Felfelani, Wada, Longuevergne, & Pokhrel, 2017; Kim, Yeh, Oki, & Kanae, 2009; Pokhrel, Felfelani, Shin, Yamada, & Satoh, 2017; Pokhrel et al., 2015; Pokhrel, Hanasaki, Koirala, et al., 2012; Pokhrel, Hanasaki, Yeh, et al., 2012). In short, the model computes river discharge, water level, and flooded areas by solving the shallow water equation for open channel flow. For a complete model description and more detailed simulation settings refer to the 2018 Pokhrel et. al., scientific report (Pokhrel, Shin, et al., 2018a).

3. METHODOLOGY

This study takes the LMB (see Figure 1) to create a gridded map of estimated riverine fish catch. The distribution method follows McIntyre and colleagues (2016) methodology, deriving a relationship potential fish catch and hydrology. The distributed data per country is then merged and clipped for the LMB area in order to extract yearly fish catch data within the LMB itself. The results are mapped as total fish catch and fish catch per capita in timeline maps and dry and wet years respectively. The study goes further explores the measurable drop in fish catch on the study area by measuring the increase of alternative meat consumption by conducting a changepoint analysis on meat and fish production and consumption. A rise in water use to compensate for the elevated meat consumption is studied constructing a meat (e.g., cattle, chicken, pork) VWT network from 1988 to 2016. The VWC of each commodity considered was retrieved from Chapagain and Hoekstra's model results (2003). Lastly, the study takes a look at the RWS from meat by comparing years with higher virtual water inflow to the LMB with years of higher virtual water outflow from the LMB following (Dalin et al., 2012) water savings calculations.

3.1 Hydrological and Flood Dynamics Model

This study employs results from the global hydrodynamic model, CaMa-Flood (Yamazaki, Kanae, Kim, & Oki, 2011; Yamazaki, Sato, Kanae, Hirabayashi, & Bates, 2014b). The model produces hydrological results (e.g., inundated area, water level, river discharge, flow velocity) by computing river hydrodynamics solving the shallow water equation of open channel flow. Local inertial approximation in CaMa-Flood accounts for backwater effects explicitly (Yamazaki, de Almeida, & Bates, 2013). The model was set up at a 10 km resolution with regional level settings for the MRB (Yamazaki et al., 2014b). The Mekong Delta requires accounting of channel bifurcation to realistically simulate river-floodplain dynamics, which is achieved by using CaMa-Flood version-3.6.

The river network at 10 km resolution was obtained by upscaling the 3 arc-second (90 m) flow direction map from HydroSHEDS (Lehner, Verdin, & Jarvis, 2008). The digital elevation model was obtained from SRTM3 DEM (Yamazaki et al., 2014b). Manning's roughness coefficient for rivers was set at 0.03 and for floodplains it was set at 0.10 following (Yamazaki et al., 2012, 2011, 2014b). The rest of the parameters remain unchanged from Yamazaki et al., (2014).

Some of the critical output variables used in this study are flood depth, flooded area, discharge, and water storage. Flood depth and flooded area are diagnosed from water storage in each unit catchment and discharge is calculated from the shallow water equation (Pokhrel, Shin, Lin, Yamazaki, & Qi, 2018b). Water storage at each unit catchment, on the other hand, requires three components for its computation, discharge input from upstream, discharge output at the downstream, and local runoff. The discharge variables are obtained from CaMa-Flood, however, local runoff variable is an input from HiGW-MAT (global hydrological model) (Pokhrel, Shin, et al., 2018b). These are the three components that update the mass conservation equation that updates water storage.

3.2 Creating a Gridded Map of Estimated Riverine Fish Catch

The first step in downscaling fish catch data is gathering the necessary data. Mean annual catches of freshwater fishes from inland waters were calculated from FAO FishStat database (FAO, 2018). The exclusive query terms for downloading catch data from FAO was “freshwater” and “inland” for species and fishing area respectively. These specifications actively exclude fish from sea waters and aquaculture. The analysis laid out in Figure 2 focuses on four nations (i.e., Cambodia, Laos, Thailand, and Vietnam) with reliable data from 1979-2010. Data outside of this specified temporal period is available, however, the analysis is limited to the results of the CaMa-Flood simulation.

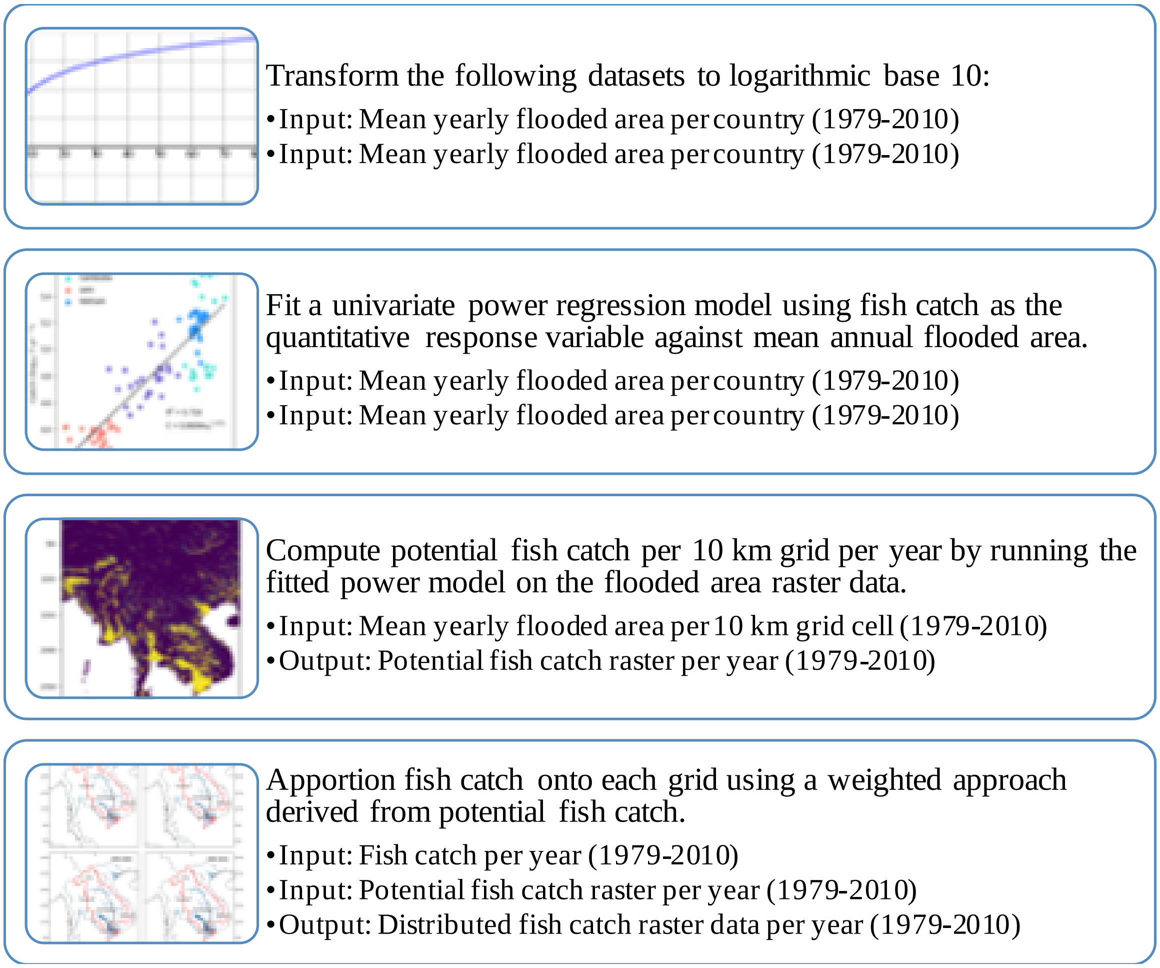

Figure 2: Workflow diagram of the 10 km fish catch downscale applying a univariate power regression model. Flooded area data is retrieved from the CaMa-Flood model results while fish catch data is calculated from FAO FishStat (Pokhrel, Shin, et al., 2018a).

The second step entails establishing an empirical power-function scaling relationship between mean annual flooded area and fish catch. Fitting the univariate power regression model requires using reduced major axis regression to fit data from 4 nations. This process yields Equation 4. Next, the study distributes fish catch into a 10 km grid system. Here, an exclusion of any grid below 10 cm is carried out using flood depth raster data from the simulation results. The exclusion follows the assumption that large fisheries, which are the sole reporters of fish catch to the FAO FishStat database, don’t fish in such shallow waters.

One of the limitations to the aforementioned downscaling method arises from the FAO statistics and the rooted assumptions. First, the analysis is limited because national governments submit catch statistics independently to FAO. This can lead to an unwanted favoritism towards large rivers, population centers, and commercial fisheries (Bartley, De Graaf, Valbo-Jørgensen, & Marmulla, 2015; R. Welcomme & Winfield, 2012). Second, fish catch is famously underreported by 100-200% (Dickson, Hutton, & Adams, 2009; Nations & Center, 2008; R. Welcomme & Winfield, 2012). Third, the statistics are confined by only one source of the comprehensive regional statistics on freshwater fisheries (McIntyre, Liermann, & Revenga, 2016). Fourth, the main assumption for the downscaling algorithm lies in that the calibration of the model is equipped for large river basin scale distribution and so it assumes accurate capture at smaller scales.

The last calculation carried out using fish catch data is the estimation of fish catch loss at each scenario presented in Pokhrel et. al., (2018a).This calculation feeds mean flooded area estimated at each scenario to Equation 4 resulting in a potential fish catch calculation of said area. Percent fish catch loss at each scenario is calculated from the baseline scenario and presented in Table 3.

3.3 Virtual Water Trade Network

The VWT network is built following a series of steps, hence, a set of regressive steps will follow.

To obtain the VWT values we employed the following equation that multiplies trade volume of a specific commodity by the virtual water content of this commodity in the LMB country of ROW country of export:

Equation 1:

$$VWT_{i,j,x}^{LMB} = VWC_{i,x} \times T_{i,j,x}^{LMB}$$

Where $VWT_{i,j,x}^{LMB}$ is the local (Cambodia, Thailand, Laos, Vietnam) virtual water trade in volume (kg_{water}) of commodity x exported from a LMB country i to a ROW country j through trade. $VWC_{i,x}$ is the virtual water content ($kg_{water}/kg_{product}$) of commodity x produced in country i. $T_{i,j,x}^{LMB}$ is the volume of commodity x ($kg_{product}$) produced in the LMB and exported from i to j.

Similarly, we calculated VWT for the importing values with the following equation:

Equation 2:

$$VWT_{i,j,x}^{for} = VWC_{ROW,x} \times T_{i,j,x}^{for}$$

Where $VWT_{i,j,x}^{for}$ is the foreign (from ROW countries) virtual water trade in volume (kg_{water}) of commodity x exported from a LMB country i to a ROW country j through trade. $VWC_{i,ROW}$ is the virtual water content ($kg_{water}/kg_{product}$) of commodity x produced in foreign country i. $T_{i,j,x}^{LMB}$ is the volume of commodity x ($kg_{product}$) produced in the ROW and exported from i to j.

As previously mentioned, VWC is the quotient of ET and yield (Y) of crops. However, the VWC of livestock products takes into consideration the production of their feed, and water consumption of the animal itself. The feed consumed consists of two components including the virtual water embedder inside the various feed ingredients and the mixing water required to put the feed mix together. For greater details on how virtual water content from feed is calculated refer to (Hoekstra, 2003). This study takes the VWC values computed and reported in Chapagain and Hoekstra (2003).

By definition regional water savings (RWS) is the difference between the VWT of the importing region and the VWT of an exporting region (see Equation 3).

Equation 3:

$$\boldsymbol{GWS_{i,e} = \sum_{p=1}^{n} T_{i,e,p} \cdot (VWC_{i,p} - VWC_{e,p})}$$

Where $GWS_{i,e}$ is the RWS in m^3/year, $T_{i,e,p} \cdot VWC_{i,p}$ is the VWT of importing region “i”, and $T_{i,e,p} \cdot VWC_{e,p}$ is the VWT of exporting region “e” in m^3/year.

4. RESULTS AND DISCUSSION

4.1 CaMa-Flood Model Validation and Results

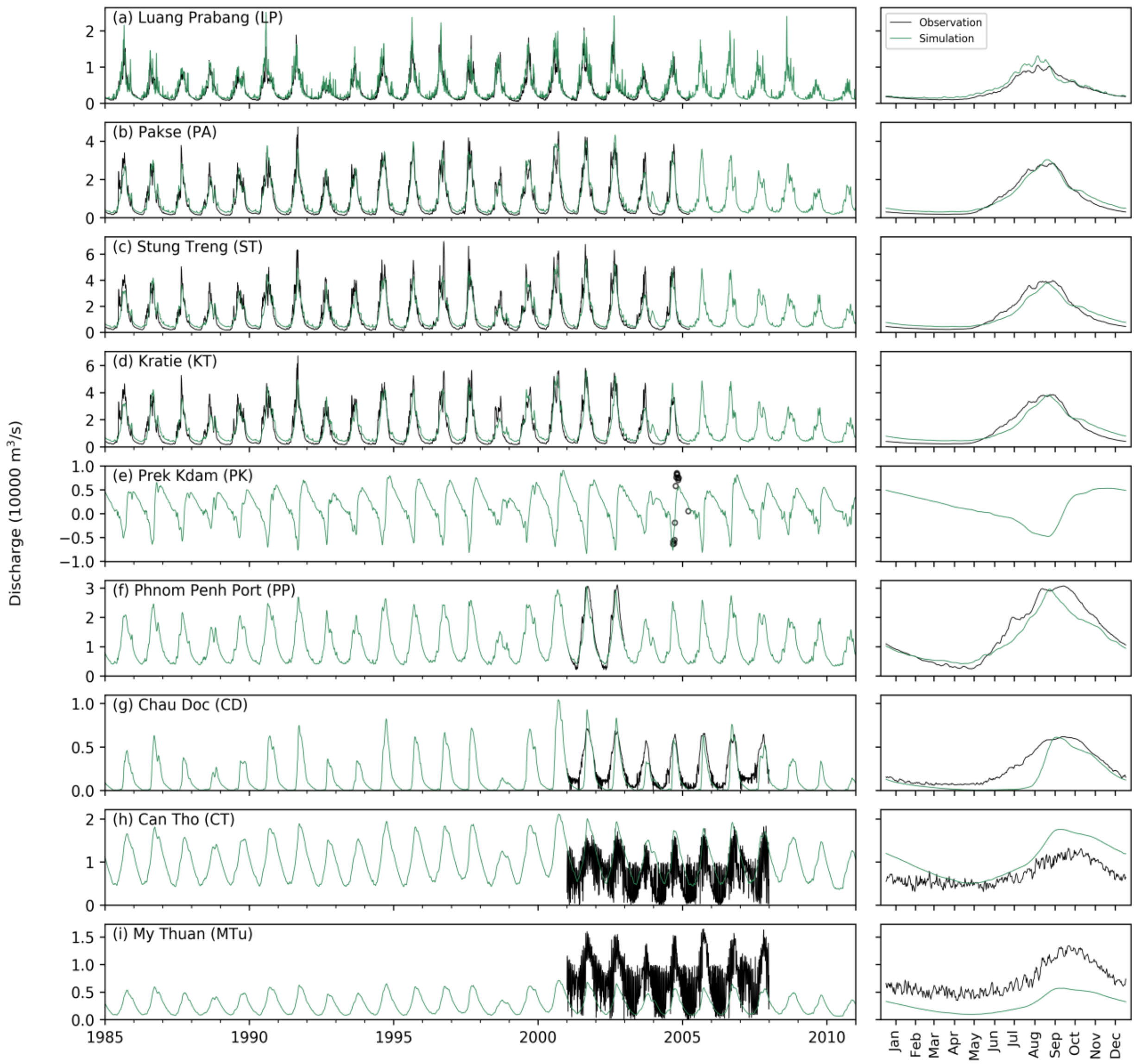

Figure 3: Observation and simulation data for nine major dams in the Lower Mekong Basin. Observation data retrieved from the MRC.

4.2 Empirical Relationship between Flooded Areas and Fish Catch

From the available fish catch datasets at FAO FishStat, data can be retrieved at a sub-basin or a nation maximum resolution. However, for the purpose of this study, the available data for the Mekong River is at a nationwide resolution, allowing the acquisition of the total fish catch per country per year. An objective for this study is to estimate the loss of fish catch in the LMB due to changes in hydrology. For this, the first step is to distribute the low-resolution fish catch data from FAO to a higher resolution grid system. Fish catch fraction that corresponds to the LMB from each LMB country can then be obtained from the high-resolution system derived from downscaling. This method allows the measurement to be more precise as opposed to obtaining fish catch values from neighboring basins that also cross the LMB countries.

A simple relationship between estimated riverine fish catch and a hydrological variable can be valuable in the quest of downscaling observed fish catch data. As previously mentioned, a model with of these characteristics has been previously developed between fish catch and river discharge variables ($C=0.3264Q^{1.256}$, $R^2=0.64$) (McIntyre, Reidy Liermann, et al., 2016). This model is intended for the purpose of its study, which is to cater for many river basins. Discharge is selected as the input variable given that it is a widely available data and does not require model results for each specific basin. Here, a model using McIntyre's univariate simple principle is implemented specifically to the LMB.

Additionally, the concept of using flooded area as a linkage to freshwater fish catch distribution is based on the findings presented in the study by Sabo and colleagues where a multivariate model to characterize fish production in the Mekong River's flood pulse is constructed (Sabo et al., 2017b). The flooded area present in the individual grids within the basin is controlled by multiple variables (e.g., discharge, topography, precipitation), thus, allowing for an implicit consideration of additional hydrological variables while only requiring one input variable for downscaling purposes.

An important and unique behavior that characterizes the Mekong river is its seasonal flood pulse, which creates large flooded areas near large water bodies at different periods throughout the year. Therefore, common catch locations were examined and it was found that most common freshwater catch species (e.g. *Notopterus notopterus*, *Channastriata*, *Cyclocheilischthys enoplus*) predominantly live in seasonally flooded areas (Kian, Yeap, Eong, Sensereivorth, & Racy, 2005). These considerations led to an attempt in linking fish catch to flooded areas by utilizing the CaMa-Flood Simulations.

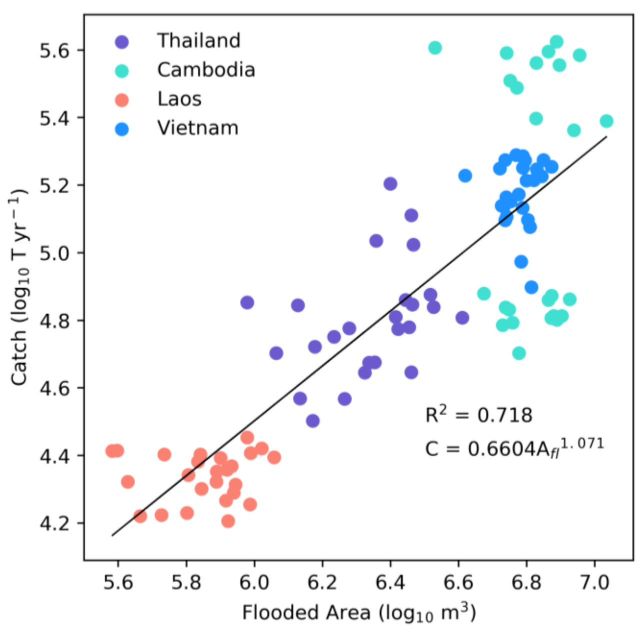

Figure 4: Relationships between measured fish catch and modeled river flooded area for years 1986 to 2010. Fish catch data are obtained from FAO FishStat and flooded area results are obtained from the CaMa-Flood model results (Pokhrel, Shin, et al., 2018b).

The relationship between fish catch and flooded area ($C = 0.6604A_{fl}^{1.071}$, $R^{2=}0.718$) is presented in Figure 4. Based on the R-squared value and the data fit, this relationship is confidently more adequate for focusing on fish distribution in the flooded areas of the Mekong than the general relationship developed by McIntyre et al. (2016). Additionally, it is important to note that a relatively longer span of data (1986-2010; See Table 5 in Appendix) was used in deriving this relationship (Equation 4) as opposed to the 1999-2008 period used by McIntyre et al. (2016) (Equation 5).

Equation 4:

$$C = 0.6604 \times A_{fl}^{1.071}$$

Equation 5:

$$C = 0.3264 \times Q^{1.256}$$

Now that a relationship with a hydrological variable has been established (Equation 4:), it is essential to test its performance. The next objective is to downscale the fish catch data to 10 km grids to compare the model developed here to that of McIntyre and colleagues. This was performed by downscaling the obtained fish catch data using both relationships shown above (Equation 4: & Equation 5:). The data used to downscale fish catch using the discharge relationship was obtained from CaMa-Flood results to keep the input data consistent between the comparison. Figure 5 shows a close match between the results obtained from the two relationships. This relationship is expected since discharge is considered a strong determinant of flooding and both variables are closely related in the described model. Furthermore, the uncertainty in each variable, shown in plots B and C are virtually identical.

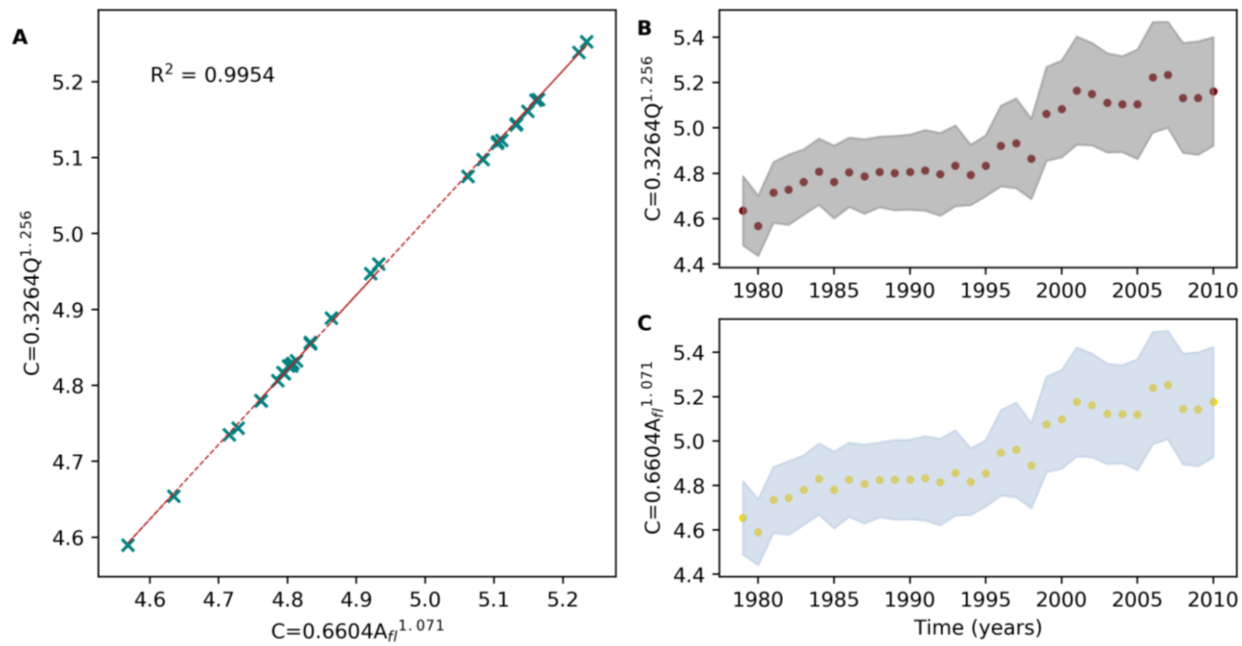

Figure 5: Model fit validation through (A) comparison between regression fitted derived relationship between fish catch and discharge (Y-axis) from (McIntyre, Reidy Liermann, et al., 2016), and the derived relationship between fish catch and flooded area (X-axis) outlined above. The time series (B) and (C) show the limitations of using the univariate models by plotting average fish catch of Cambodia, Thailand, Vietnam, and Laos with error bars of McIntyre's and the derived model form this study respectively.

Figure 5 shows that the catch distribution derived from fish catch and flooded area relationship is not significantly different from that of McIntyre and colleagues. However, the usefulness of this relationship stems from allowing catch distribution in areas with no discharge. For instance, large bodies of water that experience considerable quantities of water storage, ergo, no inflow or outflow reported by the model output.

To add further confidence to our newly derived fish catch-flooded area relationship, the study attempted to conduct an independent validation of our downscaled data with the observational data (Mekong River Commission, 2002) of fish catch in the Tonle Sap Lake in Cambodia. The aforementioned 2002 MRC report presents an average observed catch of 235,000 tonnes for the years 1995-1996, however, during these same years the FAO FishStat reports a total catch for Cambodia of 72,420 and 63,440 tonnes respectively, averaging 67,930 tonnes for these two years. After downscaling and fish catch data distribution takes place, the total Tonle Sap Lake fish catch is attained to be 44,864 and 51,988 tonnes for the years of 1995 and 1996 respectively. This results from the FAO data only using officially reported fish catch data from large fisheries, although most of the fish catch in the region is obtained from single Cambodian fishermen who typically do not report catch statistics. The River Commission report, hence, estimates the total amount assuming most of the fish catch comes from individual fishermen.

A third validation form was carried out using observation data for four years (2000-2004) in Cambodia and comparing it to that of the resulting yearly data aggregated in Cambodia (Table 2). The percent difference in these results presented in Table 2, reach a high of 0.16 %, meaning that the estimated catch values are profoundly reliable in this case. This comparison serves as independent confirmation that the methods behind catch distribution are adequate for large scale distribution. The limitations explained in the methodology section, though, still need to be considered. In short, for smaller scale downscaling, the overarching assumptions are biased towards large scale distribution. Meaning that the finer the scale, the less reliable the method of fish catch distribution becomes.

Table 2: Comparison between observation fish catch (Kian et al., 2005) and distributed fish catch in Cambodia using Equation 4**:** between the years 2000 and 2004.

Year	**Total Production, Observed (Mt)**	**Total Production, Estimated (Mt)**	**Difference (Mt)**	**Difference (%)**
2000	245,600	245,300	300	0.12
2001	385,000	384,500	500	0.13
2002	360,300	359,800	500	0.14
2003	308,750	308,250	500	0.16
2004	249,600	250,000	-400	-0.16

4.3 Fish Catch Downscale

There are three river basins in the area that Thailand, Laos, Cambodia and Vietnam conceal. These three basins and the total area of LMB countries were accounted for in the CaMa-Flood model. Here, a downscale approach was developed using the CaMa-Flood model, in which freshwater fish catch data is distributed among all the possible main river stems, tributaries, lakes, and floods inside of the LMB countries. The temporal period for this downscaling was set for 1979-2010, with a yearly timestep. This temporal period is limited by the years that the CaMa-Flood model was run (1979-2010) even though the fish catch data was available for a longer period (i.e., 1959 to 2017). However, it is important to note that older fish catch data could be less reliable given that there is a higher prevalence of gaps and inaccurate estimated data points.

One of the restrictions of the downscale carried out in this study was to eliminate grids with average water levels below 20 cm. This was achieved by using additional flood depth output data from CaMa-Flood. Water level was limited to above 20 cm since catch data is looking at large fish caught by large-scale fisheries and it would be inefficient for them to focus on shallow areas, thus distribution of fish in shallow waters would be inappropriate. The results obtained at 10 km grid scale (using Equation 4) are presented in three figures (Figure 6, Figure 7, and Figure 8).

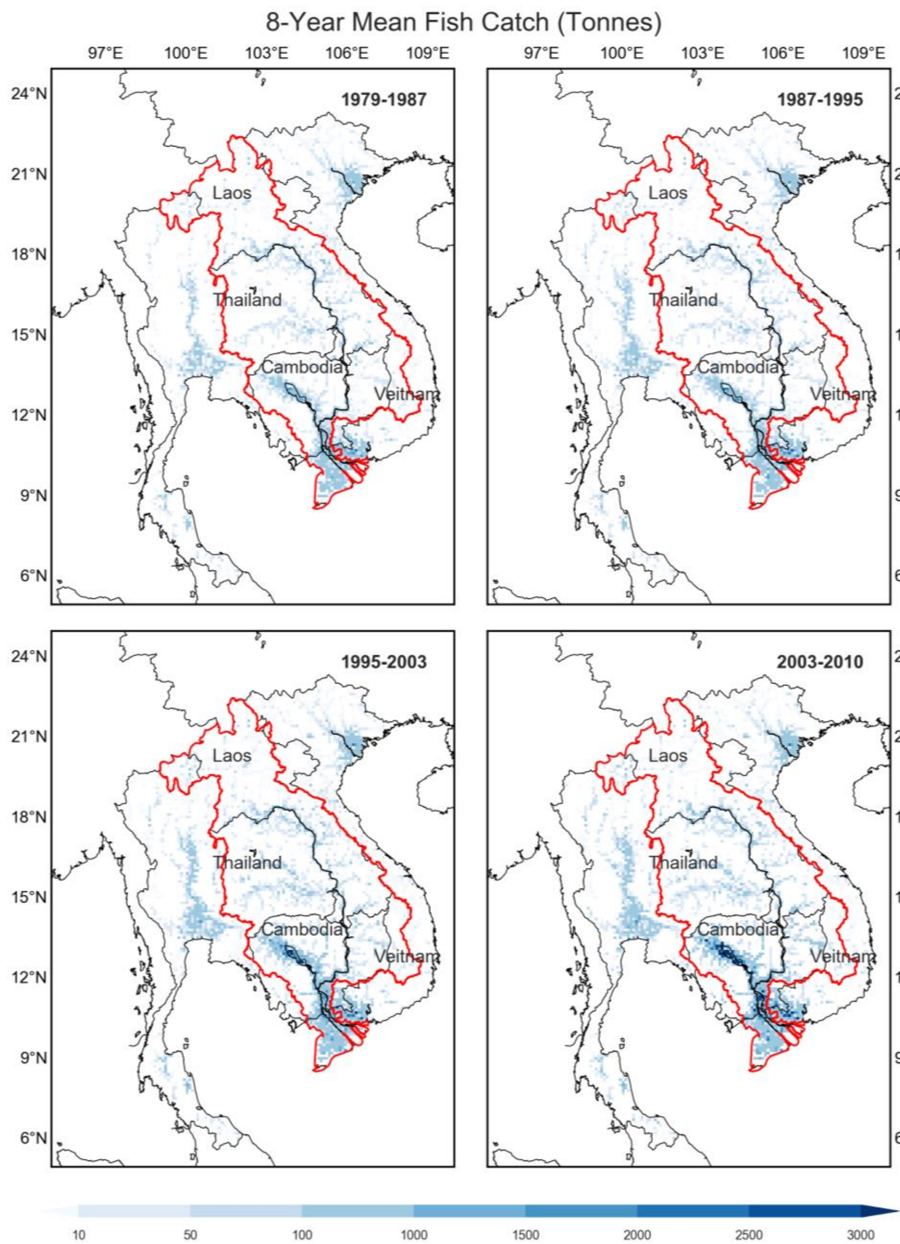

Figure 6: Fish catch distribution map as eight-year averages from 1979 to 2010. Freshwater fish catch data from FAO FishStat was distributed using to the 10 km grids using Equation 4 based on the derived relationship of catch and flooded area. Grids with flood depths lower than 20 cm where masked as the fish of interest are located in deeper waters. Flooded area and depths data are taken directly from the CaMa-Flood model results (Pokhrel, Shin, et al., 2018b). Country borders are delineated in black. LMB border is delineated in red. The higher concentrations of total fish catch are shown in dark blue, while lower concentrations are in light blue.

The total downscaled fish catch is presented in Figure 6. Firstly, the data shows a finite increase in total fish catch throughout the years. This is apparent at every spatial point presented in the maps, however, the areas of highest concentration (e.g. The Tonle Sap Lake) show the most obvious increase in fish catch. It is important to present these data as an average of multiple years since year to year flood variation is significant; that is, it is important to minimize the effect of possible bias during extremely wet and dry years.

One of the hypotheses behind the fish catch downscale relationship (Equation 4:) was that the higher the prevalence of flooded areas, the higher the fish catch concentrations would be detected in the LMB. To test this hypothesis, four dry (Figure 7) and four wet (Figure 8) years were mapped.

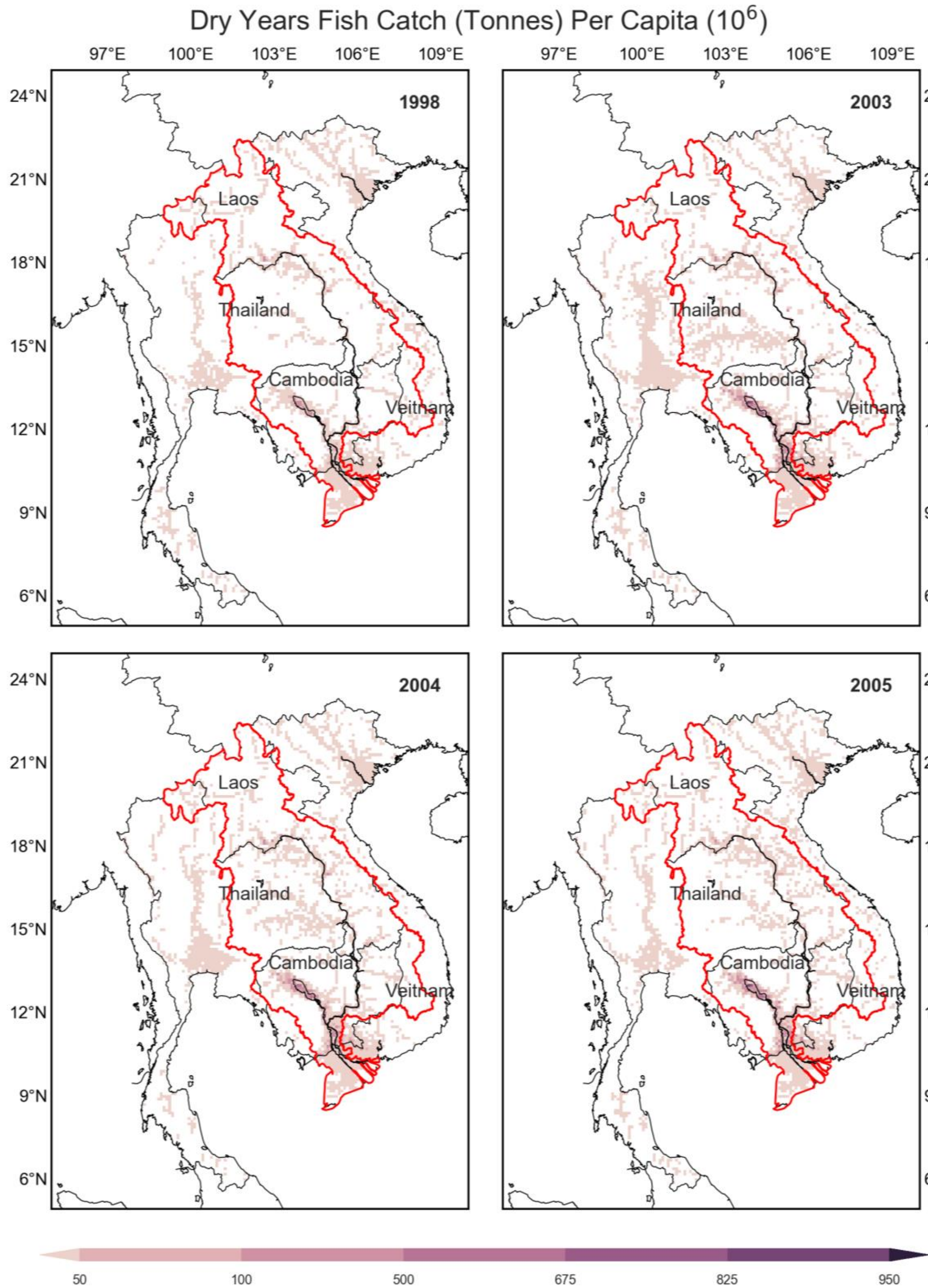

Figure 7: Fish catch per capita distribution on four dry years: 1998, 2003, 2004, and 2005. Catch per capita distribution is used to normalize the effect of fish catch increases due to population demands. Population data is retrieved from IMF (October 9th, 2018).

The main driver of fish catch increase throughout the years is population growth, so, in an effort to normalize yearly data this study divides the observed annual catch data by the population for the corresponding year. This allows for downscaling of fish catch per capita and a more appropriate catch comparison with hydrology by eliminating a strong driver of fish catch fluctuations (i.e. population growth). The temporal period for these downscaling is 1986 to 2010, which is determined by the availability of population data reported by the International Monetary Fund (IMF). The downscaling of Figure 7 and Figure 8 was carried out with fish catch per capita data instead of total fish catch data which can be seen in Figure 6.

The dry years chosen for Figure 7 are 1998, 2003, 2004, and 2005. Earlier years are not included in these maps (Figure 7 & Figure 8) because fish catch data had a considerable increase at the end of the 20th century due to the technological advances , thus prior years do not demonstrate a fair comparison. This provides an alternative way of reducing the influence of external variables to hydrology. The years chosen for Figure 8 are 2000, 2001, 2006, and 2007. All of these eight years fall in a span of nine years (1998-2007) where external variables do not play a major role in affecting the catch dynamics due to the Asian financial crisis ending in 1998. After this crisis was subsided, no major technological fishing advances are reported, and population growth is no longer an issue.

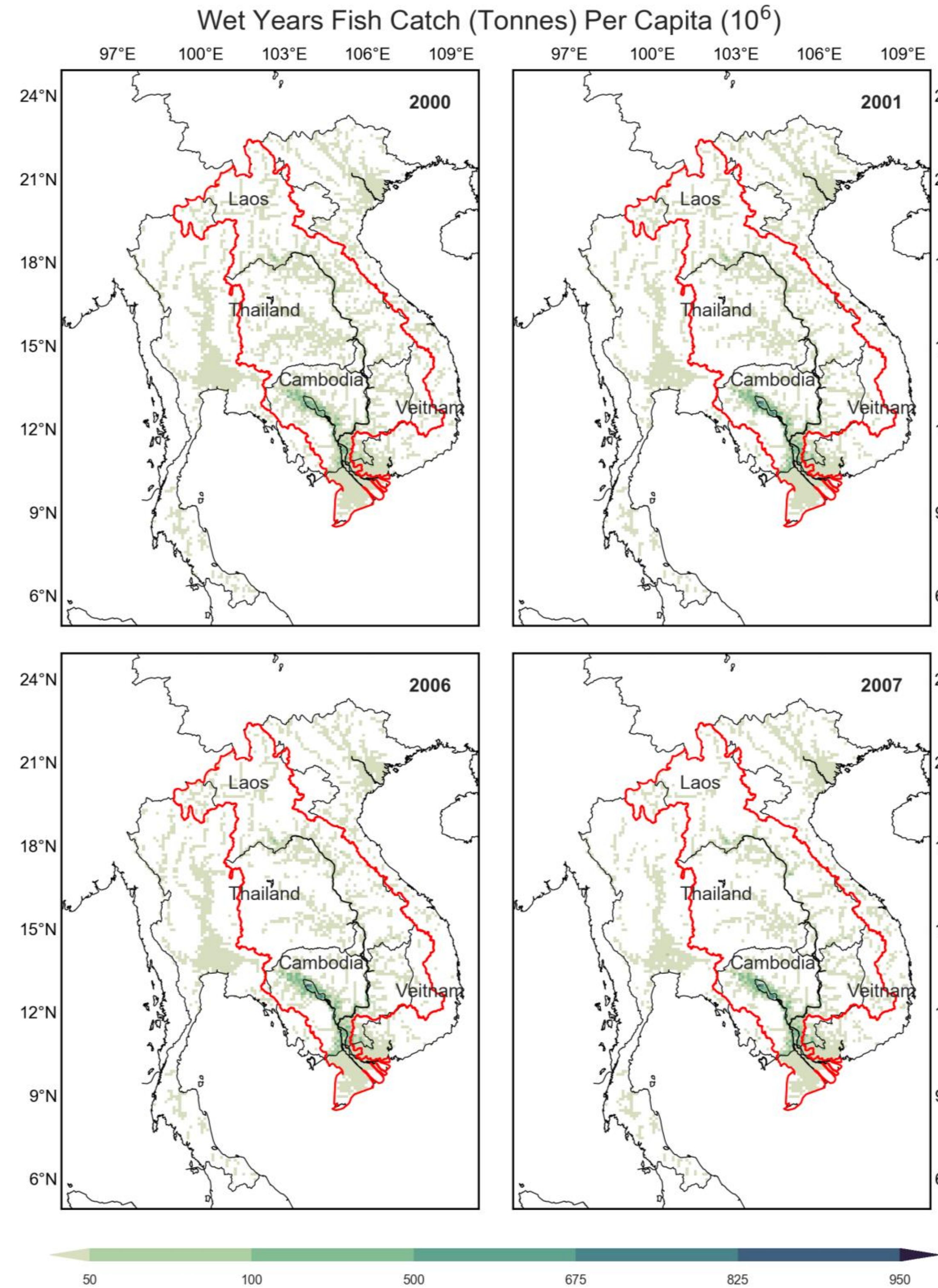

Figure 8: Fish catch per capita distribution on four wet years: 2000, 2001, 2006, and 2007. Catch per capita distribution is used to normalize the effect of fish catch increases due to population demands. Population data is retrieved from IMF (October 9th 2018).

Figure 8 shows a denser distribution of fish in the LMB and the outer basin streams compared to that of the dry years catch distribution map (Figure 7). This is especially noticeable between latitude 12°N and 13°N in Thailand, and inside of the LMB with the exception of the Tonle Sap Lake. The unnoticeable differences in the Tonle Sap are expected as this body of water is a suitable place for fishing for a wide range of water levels because of its large size and its ability to become full up to a sufficient amount to host plenty of fish every year. An important distinction is that for the years closer to present time (e.g. 2007 versus 2005) variations are harder to come by as compared to past years (e.g. 1998 versus 2000). Overall, the fish catch per capita appears to be strongly affected by the presence or lack of flooded areas in the LMB.

As previously established, dam construction in the Mekong River and its tributaries have generally reduced the peak of the flood pulse and normalized the seasonal variation of the hydrograph (Kummu & Sarkkula, 2008; Lauri et al., 2012a; Pokhrel, Shin, et al., 2018a). An additional effect of dam construction is the reduction of discharge, which consequently affects the flooded areas in the basin. In fact, in a recent study (Pokhrel, Shin, et al., 2018a), the effects of reduced discharge in the LMB were computed using hypothetical scenarios were discharge was restricted to an upstream point in the LMB. These results are next used to calculate potential fish catch losses from the response variability of flooded areas.

4.4 Fish Catch Loss

The 2018 study by Pokhrel and colleagues presents five scenarios in which water flow is restricted at the (marker) in the map below. The flow percent flow restrictions range from 10 to 50% at a 10% step count. The resulting hydrological responses at each scenario are modeled using the CaMa-Flood hydrological model.

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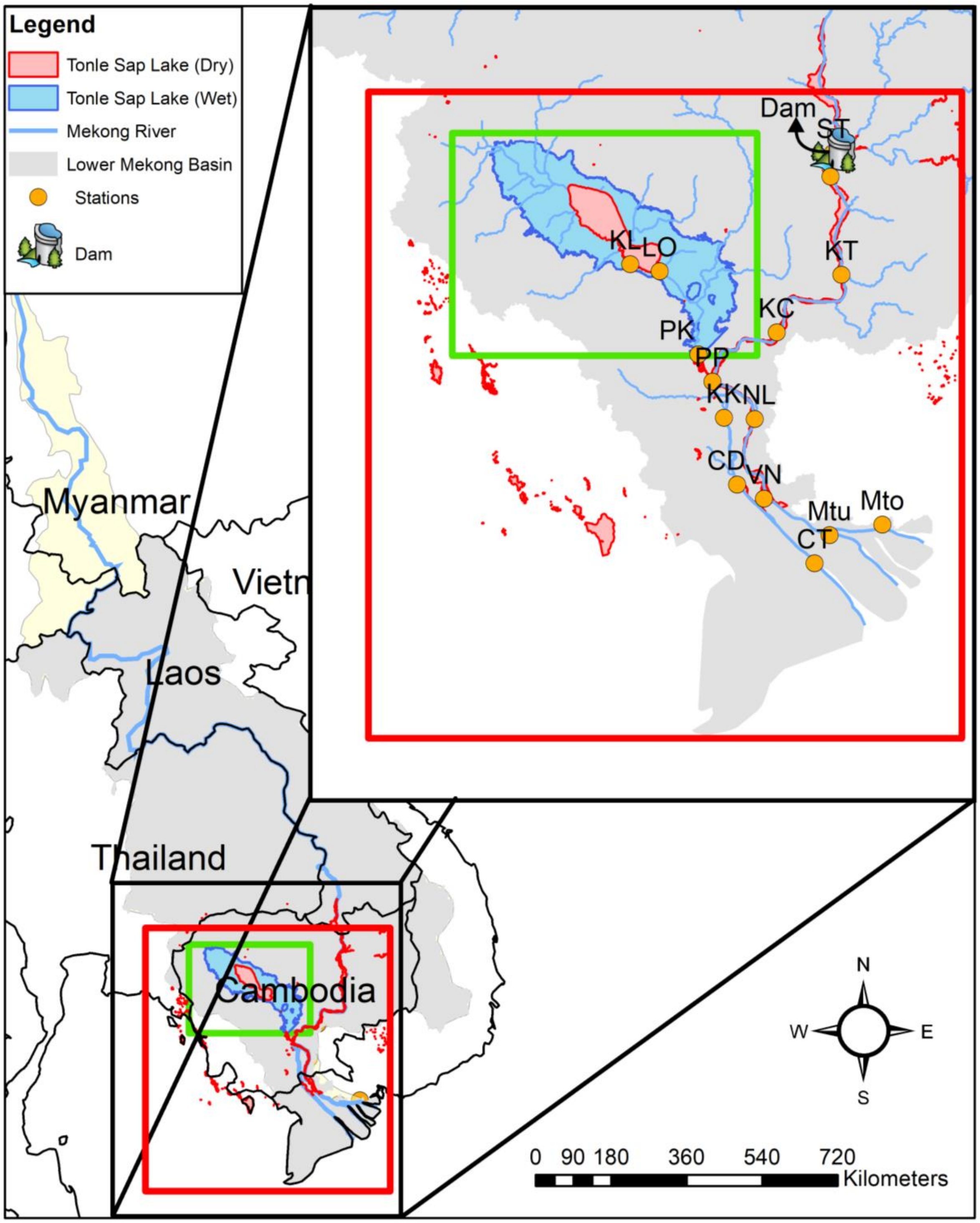

Figure 9: LMB CaMa-Flood simulation domain red box encloses the Lower Mekong sub-area, while green box encloses the Tonle Sap Lake area.

Figure 9 shows the study area used to calculate the hypothetical scenarios at hand. The mean monthly flooded area results of this specific area are used to calculate the potential fish catch loss at each scenario. This is computed employing Equation 4 to calculate the potential fish catch at each scenario. Then, the percent loss is calculated from the potential fish catch of the baseline scenario.

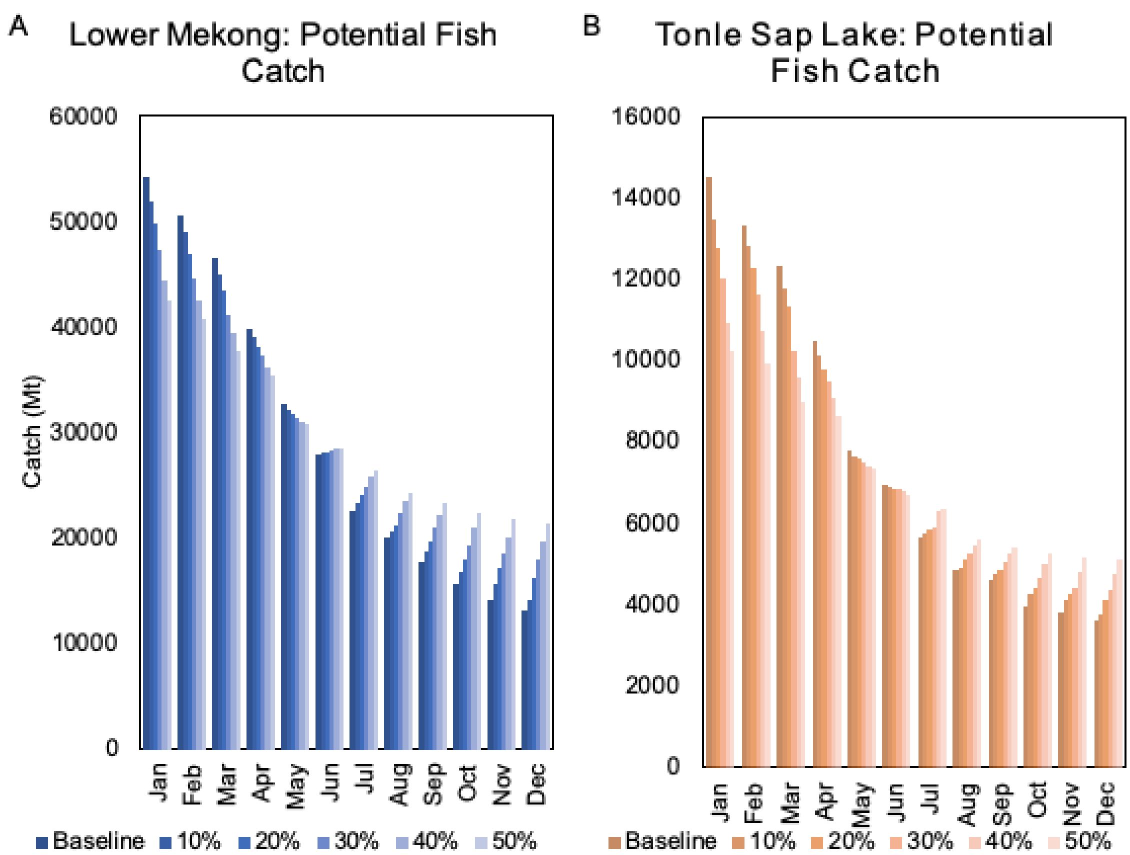

Figure 10: Estimated fish catch loss for the Lower Mekong Basin (A) and for the Tonle Sap Lake (B). Monthly calculated potential fish catch loss in the total Lower Mekong study area presented by Figure 9 is shown here. Every month in the bar graph has a different bar with a light blue tone representing each scenario (baseline to 50 % outflow restriction) (A). Monthly calculated potential fish catch loss in the Tonle Sap Lake shown in orange (B). The estimation is projected using Equation 4 on the CaMa-Flood flooded area results at each of the scenarios presented from (Pokhrel, Shin, et al., 2018a).

Reduction of seasonal discharge variability shows a clearly reduced but constant effect of the discharge that dams provide. This effect can be observed in **Figure 10**, as potential fish catch reduction is present during the months of January to May, and then we encounter a rise in potential fish catch from months June to December as we move down through the scenarios presented in both graphs shown above. Therefore, focusing on the Tonle Sap Lake, a yearly result fish catch response to the reduced discharge scenarios is summarized in **Table 3**.

Table 3: Tonle Sap Lake summary of estimated fish catch loss for each outflow restriction scenario presented above (Figure 10).

Scenario	Baseline	10%	20%	30%	40%	50%
Potential Catch (Mt)	91865	90305	89135	87374	86123	84741
% Loss	0.0	1.7	3.0	4.9	6.3	7.8
Total Loss (Mt)	0.0	1559	2730	4491	5742	7124

The modest scenario (10% outflow restriction) shows a 1.7% reduction of fish catch. Translating to fish catch in mega tonnes the result is a 1,559 Mt reduction of fish catch. At the 50% outflow restriction we obtain a 7.8% fish catch loss or 7,124 Mt reduction.

Undoubtedly, these hypothetical fish catch losses would be devastating to the livelihood of the surrounding LMB communities. But from literature, it is known that this is starting to occur, and a major dietary shift has already been taking place in the LMB countries (Orr et al., 2012b; Pittock et al., 2017). Therefore, the next question becomes, what are the consequences at a land use/land cover and water usage level? The following sections will cover results answering this question.

4.5 LMB Land Use Change

Land use changes have become easy to track with satellite data as a response to the amount of fish catch lost per capita in the past few years and an increase in the standard of living across social strata at LMB developing countries are experiencing. Looking at Figure 11 a two percent increase in cropland is reported from 1992 to 2015. We also observe a two percent rise in mosaic tree and shrub/herbaceous cover. Most of the land used to compensate for the rise in cropland and other land use types comes from tree cover, with a drop of four percent in 23 years. To put that into perspective, a one percent change in land use is equivalent to 60,600 km^2, meaning that a total of 242,400 km^2 of rainforest was lost in the past two decades.

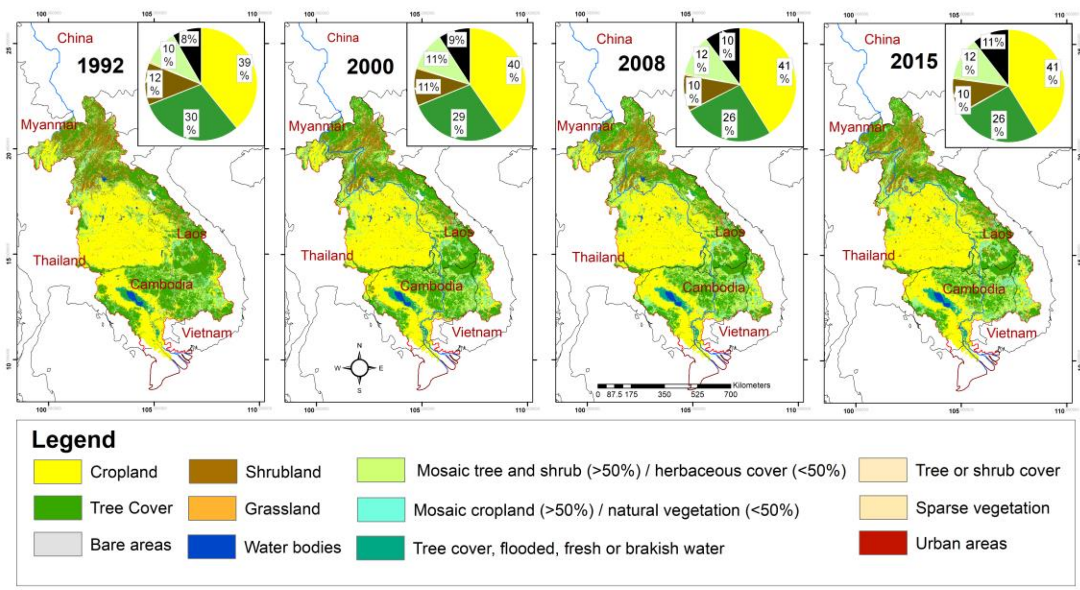

Figure 11: Land use and land cover types for 1992, 2000, 2008, and 2015. The embedded pie charts show the fraction of the main land cover types with matching color coding except for the black pieces which are a lumped representation of the minor land use types. The urban areas are excluded from the pie charts since they represent a negligible amount of area. Data source: European Space Agency-Climate Impact Initiative (ESA-CCI: https://www.esa-landcover-cci.org/, accessed on 27 January 2018).

The majority of the cropland is used to grow crops such as maize, soy, and rice. Maize and soy are primarily consumed by livestock. In the United States, for example, 87% of the maize yields are evenly split towards animal feed and ethanol production, leaving only 13% for human consumption (Ranum, Peña-Rosas, & Garcia-Casal, 2014). An FAO report calculated at least 50% of the grain we grow is fed to livestock (He & Food and Agriculture Organization of the United Nations, 2004). Regarding land use, this translates to 75% of all agricultural land, including crop and pasture, being dedicated to animal production (Foley et al., 2011).

As fish consumption per capita declines in the LMB countries, the loss of protein will eventually be replaced by land animal protein. Local production of meat in the LMB countries continues to rise (see Figure 12). This requires more feed and grassing lands for cows, pigs, chickens, and other animal products. Land use change requirements have been calculated for various scenarios and show a range of 16.5% to 55% of agricultural land increase in order to compensate for the loss of fish protein (Pittock et al., 2017). This accounts for a large amount by itself, however, this calculation fails to include the amount of feed that the livestock animals require to live, which would translate to even more land being used. Land use change not only compromises the ecosystems and biodiversity of the LMB but also rises the water footprint of the entire region as crops require irrigation efforts. The question now becomes, where will all this water come from to compensate for the fish protein loss? But before this can be answered, there is a need to look at the dynamics of meat and fish production and consumption to understand how dietary habits are changing over time for the countries of the LMB.

4.6 Meat Production and Consumption

Production of meat commodities in the LMB countries grew at a fast pace, presumably at similar rates from that of population and GDP in the past two decades. Figure 12 shows the difference between production and consumption of meat for the populations of Thailand, Cambodia, Vietnam, and Laos. As a whole, these four countries show a growth of production and consumption at similar rates.

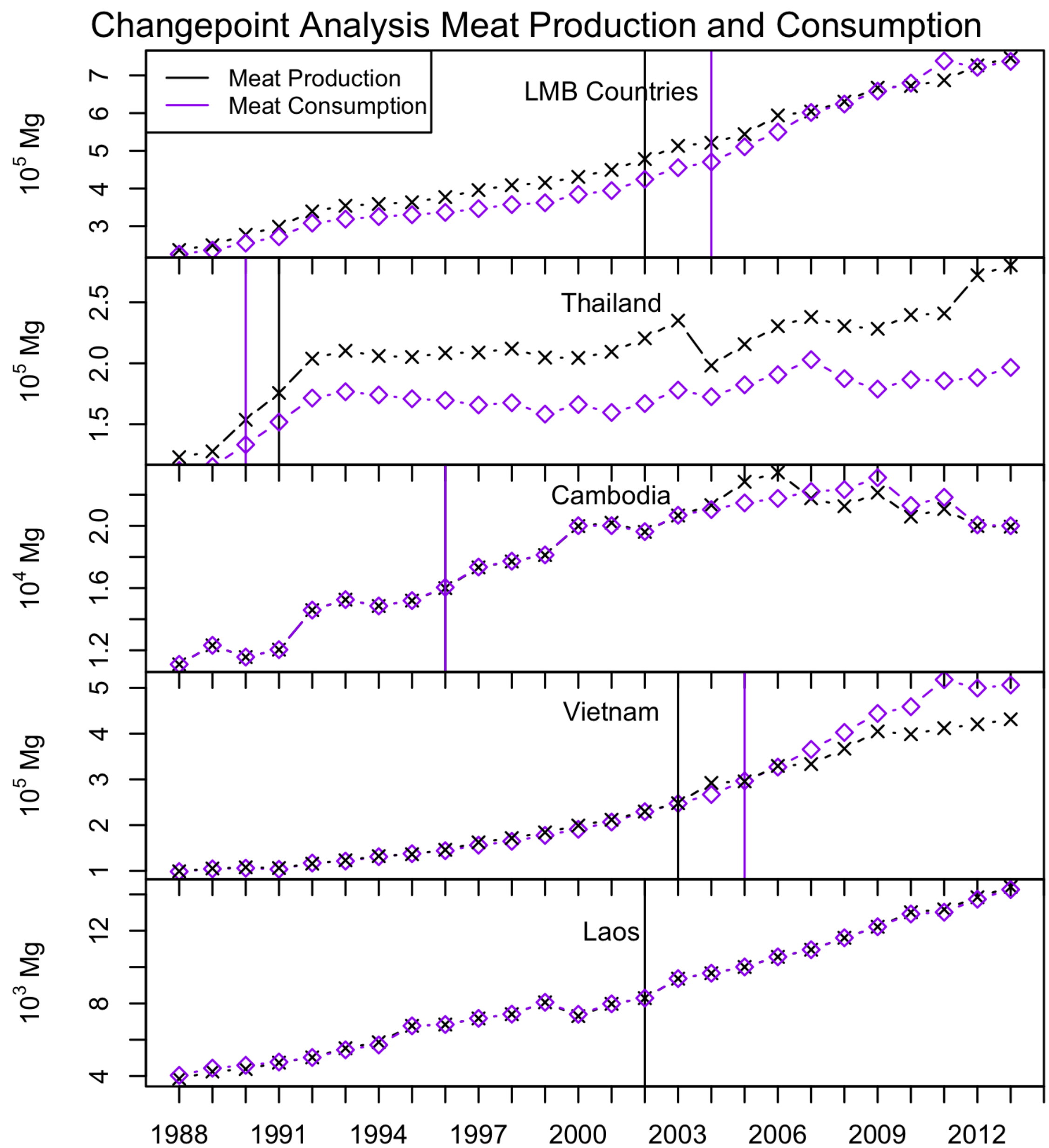

Figure 12: Time series comparing meat production and consumption between the years 1988 and 2013. The meat products (i.e., cattle, pig, sheep, goat, chicken, and horse). Additionally, a statistical mean changepoint is calculated and represented by the vertical lines on each graph (color coded accordingly). The consumption of the commodity at hand is taken directly from the supply data at FAOSTAT. The production of meat above is taken from the production data at FAOSTAT.

At the statistical changepoints for production and consumption, Thailand shows a growing gap between the production and consumption lines. In other words, Thailand produces much more meat than what its population consumes from 1992 to 2003. Thailand's growth is mainly due to the introduction of evaporative-cooling and poultry taking over the livestock market share in early years (1998-2001) rising from 30% to 53% (Costales, 2004). This is reflected on the LMB plot of Figure 12, where we see statistical changepoints calculated for production and consumption in years 2003 and 2005 respectively. Meaning the production and consumption growth of the LMB changes its pace between these two years.

As the meat industry kept growing in Thailand, it moved away from contract farming and it started implementing vertical integration to comply with the European importer's strong food safety and animal warfare requirements. Year 2004, the highly pathogenic avian influenza (HPAI), outbreaks and results in a ban by most importers of frozen broiler meat from Thailand, arguably their cash-cow livestock product (NaRanong, n.d.). The Thailand plot of Figure 12, shows sudden large drop in production from 2003 to 2004 narrowing the gap between production and consumption, which represents a reduced opportunity for meat exportation. This behavior is in congruence with the aforementioned HPAI outbreak. There is a slow recovery from this massive drop in production for the next decade and by the year 2013 the large gap between production and consumption forms again with production surpassing consumption significantly.

Cambodia in Figure 12 is characterized by their smaller meat production market at an order of magnitude less than that of Thailand and Vietnam. Meaning that changes in production and consumption will likely not influence the overall trend of the LMB a significant amount. However, it's important to highlight that Cambodia has nearly no gaps between production and consumption except for years 2005, 2006, 2008, and 2009. This is relevant because it explains the lack of data in terms of importation and exportation of meat commodities during the VWT analysis of section 4.8. The statistically calculated changepoint of Cambodia falls on year 1998, which is likely linked to the Asian financial crisis of 1997-1998, when the economic growth in general took a hit that year in the region (Costales, 2004).

A large contributor to the overall LMB countries' production and consumption of meat is Vietnam. The Vietnam plot of Figure 12 shows a slow rise in both production and consumption between the years of 1988 to 2003. We see equivalent levels of production and consumption during this period of time, suggesting little to none import or export of meat, more on this in the VWT analysis of section 4.8. In year 2003, Vietnam shows a statistically calculated point where production growth takes a hit. This is also explained by the HPAI outbreak and by additional low standards of food safety put forward by the Vietnamese meat industry. Such standards of food safety affect the population of Vietnam to this date with hundreds of cases of death by food born disease every year (Nguyen-Viet, Tuyet-Hanh, Unger, Dang-Xuan, & Grace, 2017).

On the flip side, in year 2005, following large economic growths, Vietnam displays a boom in meat consumption despite the local underproduction of the commodity (Hansen, 2018). This is corroborated by the statistically calculated changepoint of consumption which falls in 2005. Vietnam's plot at hand shows an increasing gap between consumption and production between the years 2007 and 2013, which must be explained by large meat importations.

Lastly, Laos plot in Figure 12, makes up a very small portion of the overall growth of meat of the LMB countries, with an underproduction difference of two orders of magnitude compared to that of Thailand and Vietnam. The consumption and production of meat for this small nation grows simultaneously and at the same pace. This trend will reflect the subtle imports and exports of meat in section 4.8. The calculated changepoints for this nation falls on 2002 for both production and consumption. This point is relevant because it shows a recuperation of growth after the significant production and consumption of meat drop in 1999-2000 likely correlated to the Asian financial crisis of 1997-1998 (Costales, 2004).

4.7 Fish Production and Consumption

A steady increase in the production of the fish commodity is seen for the LMB countries over time. Fish production and consumption variables moved closer together on years from 1988 to 1994. The consumption of the commodity at hand becomes greater by four-fold by the end of 2013. This phenomenon is quantified in the FAO databases due to fish catch being grossly underreported given that a big portion of catch comes from local family catch and single fishers inland. There is no accurate system at place for reporting fish catch, and only large fisheries report to FAO (Sverdrup-Jensen, 2002). This trend, however, is the main focus of interest in this section. Here, the discussion of fish production and consumption will be analyzed in more detail, not focusing solely on total values, hence, the following discussion based on Figure 13.

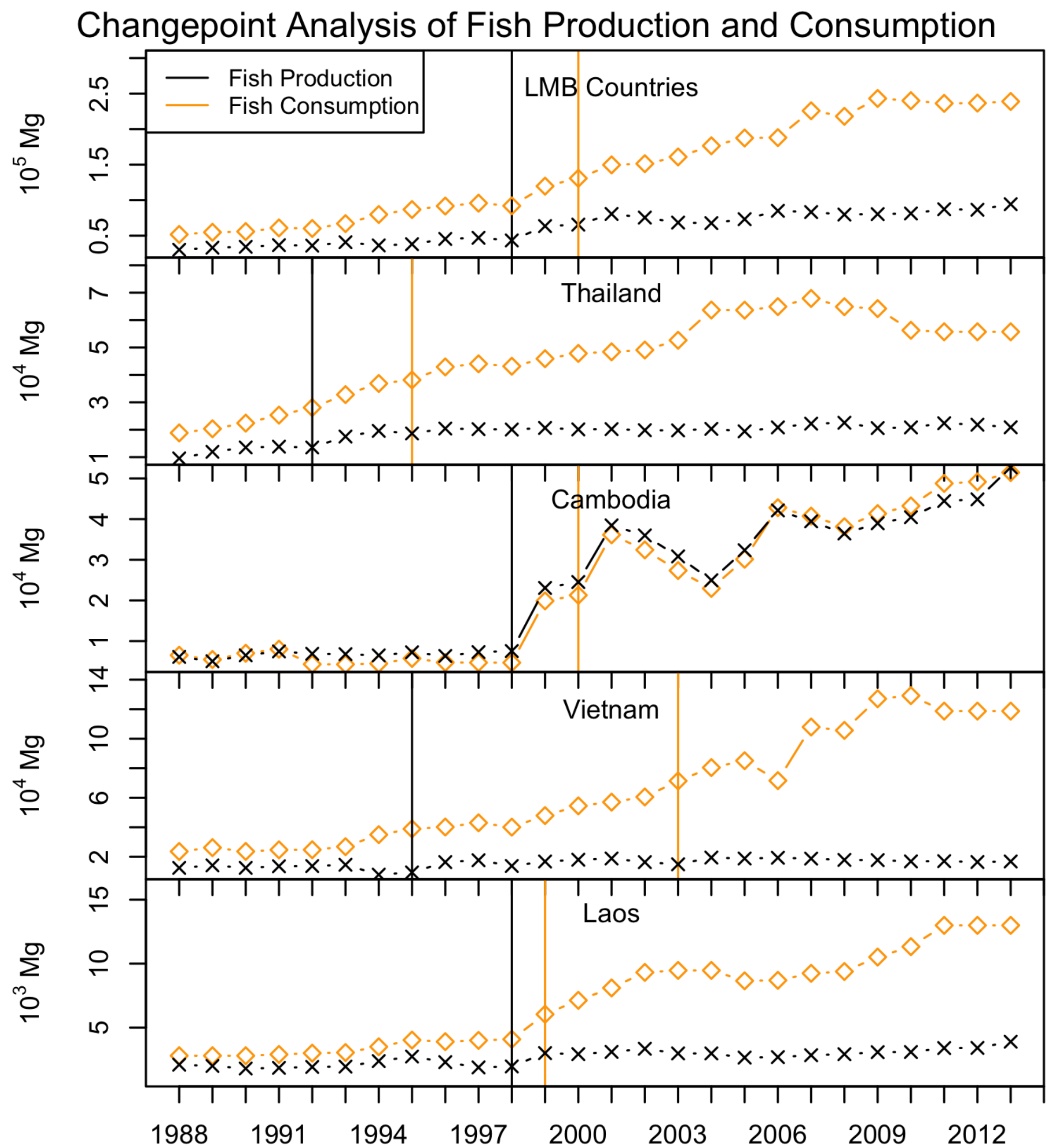

Figure 13: Time series comparing fish production and consumption between the years 1988 and 2013. The fish catch products are exclusively freshwater fish in order to isolate fish from rivers and lakes. Additionally, a statistical mean changepoint for each variable is calculated and represented by the vertical line on each graph. The consumption of fish is taken directly from the supply data at FAOSTAT. The production of fish above is taken from the catch data at FAOSTAT.

In 2005, Figure 13 shows a noticeable leveling of fish consumption. This can be attributed to three main catalyzers; First, the “Livestock Revolution”, a concept coined to explain the increase in livestock consumption from developing countries (C. Delgado, Rosegrant, Steinfeld, Ehui, & Courbois, n.d.). By the livestock revolution, as the economy of a country expands, its population gravitates towards an increased consumption of livestock products. This concept can be seen in Southeast Asia where a total meat consumption change from 4 to 16 million metric tons (1983-2020) was projected (C. Delgado et al., n.d.). Second, with accelerated construction of dams, 40-70% of fish species in the Mekong are now faced with incapacitated migration (Barlow et al., 2008), meaning that higher placement of dams leads to higher physical barriers presented for migratory species. Additionally, hydrological changes such as a decreased seasonal discharge variation pose a threat to fish catch distribution, which ultimately results in tampering of their reproductive cycles. Third, the exportation of fish is highly lucrative for large fisheries and preferred over selling for local consumption. In fact, 1.6 million tonnes of fish were exported in 2009 from Thailand alone (FAOSTAT, 2009).

Figure 13 demonstrates that initially Thailand has a higher consumption rate when compared to production rate of fish. However, in 1992 it shows decline in calculated statistical changepoint production, but from then on, fish production remains approximately the same until year 2012. The shift in 1992 occurs around the time efficient fishing technologies were emerging in Southeast Asia. In the year 1995 the calculated changepoint for consumption highlights a sudden change in rate of increase, which then a sustained increase in consumption is seen until the year 2007 when consumption stalls and drops a small amount. At this time, meat consumption (see Figure 12) starts to increase after three years of decreased production and consumption.

Shifting the focus to Cambodia, Figure 13 shows a low production and consumption of fish up to year 1998, when the Asian financial crisis was ending, and better fishing technology was adopted. At this statistical changepoint Cambodia's production begins to rise significantly and the consumption follows it very closely. From 2001 to 2013, fish consumption fluctuates alongside production starting with a changepoint detected near 2000 were a slow rise followed by a steep production rise is seen. Cambodia's fluctuation in production and consumption moving together is an indication that there is little to none import and export of freshwater fish catch. However, Tonle Sap Lake is also part of Cambodia's territory, which indicates that most of the fish catch originates from this body of water. Notably, a decrease in fish catch and consumption is observed in dry years, for example in 2003 and 2004 (see Figure 13). Congruently, wet years such as 2006 and 2007 (see Figure 13) are very productive in terms of fish catch.

Vietnam is similar to Thailand in regard to the consumption and production rates being close together for years 1988 to 1993. From this timepoint on, production drops even further while consumption of fish starts to quickly rise. In 1995, a changepoint for production is encountered, indicating a change in productivity. From there fish production recovers to the same level of the starting years and maintains those numbers through 2013. On the other hand, consumption steadily rises from 1995 to 2003 where the consumption changepoint occurs, which highlights a steeper climb in consumption. This is close to the year of the HPAI outbreak, where a rise in other sources of calories replacing that of poultry is expected in the Southeastern Asian diet.

Laos follows a similar trend to that of Thailand and Vietnam, but at a much lower scale. For the first ten years (1988-1998) the production and consumption of fish is an entire order of magnitude smaller than the rest of the LMB countries. This is expected, however, since it is the smallest country in the LMB. In 1998, when the Asian financial crisis ends, we get a calculated statistical changepoint on fish catch. Moving forward, the fish catch production continues to rise very slightly up to year 2013. In 1999, there is a consumption changepoint detected where a steep raise in fish consumption can be observed. Presumably this is due to an economic recuperation after the financial crisis.

Now, with a stronger understanding of the economical dynamics of the two main sources of protein for the LMB countries, meat and fish, the first analysis on the impact that these commodities have on water can be explored. As previously mentioned, every commodity has a specific water footprint, which varies depending on the production location and time. Since the water footprint of fish products is not comparable to that of livestock (green vs blue water), virtual water flows of meat products will be investigated exclusively. These are the main products that are progressively replacing fish protein calories in the LMB and will continue to do so in the foreseeable future.

4.8 Virtual Water Flows

The concept of virtual water trade shows the amount of water that flows from one point to the other in the form of a commodity at a given time period. The water allocated towards a specific commodity under this calculation includes production, manufacturing, processing, and transportation water usage attached to it. Understanding the amount of virtual water that flows in and out of nations is crucial when optimizing water use at regional and global or even local levels. A complete analysis of this concept includes the calculation of virtual water exports as well as virtual water imports. For the purpose of this study VWF of meat products including, cattle, pig, sheep, goat, chicken, and horse, are explored and summarized in Figure 14.

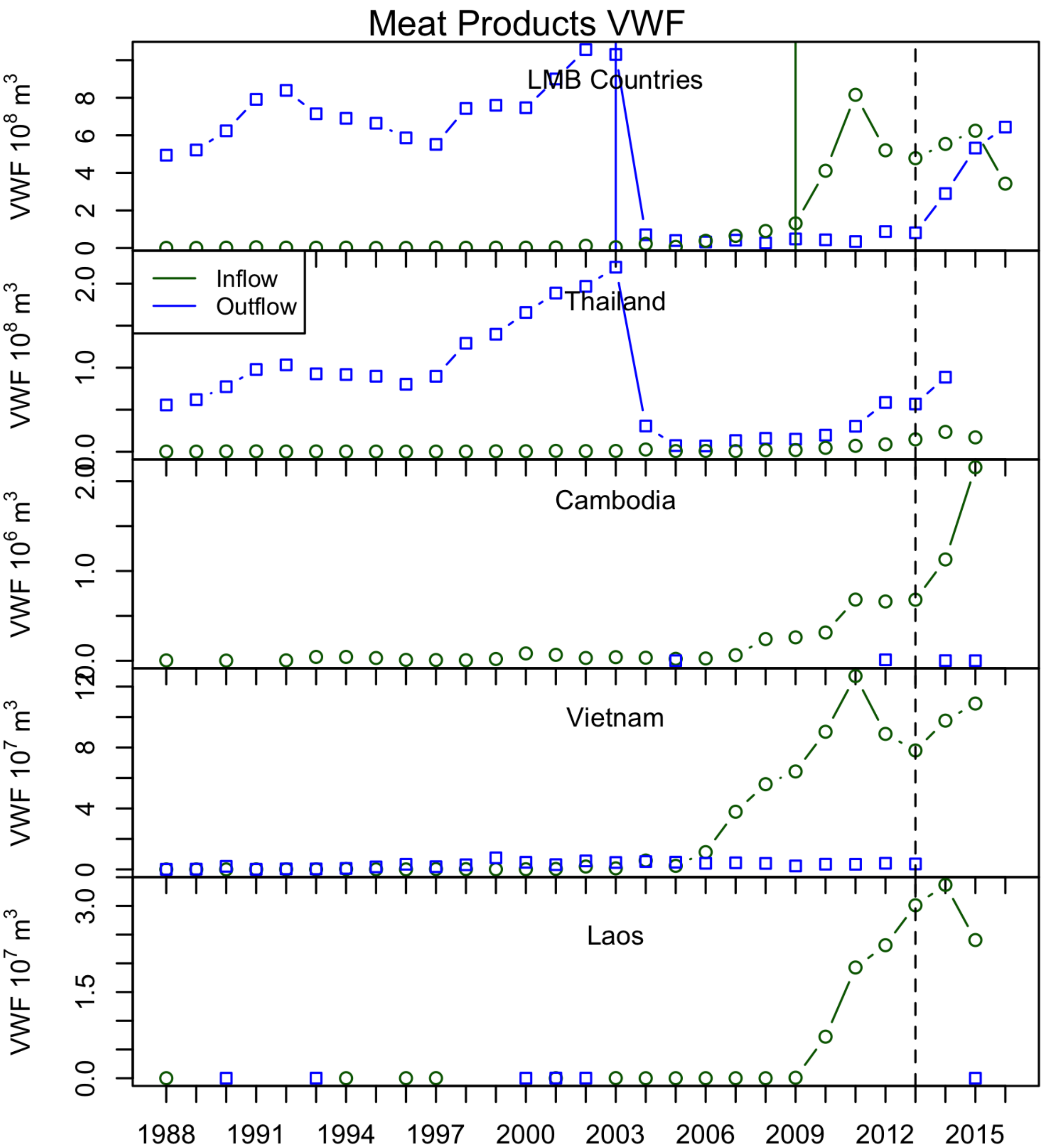

Figure 14: Time series shows the virtual water imports, ROW to LMB (green line), and virtual water exports, LMB to ROW (blue line), through the years. Data shown is derived from VWT calculations (VWC data retrieved from A.K. Chapagain & Hoekstra (2003), and trade data from FAOSTAT detailed trade matrices.

The LMB countries VWF exportations are mostly driven by the flow fluctuations of Thailand from year 1988 to around 2005, 2006 when Cambodia, Vietnam, and Laos start to contribute at an equal level on the import side of VWF (Figure 14). The above discussion on meat production and consumption explains why this is the case. In short, Thailand sits at higher production levels than that of consumption (see Figure 12). Ergo, the gap between production and consumption put forward by Thailand is equal to the amount of meat products available for exportation. The same process is true for the three smaller economies remaining, except that in their case, the consumption grows at a higher rate than production, thus, importations of meat are reported to those nations.

Changepoint statistical analyses where only carried out for the LMB countries section of Figure 14 because there are missing data points at varying time steps of the four individual countries. The statistically calculated changepoint corresponding to VWF exports fall in year 2003. This is the same year that Thailand's poultry industry takes a hit from the HPAI outburst and their chicken production and trade plummets. This point serves as independent confirmation for the validity of the observational data as well as the methodology behind the VWF calculations. The second calculated changepoint corresponds to VWF inflow, and it falls in the year 2009. This is in harmony with the raising spikes in meat consumption of Vietnam, Cambodia. We do observe a rise in Laos' VWF inflow for this same year, however, this is not in congruence with the reported production and consumption of meat products, where an equivalent production and consumption fluctuations is observed.

Thailand's inflow of virtual water demonstrates an expected near zero inflow of virtual water until year 2013. From this year on, data is blinded by the lack of meat production and consumption data (see vertical dotted line on Figure 14). Through assumptions, some of the meat products that are starting to be imported to Thailand are not part of their main production commodities. Meaning that the meat category most likely falls to sheep, goat, or horse. Year 2014 shows a recuperating rise virtual water outflow combined with a drop of virtual water inflow. This tells that that local production is picking up again and the country is able to sustain the local and global demand of meat products (more on this in section 4.9). The virtual water outflow of Thailand stands out the most, as it follows a strong increase in meat exportation up to year 2003, where it drops dramatically, only to be able to recover a decade later (2013). While this drop is in harmony with the decline in production (Figure 12), the production graph shows a quick recovery of three years. The VWF however, demonstrate a much harsher consequence. This is due to chicken being the most affected product, which was their main exportation product, and one of the most water resource intensive. The other products such as cattle and pig pick up due the lack of chicken production and thus, a fast recovery on the production side is seen.

As previously mentioned, literature on this phenomenon points to the HPAI outburst as the main cause for the drop in VWF (outflow from chicken). However, literature fails to explain why the recovery process lasts for ten years. Speculations about this struggle point to three possibilities; First, the loss business relationships with partnering nations; Second, extended contracts being formed between former partner nations and their replacing suppliers; And third, the inability of the meat industry to overcome the financial burden of losing such massive amounts of products and receiving nothing in return.

In the case of Cambodia an expected close to zero inflow of virtual water is shown in Figure 14 from years 1988 to 2007. From 2007 to 2016 an accelerated rate of meat importation is observed. This coincided with the inflow changepoint analysis calculated at year 2008 for the LMB countries confirming. In Figure 12 these are the same years (2007-2013) in which a gap is created putting consumption over production. Another point to highlight is that outflow data is only available for years 2005, 2011, 2014, and 2015. Years 2005 and 2011 are the only years where production exceed consumption of meat products (Figure 12). This, again, acts as independent validation for the methodology behind VWT calculations and the trade data retrieved.

Similarly, this is the case for Vietnam with a near-zero inflow and outflow reported until 2007, when their meat consumption increased at a faster rate than production, opening a gap of importation for meat products. The observed rise in meat imports also gently coincides with the changepoint calculation for virtual water inflow of the LMB. Vietnam's inflow peaks in year 2011 and then drops, which coincides with the years when we a gap between meat consumption and production gets smaller for Vietnam. As Vietnam's production never exceeds that of consumption, a significant amount of outflow is then not reported between 1988 and 2013. This instills confidence on the reliability of Vietnam's meat trade data.

Finally, Laos presents sparse data for its outflow of virtual data. Years 1990, 1993, 2000, 2001, 2002 and 2015 are the only years with reported exportation of meet. None of these years stand out when looking at Figure 12, in fact, all of the production markers fall inside of the consumption markers. Admittedly, the years with reported outflow in Figure 14 have very small values, so it's still possible that the difference between production and consumption is just outside of the naked eye inspection limits. Laos' inflow, on the flip side, shows very small amounts of inflow until year 2009, when the inflow of virtual water seems to skyrocket by triplicating its inflow. It is important to keep in mind, however, that at the scale that Laos operates this is still a small change compared to that of any of the other three nations. Nonetheless, in comparison to itself in the production and consumption side of the graph this is significant and the reliability of the trade data for this nation becomes questionable.

To further investigate the VWT of meat commodities in the LMB countries, a VWT network is constructed and presented in the next section. This will highlight the trade dynamics of the LMB countries with the rest of the world. It will provide a deeper understanding of the effects of a dietary shift of the four nations at focus onto the rest of the world. Ultimately, the response of the LMB countries that progressively rely less on the Mekong Basin's ecosystem as a source of nutrition will be visualized.

4.9 Virtual Water Trade Network

The following VWT circle plots on Figure 15 represent the magnitude and direction of either exported or imported virtual water from meat products (e.g., cattle, chicken, pork).

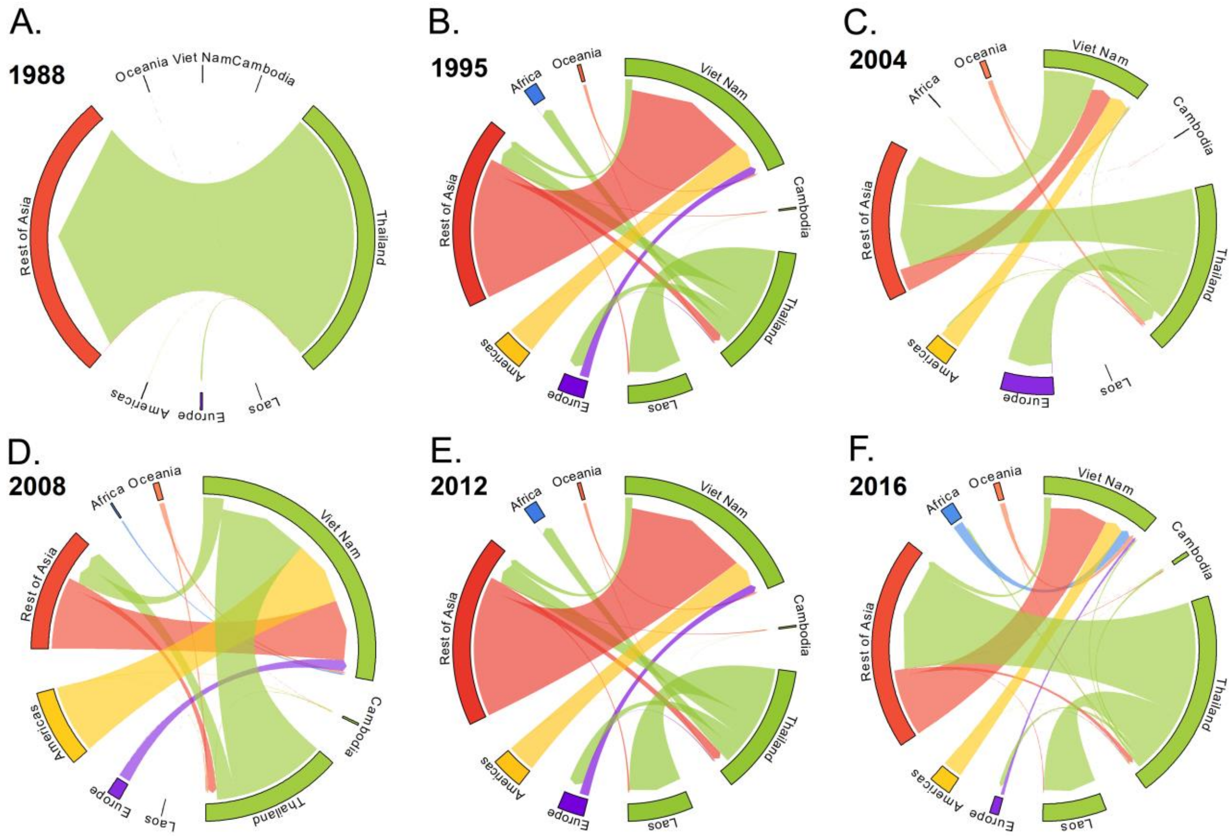

Figure 15. VWT flows of animal-based protein products (cattle, pig, sheep, goat, chicken, and horse) between 1988 and 2016. The width of each band represents quantity of water in ($\boldsymbol{km^3}$) traded. The LMB basin countries are represented with green bands while the Rest of Asia and other continental regions have individual colors. The circular figure areas are scales to the total area traded. Data retrieved from A.K. Chapagain and Hoekstra (2003) and FAOSTAT detailed trade matrices. This figure was created using the network visualization tool, Circos (Krzywinski et al., 2009).

Circle plot A shows that the majority of the virtual water outflow was carried out by Thailand (green) and was driven towards the Rest of Asia (red) (i.e., the remaining Asian countries excluding Thailand, Cambodia, Vietnam, and Laos) in 1988. From circle A it seems as though none of the other regions trade meat products. However, due to the nature of these plots, the thickness of the arrows represents the shear amount of flow carried out compared to that of the regions. In other words, Thailand's export was so large compared to that of the other regions, that the trade among the rest of the world becomes negligible, thus, very narrow. Circles A, C, F show noticeably large interactions between Thailand and the Rest of Asia, this is because throughout history, Japan has been the main recipient of chicken/poultry from Thailand (Costales, 2004).

Moving forward to year 1995, circle plot B, shows a dramatic increase in intercontinental virtual water flows when Vietnam becomes a large importer from the Rest of Asia, the Americas, and Europe. This doesn't mean Thailand reduced its exports to Japan, it merely alludes that the other regions with thicker export bands became larger virtual water exporters than Thailand. In 2004 (circle C), one year after the aforementioned HPAI outbreak, Thailand's chicken export reduced to such a significant extent that its virtual water export is on par to that of Vietnam.

By the year 2008, we see Thailand beginning to recover by starting to export their meat products to neighboring nations that are part of the LMB. This finally explains why Thailand in Figure 14 doesn't show any signs of recovery while Figure 12 still shows high levels of production. Vietnams increase in meat consumption is highlighted in year Circle D as it increases its virtual water inflow amounts becoming the highest LMB country importer of meat. Year 2012, Circle E, we see the first noticeable interaction of Laos by becoming Thailand's largest virtual water importer. Thailand also shows signs of economic recovery by branching out its trade to countries regions like Africa and Europe. The last circle plot of Figure 15, circle F, shows Thailand full trading recovery. Though, not noticeable in the circle, Thailand in fact returned to exporting levels almost comparable to those of year 1988. More on this in section 4.10.

4.10 Regional Water Savings

The amount of virtual water exported on imported to a region is an important marker to explore. However, when thinking about constructing a trade system that is characterized by water use efficiency, we need to explore water savings (WS). As mentioned before, WS is the difference between the total VWT outflow minus the total VWT inflow. This calculation can be carried out at a global, regional, nation, or even sub-national level. For the purpose of this study we conduct a regional water savings (RWS) analysis and present the results in Figure 16 and Table 4.

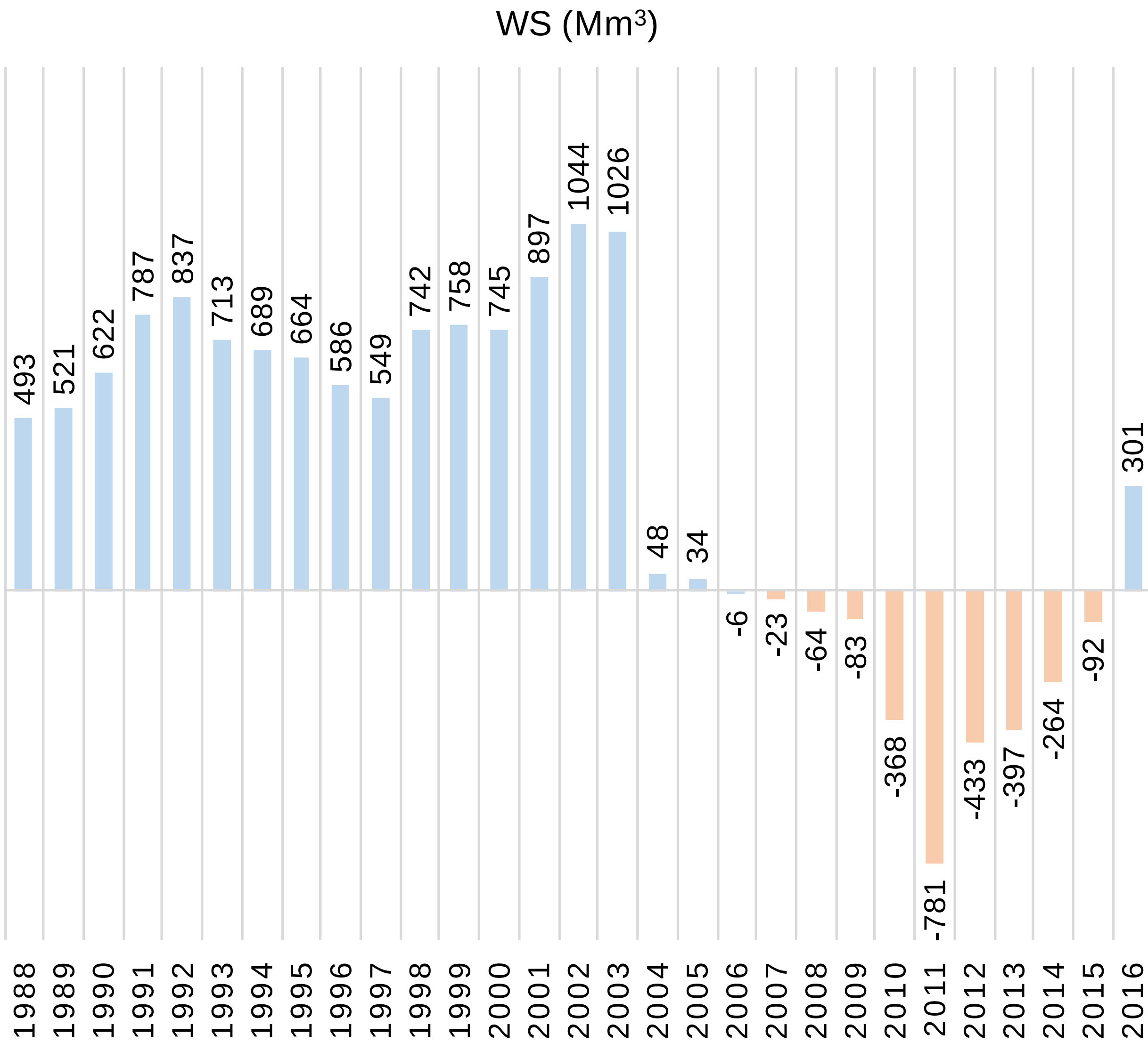

Figure 16: Water savings time series showing the difference between VWT outflow and VWT inflow using data from VWT network results.

The WS timeseries, Figure 16, shows a drastic turn of events through the years. Between the years 1988 and 2003, the LMB countries were collectively virtual water outflow dominant. The peak outflow in this period of time was 1044 Mm^3/year. Most of the measurable virtual water outflow can be attributed to Thailand's massive chicken exportation. But the virtual water flow balance presented in Figure 16 reaches those high levels because there are barely no virtual water flow imports from the other LMB nations to counterbalance the scale. Both of these phenomena translate to massive amounts of negative regional water savings for the Mekong (i.e., much water is used in the Mekong instead of saved through importation). Upon the previously discussed HPAI outbreak, the tables turn in 2004. In fact, between the years of 2007 and 2015, the LMB nations experience positive RWS collectively. Their WS peak in the year 2011, probably due to the massive amounts of meat product imports to Vietnam. And while, Thailand still exports virtual water, in the form of meat, it does so to other LMB nations such as Vietnam and Laos during this period of time. In 2016, Thailand seems to recover its previous trade relationships and begins driving large exportations of virtual water to the ROW turning the tables on RWS once again.

Table 4: Summary of water savings results in Mm^3/year.

Year	**VWT, Local**	**VWT, Inflow**	**VWT, Outflow**	**WS**
1988	0	1	494	493
1989	0	1	522	521
1990	0	2	624	622
1991	0	4	791	787
1992	0	2	839	837
1993	0	1	715	713
1994	0	2	691	689
1995	0	1	664	664
1996	0	1	586	586
1997	0	2	552	549
1998	0	1	743	742
1999	0	2	760	758

Table 4 (cont'd)				
2000	1	2	747	745
2001	1	3	900	897
2002	2	12	1056	1044
2003	3	4	1030	1026
2004	18	22	71	48
2005	3	6	40	34
2006	28	38	32	-6
2007	100	65	42	-23
2008	128	91	27	-64
2009	86	131	48	-83
2010	115	411	44	-368
2011	190	816	34	-781
2012	226	520	88	-433
2013	291	478	81	-397
2014	330	554	290	-264
2015	269	624	532	-92
2016	338	343	644	301

A scenario like that of year 2011 in Table 4 is probably the ideal scenario for the LMB in terms of water usage. Meat production represents a large water footprint on a region relative to other means of production and food security. The problem with making a broad declaration like this one is that RWS doesn't tell us the big picture. The end goal is to reduce water footprint in the regions with water scarcity problems. So, we need to analyze global water savings (GWS) and water scarcity indices to do this, which falls outside of the scope for this thesis. Nonetheless, RWS points in the right direction of action. The amount of water needed to produce enough meat to sustain the LMB can be easily achieved at a balanced of inflow to outflow ratio, like that of year 2014 which still presents 92 Mm^3/year of positive RWS. From the limited information that RWS provides, striving for the maximum amount of positive RWS without affecting the economy (i.e., small virtual water outflows) is the most sensible thing to do.

5. CONCLUDING REMARKS

The thesis studies two overarching topics, the first is an exploration of fish catch dynamics in the LMB and the second is a construction of the VWT system relating to meat products from the LMB countries. The developed relationship between fish catch and flooded area suggests that there is a correlation between flood and fish catch upon isolating fish catch years variation for dry and we years individually. This relationship is studied by isolating both variables as best as possible by ridding the trend of population growth. Ultimately, the overall trend and literature point to a significant transition of protein source from fish to land-based meat products. This opens the door to an extensive analysis in meat production and consumption as well as fish production and consumption. Plenty of conclusions can be drawn from these results, however, the most important being that the so-called livestock revolution, which comes with the growth of the LMB developing economies, already causes measurable effects on the local ecosystem. This leads to the secondary set of analyses.

To test for the extent of the impact from the studied dietary shift, land use is mapped for four separate years from 1992 o 2016 with 8 years between each plot. From these maps, the results show major shifts from tree cover and other native species to cropland. This is a direct confirmation of population and economical growth. Literature points at livestock production as most of the crops grown are meant for animal feed. The water resources impact of the dietary shift is further studied by constructing various VWT networks from 1988 to 2016. Six main VWT network plots are presented in along with a discussion on each one, which explain the LMB countries trading dynamics with the ROW. This leads to a RWS short calculation and discussion, which sheds some light on the topic of constructing a more efficient trading network. Conclusively, it is in the LMB's interest to import most of its meat products as this would be beneficial to the ecosystem by saving the precious resource that is water. However, two problems arise from this conclusion. First, this does not consider the economic ramifications of exclusively importing these products. Second, the water savings can’t be echoed at a global scale. Future studies should focus on these issues in order to further the discussion and aid policy makers in making the right decisions in the interest of the environment and the economy.

APPENDIX

APPENDIX

A.1. Fish Catch Data and CaMa-Flood Results

Table 5: Yearly fish catch data from FAO FishStat and flooded area from CaMa-Flood modeling results (Pokhrel, Shin, et al., 2018a).

Year	Country	Catch (tonnes)	Population (millions)	Flooded Area (m^2)
1986	Cambodia	64181	7.99	7449842.937
1987	Cambodia	62154	8.228	5743618.036
1988	Cambodia	61155	8.467	5367193.871
1989	Cambodia	50477	8.724	5978190.038
1990	Cambodia	65081	9.009	7591378.873
1991	Cambodia	74672	9.324	7461522.237
1992	Cambodia	68881	9.659	5466623.661
1993	Cambodia	67880	10.007	5601417.416
1994	Cambodia	64960	10.43	8023884.851
1995	Cambodia	72420	10.769	7306399.47
1996	Cambodia	63440	11.091	7736345.108
1997	Cambodia	72900	11.396	8433418.349
1998	Cambodia	75600	11.685	4715221.418
1999	Cambodia	230700	11.96	8688194.163
2000	Cambodia	245300	12.223	10836736.17
2001	Cambodia	384500	12.473	9042568.737
2002	Cambodia	359800	12.709	7871865.977

Table 5 (cont'd)

2003	Cambodia	308250	12.934	5899931.059
2004	Cambodia	249600	13.149	6713935.735
2005	Cambodia	323500	13.356	5642441.882
2006	Cambodia	421400	13.555	7734468.114
2007	Cambodia	394500	13.747	7314523.61
2008	Cambodia	364600	13.941	6750178.82
2009	Cambodia	389700	14.144	5502564.432
2010	Cambodia	404600	14.365	3394043.589
1986	Laos	21000	3.618	773557.3388
1987	Laos	22000	3.721	639985.6546
1988	Laos	21000	3.828	424875.4926
1989	Laos	20000	3.938	698878.435
1990	Laos	18000	4.087	971051.2318
1991	Laos	18500	4.208	824015.0301
1992	Laos	16740	4.331	533118.4677
1993	Laos	17000	4.454	634470.5043
1994	Laos	20600	4.575	879182.4432
1995	Laos	23370	4.691	856762.2944
1996	Laos	19500	4.801	868674.2496
1997	Laos	16057	4.907	835684.809
1998	Laos	16642	4.991	460912.5461
1999	Laos	25541	5.076	973953.1085

Table 5 (cont'd)

2000	Laos	24850	5.162	1142034.91
2001	Laos	26350	5.25	1048796.202
2002	Laos	28440	5.339	951912.8518
2003	Laos	25300	5.43	543321.3001
2004	Laos	25300	5.522	692934.2924
2005	Laos	22560	5.621	774996.377
2006	Laos	22825	5.702	828989.5548
2007	Laos	24110	5.784	682768.2364
2008	Laos	24700	5.867	796932.0428
2009	Laos	25950	5.952	382228.6704
2010	Laos	26000	6.038	394575.0301
1986	Thailand	44199	52.97	2110210.497
1987	Thailand	31860	53.87	1483368.398
1988	Thailand	44304	54.96	2888019.589
1989	Thailand	47440	55.29	2258039.379
1990	Thailand	47316	56.303	2172420.281
1991	Thailand	37012	56.961	1841197.065
1992	Thailand	37054	57.789	1360666.753
1993	Thailand	52763	58.096	1508179.352
1994	Thailand	64587	58.797	2597340.804
1995	Thailand	60272	59.47	2850923.489
1996	Thailand	105726	60.077	2934031.101

Table 5 (cont'd)

1997	Thailand	108551	60.677	2282071.275
1998	Thailand	70011	61.277	1342449.494
1999	Thailand	59376	61.849	2639742.633
2000	Thailand	64241	62.321	4087454.618
2001	Thailand	69000	62.908	3353677.05
2002	Thailand	70300	63.488	2911686.213
2003	Thailand	75171	64.05	3288702.276
2004	Thailand	72500	64.603	2777687.513
2005	Thailand	56310	65.152	1712026.813
2006	Thailand	129200	65.632	2891868.983
2007	Thailand	159800	66.094	2506614.072
2008	Thailand	59700	66.533	1900246.74
2009	Thailand	50418	66.953	1160043.846
2010	Thailand	71254	67.341	952472.5536
1986	Vietnam	119061	60.92	6460020.44
1987	Vietnam	127914	62.3	5510192.656
1988	Vietnam	124736	63.5	5454192.075
1989	Vietnam	141757	64.774	5660954.278
1990	Vietnam	124915	66.017	6350668.234
1991	Vietnam	135822	67.242	6133982.851
1992	Vietnam	137154	68.45	5410931.14
1993	Vietnam	145839	69.645	5501023.083

Table 5 (cont'd)

1994	Vietnam	79087	70.825	6517556.834
1995	Vietnam	94189	71.996	6080357.49
1996	Vietnam	163936	73.157	6621183.257
1997	Vietnam	176589	74.307	6765012.73
1998	Vietnam	137800	75.456	5318329.523
1999	Vietnam	168107	76.597	6985115.16
2000	Vietnam	180000	77.635	7467048.856
2001	Vietnam	188542	78.686	7062966.645
2002	Vietnam	163615	79.727	6289337.431
2003	Vietnam	148959	80.899	5966124.477
2004	Vietnam	194621	82.032	5875215.785
2005	Vietnam	188400	82.392	5457452.756
2006	Vietnam	193300	83.311	6153429.565
2007	Vietnam	187800	84.219	6231355.705
2008	Vietnam	178700	85.119	6147961.547
2009	Vietnam	177400	86.025	5263087.379
2010	Vietnam	168855	86.933	4160992.987

A.2. Nationwide Population Data

Table 6: Population (millions) data from IMF, retrieved October 9th, 2018.

Year	Cambodia	Laos	Thailand	Vietnam
1986	25.707	3.618	52.97	60.92
1987	17.116	3.721	53.87	62.3
1988	32.608	3.828	54.96	63.5
1989	39.704	3.938	55.29	64.774
1990	99.833	4.087	56.303	66.017
1991	215.671	4.208	56.961	67.242
1992	252.491	4.331	57.789	68.45
1993	242.479	4.454	58.096	69.645
1994	265.056	4.575	58.797	70.825
1995	319.537	4.691	59.47	71.996
1996	316.188	4.801	60.077	73.157
1997	302.166	4.907	60.677	74.307
1998	267.864	4.991	61.277	75.456
1999	293.699	5.076	61.849	76.597
2000	299.982	5.162	62.321	77.635
2001	320.046	5.25	62.908	78.686
2002	337.501	5.339	63.488	79.727
2003	360.659	5.43	64.05	80.899
2004	405.629	5.522	64.603	82.032
2005	470.683	5.621	65.152	82.392

Table 6 (cont'd)

2006	536.151	5.702	65.632	83.311
2007	627.78	5.784	66.094	84.219
2008	741.855	5.867	66.533	85.119
2009	734.655	5.952	66.953	86.025
2010	781.912	6.038	67.341	86.933
2011	877.635	6.124	67.638	87.84
2012	945.702	6.213	67.956	88.809
2013	1,009.34	6.302	68.297	89.76
2014	1,090.71	6.393	68.657	90.728
2015	1,163.41	6.492	68.838	91.713
2016	1,270.48	6.585	68.981	92.691

A.3. Virtual Water Trade Network Results

Table 7: Virtual water trade network results summary at a regional level for years 1988, 1995, 2004, 2008, 2012, and 2016.

Year	Origin	Destination	Flow (km3)
1988	Americas	Thailand	**503150**
	Europe	Viet Nam	**2084**
		Cambodia	**41520**
		Thailand	**46056**
	Oceania	Thailand	**321993**
	Rest of Asia	Thailand	**715716**
	Thailand	Viet Nam	**24430**
		Laos	**11526**
		Rest of Asia	**494038938**
		Europe	**3699846**
1995	Africa	Cambodia	**15752**
	Americas	Viet Nam	**92584**
		Thailand	**654095**
	Europe	Thailand	**115698**
	Oceania	Viet Nam	**84735**
		Thailand	**321993**
	Rest of Asia	Viet Nam	**405396**
		Cambodia	**161564**

Table 7 (cont'd)

		Thailand	**506745**
	Thailand	Cambodia	**132549**
		Oceania	**69156**
		Americas	**795294**
		Europe	**55757025**
		Rest of Asia	**664301010**
		Africa	**12378924**
	Viet Nam	Rest of Asia	**3167932**
2004	Africa	Thailand	**5035**
	Americas	Viet Nam	**20805320**
		Thailand	**473509**
	Europe	Viet Nam	**39200**
		Cambodia	**7362**
		Thailand	**353430**
	Oceania	Viet Nam	**1143786**
		Cambodia	**241414**
		Thailand	**3929550**
	Rest of Asia	Viet Nam	**22228065**
		Cambodia	**63510**
		Thailand	**648432**
	Thailand	Viet Nam	**1970946**
		Laos	**7039**

Table 7 (cont'd)

		Cambodia	**28815**
		Thailand	**16165215**
		Americas	**1716156**
		Europe	**47896293**
		Rest of Asia	**70579461**
		Africa	**432225**
	Viet Nam	Rest of Asia	**53612894**
2008	Africa	Viet Nam	**2154093**
	Americas	Viet Nam	**90645066**
		Cambodia	**845292**
		Thailand	**560720**
	Europe	Viet Nam	**15308929**
		Cambodia	**11198**
		Thailand	**419265**
	Oceania	Viet Nam	**3343557**
		Laos	**25412**
		Cambodia	**406592**
		Thailand	**3303560**
	Rest of Asia	Viet Nam	**85981467**
		Cambodia	**57159**
		Thailand	**10948088**
	Thailand	Viet Nam	**126855156**

Table 7 (cont'd)

		Cambodia	**1025814**
		Thailand	**121023**
		Rest of Asia	**23511088**
		Europe	**213231**
	Viet Nam	Rest of Asia	**27069366**
2012	Africa	Viet Nam	**484335**
		Thailand	**402375**
	Americas	Viet Nam	**113269128**
		Laos	**532032**
		Cambodia	**734599**
		Thailand	**1226514**
	Cambodia	Thailand	**109700**
	Europe	Viet Nam	**34243440**
		Laos	**34650**
		Thailand	**3080385**
	Oceania	Viet Nam	**7903132**
		Laos	**64071**
		Cambodia	**146119**
		Thailand	**4281922**
	Rest of Asia	Viet Nam	**520242165**
		Laos	**7013448**
		Cambodia	**3844764**

Table 7 (cont'd)

		Thailand	**36974068**
	Thailand	Laos	**223664473**
		Cambodia	**1077681**
		Thailand	**973947**
		Rest of Asia	**87563022**
		Oceania	**144075**
		Americas	**478329**
		Europe	**57572370**
		Africa	**47740692**
	Viet Nam	Rest of Asia	**29224334**
2016	Africa	Viet Nam	**57797145**
	Americas	Viet Nam	**107770384**
		Cambodia	**1056615**
		Thailand	**3054588**
	Cambodia	Viet Nam	**837012**
	Europe	Viet Nam	**15406080**
		Laos	**86625**
		Thailand	**3769920**
	Oceania	Viet Nam	**24128610**
		Laos	**25412**
		Cambodia	**1255110**
		Thailand	**5242272**

Table 7 (cont'd)		
Rest of Asia	Viet Nam	**342814365**
	Laos	**5623644**
	Cambodia	**4251520**
	Thailand	**26981884**
Thailand	Viet Nam	**9422505**
	Laos	**311536254**
	Cambodia	**14516997**
	Thailand	**1256334**
	Americas	**28815**
	Africa	**11335821**
	Rest of Asia	**643825071**
	Europe	**25576194**
Viet Nam	**Rest of Asia**	**40337904**

Table 8: Calculated virtual water contents of all the meat commodities for every nation (m^3/ton) (A K Chapagain & Hoekstra, 2003).

Country	**Cattle**	**Pig**	**Sheep**	**Goat**	**Chicken**	**Horse**
Afghanistan	13685	2794	6515	5518	7510	5646
Albania	13426	6586	6454	5440	5584	5675
Algeria	15142	8671	7400	5056	9625	6130
Andorra	10586	2802	5650	3770	1849	5408

Table 8 (cont'd)

Angola	12891	2245	6081	5365	10243	5614
Anguilla	11781	2245	5645	4776	2392	5390
Antigua and Barbuda	11348	4231	5862	4207	4860	5638
Argentina	11549	3471	5943	4052	2327	5782
Armenia	12983	2699	6227	5251	3963	5544
Aruba	10586	2802	5650	3770	1849	5408
Australia	11730	6126	6353	3351	2373	6251
Austria	8025	2307	5369	2494	884	4741
Azerbaijan	13814	13772	6707	5761	4467	5813
Bahamas	13865	6554	7030	4985	4095	5997
Bahrain	10586	2802	5650	3770	1849	5408
Bangladesh	15546	4359	7515	6388	7828	5938
Barbados	11007	3739	5767	4011	3513	5535
Belarus	11821	4536	6251	4241	3601	5442
Belgium	7670	1833	5203	2431	893	4813
Belize	11254	4415	5902	4213	4448	5766
Benin	12729	5938	6122	5479	8482	5754
Bermuda	13548	3083	6536	5521	4618	5658
Bhutan	11781	2245	5645	4776	2392	5390
Bolivia	14843	3974	7145	5996	7087	5823
Bosnia and Herzegovina	11599	2238	5618	4780	2842	5285
BI Ocean Territory	11781	2245	5645	4776	2392	5390

Table 8 (cont'd)

British Virgin Islands	11781	2245	5645	4776	2392	5390
Brazil	13133	5005	6281	4401	3342	6552
Brunei Darussalam	9391	3359	5655	2763	1305	5427
Bulgaria	11078	4059	5920	4085	3409	5568
Burkina Faso	12899	9265	6181	5622	9366	5793
Burundi	13153	4471	6182	5466	12645	5717
Cambodia	12309	2289	5886	5069	5485	5510
Cameroon	12442	4027	5949	5177	7299	5626
Canada	9636	3276	5674	2775	1358	5567
Cabo Verde	14953	10998	6867	6275	19116	6724
Cayman Islands	11781	2245	5645	4776	2392	5390
Central African Republic	12299	3875	5866	5140	5867	5533
Chad	13973	9055	6563	6034	16651	5915
Chile	10080	2667	5495	3686	1979	5312
China, mainland	12596	2522	5948	5076	3111	5671
Christmas Island	11781	2245	5645	4776	2392	5390
Cocos (Keeling) Islands	11781	2245	5645	4776	2392	5390
Colombia	11782	4035	5972	4187	3878	5835
Comoros	12035	2245	5748	4949	4236	5452
Congo	11781	2245	5645	4776	2392	5390
DR of the Congo	15810	7254	7656	6700	12181	6178
Cook Islands	11781	2245	5645	4776	2392	5390

Table 8 (cont'd)

Costa Rica	10761	3558	5779	3911	3078	5360
Cote d'Ivoire	12866	9659	6162	5594	9042	5774
Croatia	10717	3361	5807	3870	2667	5250
Cuba	12281	4516	5908	5003	4236	5508
Cyprus	12373	4829	6338	4317	4716	5688
Czechia	9901	2609	5514	3668	1716	5088
Denmark	7827	2232	5334	2484	865	4693
Djibouti	12549	2245	5957	5297	7966	5578
Dominica	12819	6915	6492	4737	5617	5893
Dominican Republic	10586	2802	5650	3770	1849	5408
Ecuador	14763	8102	7322	5150	7232	6134
Egypt	15752	4680	6743	4892	2268	8067
El Slavador	12591	4989	6034	4283	4285	6461
Equatorial Guinea	11781	2245	5645	4776	2392	5390
Eritrea	14258	4254	6742	5855	11688	5783
Estonia	12367	4479	6398	4270	3042	5627
Ethiopia	14882	5260	7089	5987	10135	5828
Faroe Islands	11781	2245	5645	4776	2392	5390
Falkland Islands (Malvinas)	11781	2245	5645	4776	2392	5390
Fiji	10586	2802	5650	3770	1849	5408
Finland	9596	4273	5818	2864	1981	5248
France	7744	1936	5257	2424	795	4689

Table 8 (cont'd)

French Guiana	12109	5660	6074	4644	7871	5867
French Polynesia	9391	3359	5655	2763	1305	5427
FS&A Territories	11781	2245	5645	4776	2392	5390
Gabon	10979	3601	5770	4006	3403	5553
Gambia	12640	6141	6046	5315	7165	5624
Georgia	14123	3031	6357	5535	5476	6324
Germany	7768	2110	5275	2440	877	4672
Ghana	11781	2245	5645	4776	2392	5390
Gibraltar	11781	2245	5645	4776	2392	5390
Greece	12763	5037	6315	4306	3916	6167
Greenland	11781	2245	5645	4776	2392	5390
Grenada	10704	3176	5709	3865	2317	5510
Guadeloupe	11781	2245	5645	4776	2392	5390
Guatemala	14861	7282	7259	5127	3418	6489
Guinea	12273	5274	5865	5132	5432	5541
Guinea-Bissau	12600	5181	5998	5353	7822	5620
Guyana	12420	2245	5904	5209	7026	5546
Haiti	12889	4732	6126	5507	9578	5678
Honduras	12534	4099	5936	5052	7250	5516
China, Hong Kong SAR	9391	3359	5655	2763	1305	5427
Hungary	10298	2776	5623	3740	1771	5207
Iceland	9391	3359	5655	2763	1305	5427

Table 8 (cont'd)

India	14379	7562	6629	5734	8499	6251
Indonesia	13383	4589	6053	5225	8676	5969
Iran	15783	9133	7881	5518	5203	6321
Iraq	15776	16607	7653	5488	11585	6572
Ireland	7586	2017	5251	2455	908	4664
Israel	15500	7734	7755	5343	5434	6241
Italy	9595	3465	5716	2756	1637	5436
Jamaica	12324	4859	6037	4479	6020	6147
Japan	9535	4082	5658	2913	2044	5549
Jordan	14478	8682	6985	4400	12876	5844
Kazakhstan	18959	6302	7233	5416	6837	9661
Kenya	12789	5156	6086	5291	8122	5640
Kiribati	11781	2245	5645	4776	2392	5390
Kuwait	9391	3359	5655	2763	1305	5427
Kyrgyzstan	12834	15588	6190	5418	6061	5754
Laos	12133	2742	5827	5048	4883	5539
Latvia	11741	4257	6173	4208	2773	5634
Lebanon	11106	4448	5911	4189	3908	5854
Liberia	11106	4448	5911	4189	3908	5854
Libya	15167	6239	7276	6168	8601	5880
Lithuania	12398	2831	5995	5069	3249	5492
Macau	10586	2802	5650	3770	1849	5408

Table 8 (cont'd)

Yugoslav	10963	3620	5805	3946	2190	5498
Madagascar	12989	8238	6199	5599	10110	5775
Malawi	12539	4833	5955	5121	7785	5584
Malaysia	12934	5913	6521	4498	7468	5882
Maldives	10586	2802	5650	3770	1849	5408
Mali	12700	5889	6028	5218	8087	5592
Malta	10264	2761	5610	3719	1849	5204
Marshall Islands	10586	2802	5650	3770	1849	5408
Martinique	11781	2245	5645	4776	2392	5390
Mauritania	19223	15006	9063	8275	27332	6693
Mauritius	10639	2902	5665	3801	2060	5425
Mexico	12493	4062	6080	4265	2806	6375
Micronesia	10586	2802	5650	3770	1849	5408
Republic of Moldova	12698	2881	6103	5201	4545	5566
Mongolia	12977	2245	5941	4878	12923	5455
Montserrat	12325	2245	5866	5145	6341	5523
Morocco	15876	12428	7531	6051	14457	6693
Mozambique	12264	4069	5818	4984	5928	5484
Myanmar	13781	4888	6601	5658	8208	5750
New Caledonia	10586	2802	5650	3770	1849	5408
Northern Mariana Islands	11781	2245	5645	4776	2392	5390
Nauru	11781	2245	5645	4776	2392	5390

Table 8 (cont'd)

Nepal	14007	3724	6747	5747	8422	5821
Netherlands Antilles	11781	2245	5645	4776	2392	5390
Netherlands	7676	2084	5259	2451	914	4658
New Zealand	10551	3764	5649	4045	4179	5445
Nicaragua	13496	3743	6167	5483	7713	6072
Niger	15594	22346	7601	6796	12703	6356
Nigeria	13193	8250	6313	5710	12563	5917
Niue	11781	2245	5645	4776	2392	5390
Norfolk Islands	11781	2245	5645	4776	2392	5390
North Korea	11884	4649	5961	4153	2860	6125
Norway	9439	3382	5690	2764	1054	5434
Oman	17777	9229	8066	5838	5427	7764
Pakistan	14610	10618	7100	5978	7853	5942
Palau	10586	2802	5650	3770	1849	5408
Panama	11934	5773	6121	4413	6865	5915
Papua New Guinea	11834	2151	5666	4812	2796	5402
Paraguay	13302	6648	6570	4640	4443	6253
Peru	14179	6301	6921	4890	5275	6379
Philippines	12203	4119	5847	5074	5288	5534
Pitcairn Islands	11781	2245	5645	4776	2392	5390
Poland	10164	2560	5566	3725	2003	5211
Portugal	15177	5279	6800	4739	4029	7318

Table 8 (cont'd)

Qatar	10893	3096	5776	3845	2172	5446
Reunion	10980	3369	5808	3859	2465	5486
Romania	11198	3681	5854	3993	2527	5600
Russian Federation	13089	6010	6510	4600	4702	6205
Rwanda	11781	2245	5645	4776	2392	5390
Saint Vincent-Grenadines	11781	2245	5645	4776	2392	5390
Samoa	10586	2802	5650	3770	1849	5408
Sao Tome Principe	11781	2245	5645	4776	2392	5390
Saudi Arabia	11359	4985	5904	4179	4146	5648
Senegal	12535	5368	5982	5284	7033	5600
Seychelles	10586	2802	5650	3770	1849	5408
Sierra Leone	12306	4757	5875	5151	5764	5544
Singapore	11261	6162	6351	3317	3107	5879
Slovakia	10513	3427	5715	3878	2323	5333
Slovenia	10625	2875	5661	3792	2002	5420
Solomon Islands	11781	2245	5645	4776	2392	5390
Somalia	11781	2245	5645	4776	2392	5390
South Africa	16095	8799	7476	5440	5035	7248
South Korea	10586	2802	5650	3770	1849	5408
Spain	11963	3057	5935	4042	1912	6114
Spec Cats	11781	2245	5645	4776	2392	5390
Sri Lanka	12736	7283	6134	5390	7414	5707

Table 8 (cont'd)

Saint Helena	11781	2245	5645	4776	2392	5390
Saint Kitts and Nevis	10586	2802	5650	3770	1849	5408
Saint Lucia	10586	2802	5650	3770	1849	5408
Saint Pierre and Miquelon	11781	2245	5645	4776	2392	5390
Sudan	13265	6548	6248	5689	13072	5783
Suriname	11842	5653	6087	4581	6819	6003
Sweden	8339	2645	5463	2597	929	4886
Switzerland	8778	2383	5425	2574	858	5288
Syrian Arab Republic	20992	12197	10379	8612	9820	6789
China, Taiwan Province of	10586	2802	5650	3770	1849	5408
Tajikistan	13135	8002	6244	5329	7575	5641
United Republic of Tanzania	13260	6647	6398	5729	11305	5948
Thailand	14668	6452	7039	4836	5763	6505
Togo	12805	6027	6081	5092	7986	5567
Tokelau	11781	2245	5645	4776	2392	5390
Tonga	10586	2775	5650	3770	1849	5408
Trinidad and Tobago	11082	3967	5825	4107	3788	5655
Tunisia	40101	13205	10331	9054	3435	22722
Turkey	11070	3242	5624	3828	2301	5821
Turkmenistan	19703	5445	9705	7990	6471	6439
Turks Caicos Islands	11781	2245	5645	4776	2392	5390
Tuvalu	11781	2245	5645	4776	2392	5390

Table 8 (cont'd)

Uganda	12645	3687	6026	5260	8198	5625
Ukraine	13070	4682	6209	5380	6160	5749
United Arab Emirates	12476	8472	6541	3007	9026	5791
United Kingdom	7759	2106	5309	2476	784	4659
Uruguay	13684	4277	6294	4410	2814	7024
US miscellaneous pacific	10586	2802	5650	3770	1849	5408
United States of America	10063	3374	5718	2843	1304	5874
Uzbekistan	13471	4010	6527	5570	4851	5715
Vanuatu	11781	2245	5645	4776	2392	5390
Venezuela	14615	6616	6912	4699	9072	6490
Viet Nam	13948	3226	6754	5718	4947	5729
Wallis and Futuna Islands	11781	2245	5645	4776	2392	5390
Yemen	13873	4140	6616	5707	8435	5721
Yugoslavia	11443	3682	5949	4042	3016	5618
Zambia	14766	6104	7164	6188	6340	5888
Zimbabwe	13119	5733	6335	5486	4939	5671

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